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MANUAL OF FIRST-ORDER TRAVERSE

BY

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PREFACE

The purpose of this manual is to summarize the methods employed at present by the United States Coast and Geodetic Survey in executing first-order traverse. It is designed primarily for the engineers and mathematicians of this bureau engaged in the execution of the field work and in making the office computations. The methods outlined, however, may be used by engineers outside the bureau with such modifications as may be necessary to conform to local conditions.

Very little space has been given to the actual routine of making invar tape measurements, except where the methods differ from those of base measurement; or to the care and use of theodolites and other instruments and the methods of observing. These subjects have been thoroughly covered in the Manual of First-Order Triangulation, Special Publication No. 120. It is assumed that an officer engaged in executing traverse has had experience in first-order triangulation and base measurement.

In describing the methods of making the office computation of traverse, those computations which are the same as for triangulation have been only briefly mentioned. This applies especially to the solution of equations in the least-squares adjustment of traverse. Special Publication No. 138, Manual of Triangulation Computation and Adjustment, contains detailed explanations and examples of these computations.

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MANUAL OF FIRST-ORDER TRAVERSE

By Casper M. Durgin, *Hydrographic and Geodetic Engineer*

and

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United States Coast and Geodetic Survey

Part I.—FIELD METHODS

GENERAL STATEMENT

Traverse has been used in place of triangulation by the United States Coast and Geodetic Survey at various times in the past but only during the past 10 years has it been used on an extensive scale as first-order horizontal control. Since 1916 about 3,500 miles of first-order traverse have been run as well as several hundred miles of second and third order traverse. Traverse is used in place of triangulation in country that is flat and heavily wooded where high scaffold signals would be required to give clear lines for triangulation. Traverse usually follows a railroad and therefore requires but little signal building or clearing of lines. At the present cost of lumber the building of signals is a large item in the expense of operating a triangulation party.[1]

The methods used on first-order traverse, both in the field and in the office, have been gradually changed and improved until they have become practically standard. In 1919 Special Publication No. 58, General Instructions for Precise and Secondary Traverse, was issued. Later "Supplemental instructions for precise traverse" were printed in United States Coast and Geodetic Survey Bulletin No. 67, December 31, 1920. In recent years many changes and improvements have been made, and therefore this manual, giving present approved methods, supersedes the above-mentioned publications.

Changes in the methods described in this manual will undoubtedly be made from time to time as improvements are developed. Engineers and mathematicians of the bureau engaged on first-order traverse and its computation are invited to offer suggestions which may make it possible to do the work more expeditiously without decreasing the accuracy or increasing the cost. Suggestions from engineers not in the bureau will also be appreciated.

[1] On a recent arc of triangulation movable steel towers have been used instead of wooden signals and have been found to be more satisfactory and less expensive than the latter.

SPECIFICATIONS FOR HORIZONTAL CONTROL

Until very recently much confusion was caused by the conflicting terms used by different Federal organizations in describing the various classes of triangulation and traverse which they execute. Usually the more accurate class of work was called "primary" triangulation or traverse, irrespective of the degree of accuracy actually obtained, while the term "secondary" was applied to work of inferior accuracy. In order to secure more uniform specifications and nomenclature, representatives of the various Federal map-making and map-using organizations in Washington agreed in 1921 upon a uniform classification. Under this agreement triangulation and traverse of the highest accuracy were termed "precise," of the next lower accuracy "primary," and of the next "secondary," corresponding, respectively, to what had been previously known in the Coast and Geodetic Survey as primary, secondary, and tertiary.

This terminology did not find wide favor or acceptance, and in May, 1925, the Federal Board of Surveys and Maps, after referring the matter to the various Federal map-making bureaus represented on the board, recommended that the four grades of vertical and horizontal control ordinarily used be designated as first order, second order, third order, and fourth order, the first named being the most accurate. These terms have been authorized by the Director of the Coast and Geodetic Survey and made applicable to the various grades of control executed by this bureau.

The specifications for the various grades of horizontal control now in use by the Federal map-making organizations are given in tabulated form below:

Specifications for horizontal control

	First order	Second order	Third order	Fourth order
Triangulation	Average triangle closure 1", check on base 1/25000.	Average triangle closure 3", check on base 1/10000.	Average triangle closure 5", check on base 1/5000.	Graphic or transit angles.
Traverse	Position check 1/25000.	Position check 1/10000.	Position check 1/5000.	Stadia, transit and tape or wheel.

The result of the adoption of the above nomenclature and the corresponding specifications will be very beneficial, for the reason that any piece of triangulation or traverse will be classified in accordance with the accuracy obtained, irrespective of what the instructions for executing the work may have been, and much confusion will be avoided.

According to the plan adopted by the Federal Board of Surveys and Maps for the completion of the standard topographic map of the United States, the first-order triangulation or traverse will be

executed in belts or lines about 100 miles apart. Second-order triangulation or traverse will then be used to subdivide the intervening areas until no considerable area is more than 25 miles from a horizontal-control point of the first or second order. Horizontal control of the third order will then be established, with a density of distribution of points depending upon the requirements of the topography.

To insure that the requisite accuracy is maintained throughout a traverse, it is essential to give careful consideration to the instruments and methods in order that the effect of unavoidable constant and systematic errors may be eliminated, that the accidental errors may be made as small as possible, and that no part of the traverse will exhibit undue weakness.

RECONNAISSANCE

GENERAL STATEMENT

First-order and second-order traverse will, in general, be done in those sections of the country where the topographic conditions make it impracticable to carry on first or second order triangulation. If triangulation is used in flat country where there is considerable timber, it is necessary to use comparatively short lines and to erect high scaffold signals to make the stations intervisible. Under these conditions traverse may be substituted for triangulation to advantage.

In deciding whether the control shall be triangulation or traverse, several considerations should be kept in mind. Traverse stations are usually along a railroad and therefore more readily available for control of local surveys than triangulation stations, which are necessarily located in places more difficult of access. This question of accessibility is also an important factor where concrete marks must be placed and high scaffold signals erected. On the other hand, triangulation stations are usually on high ground and therefore are visible from much larger areas than are traverse stations. Besides, an arc of triangulation covers a belt of country at least 10 or 15 miles wide while the traverse is just a single line.

Another important factor to be considered in choosing between triangulation and traverse is the lack of any check on the accuracy of the traverse, either in the field work or the office computation, except that afforded by a connection to an arc of triangulation or another traverse line. Even then the discrepancy is sometimes of such a size that it is difficult to tell whether it is caused by a blunder or an accumulation of small errors in the traverse. If it is apparent that a blunder has been made, locating the blunder is usually very difficult, and it may become necessary to rerun a large part or all of the traverse line. In triangulation, on the other hand, as each quadrilateral is completed in the field, there are checks on both the

angles and the lengths. Furthermore, the office computation and adjustment of triangulation have automatic mathematical checks which are entirely lacking in the computation of traverse. Even when the traverse computations are made in duplicate there is a possibility that two men may make the same mistake. For these reasons triangulation should always be selected in preference to traverse for first-order control where the cost of reconnaissance, building, and observing for the triangulation will not exceed the cost of traverse by 100 per cent.

LOCATION OF STATIONS

Traverse is generally run along a railroad track, although it is sometimes run along paved streets and highways, and, in coastal regions, may be run along the beach.

In making the reconnaissance for the location of traverse stations several considerations must be kept continually in mind. The stations must be intervisible with the smallest possible amount of build-

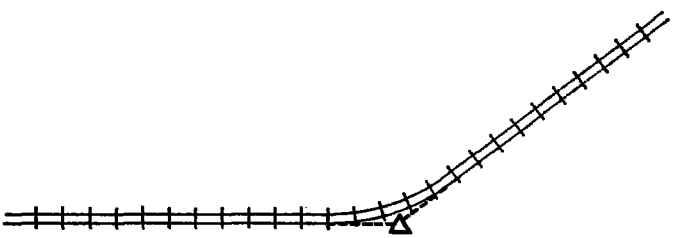


FIG. 1.—Traverse station at intersection of two tangents

ing and clearing and so located that the distance between them may be measured economically and rapidly. The line of sight must not pass close to any object which will cause lateral refraction. Each station should be placed in a spot where there is the least chance of its being disturbed unless such a location would involve undue inconvenience and extra work. Stations, as a rule, should not be more than 5 miles apart, both because delays caused by observing longer lines will more than offset the time gained by having fewer stations and because stations more than 5 miles apart are not of maximum benefit for public and private surveys.

A station should be located near each town along the route of the traverse, and when practicable another station should be located within 2 miles of the one in town in order to enable the local engineers and surveyors to obtain an azimuth with little difficulty. When the traverse follows a railroad, a station should be placed near each railroad crossing or point where a branch line leaves the railroad followed by the traverse and also if possible near each important highway crossing. This will make the stations more accessible for

the traverse party and for other persons using them, and will make the descriptions more definite and the stations easier to recover in the future.

An excellent location for traverse stations is at the point of intersection of two adjacent tangents of the railroad, any one of the four points of intersection of the two rails being available. (See fig. 1.) This location is prohibited at times by buildings or other structures, by the topography of the country, the amount of clearing necessary, or the degree of curvature of the curve. If the station can not be placed at the intersection of the tangents, it may be placed at such a point on the extension of one tangent as to be only a short offset distance from the extension of the other tangent. (See fig. 2.) It may be necessary in some cases to put an offset station at the intersection of the two tangents with the traverse station a short distance away. This will be the case where the point of intersection is too close to the track for an observing stand and for a permanent location for the mark. In other cases it will be necessary to place the traverse station

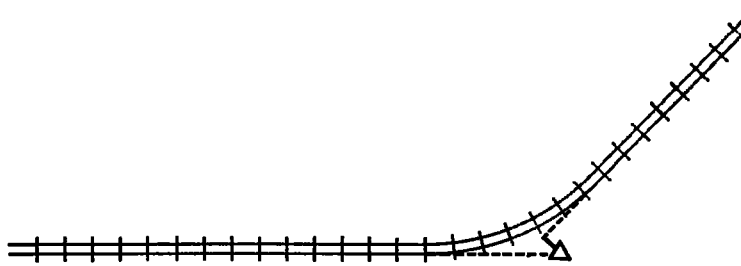


FIG. 2.—Traverse station on extension of one tangent

where two offsets will be required—one to the extension of the tangent from one direction and the other to the extension of the tangent from the other direction. The ratio of offset distances to the length of the line between stations should not exceed 1 in 100, and the actual distance should very seldom exceed 20 meters. The offset should be as nearly perpendicular to the tangent as possible.

Where the tangent is particularly long or where the stations at the two ends of a tangent are not intervisible, one or more intermediate main angle stations should be placed at the side of the track at distances apart usually depending on the profile of the track. For these intermediate stations the offset point is on the rail and is called a "rail station." Where the offset point is on a stake of a line of stakes it is called an "offset station." If the ground is practically level along a tangent, the intermediate stations may be placed anywhere, but preferably near a crossroad. If possible, they should be fairly evenly spaced and alternated from one side of the track to the other to reduce the effect of lateral refraction which is greater when

the line of sight is parallel to the track. Because of the difference in the temperature of the air over the track and over the ground at the side, a line of sight passing alongside the track is apt to be refracted horizontally entirely in one direction. If it crosses the track it is refracted about equally and in opposite directions as it enters and leaves the heated air over the track.

Where the railroad along which a traverse is being run passes through a city of considerable size which has congested freight yards, it is well to leave the railroad and carry the traverse through the streets of the city. This will avoid the delay caused by the ob-

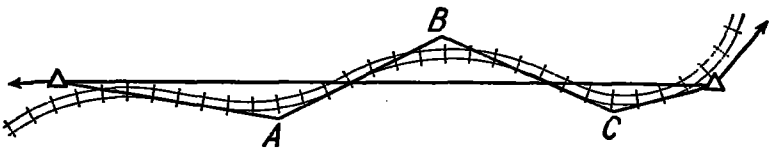


FIG. 3.—Traverse loop

struction of lines by smoke and freight cars. By a careful selection of side streets the traverse can be carried through the city without serious delay.

TRAVERSE LOOPS

Where curves are numerous and the tangents very short it is well when practicable to lay out comparatively long lines extending over several curves in order that the azimuth may be carried forward with greater strength than if it had to be carried through a number of short lines. The length of the long line in each case can be obtained by measuring several short lines and angles along the track to form a loop with the long line. (See fig. 3.) These additional points between the main traverse stations are designated by the name of the main traverse station at the beginning of the loop, followed

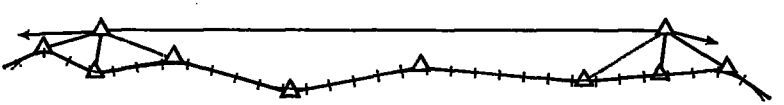


FIG. 4.—Traverse loop, end stations connected by triangles

by the letters A, B, C, etc. These are supplemental stations and need not be permanently marked.

To aid in carrying an accurate azimuth through the traverse it is well in some cases to have extra stations, on or off the railroad along which the traverse is measured, which are intervisible for much longer distances than occur between the regular traverse stations. Each of these extra stations should be so located that it can be connected in azimuth and distance with the regular traverse stations along the track, thus forming loops similar to those described in the preceding paragraph. (See fig. 4.) In this case, however, all the

stations in the loop should be named and permanently marked in the same manner as other main traverse stations.

Where the azimuth is carried through a long line great care must be taken that each end of the line is carefully tied into the scheme running along the railroad between its ends. No section of a loop should be inclined at an angle of more than 30° to the line through which the azimuth is carried and on which the sections of the loop are projected.

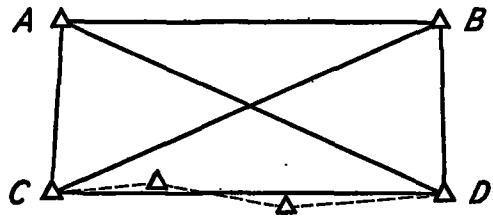


FIG. 5.—Connection between triangulation and traverse by quadrilateral

CONNECTIONS WITH EXISTING CONTROL

In connecting traverse with triangulation the minimum requirements are a connection in azimuth and a check in length, unless there are special instructions to the contrary. In case the connection between the triangulation and the traverse can not readily be made by means of a quadrilateral (see fig. 5), it may be obtained by two triangles each formed by two adjacent traverse stations and a triangulation station, with perhaps several traverse stations intervening between the two triangles (see fig. 6). A connection in azimuth is necessary at both of the triangulation stations. The traverse may also be connected to the triangulation by observing two traverse stations, not adjacent, from two triangulation stations. (See fig. 7.)

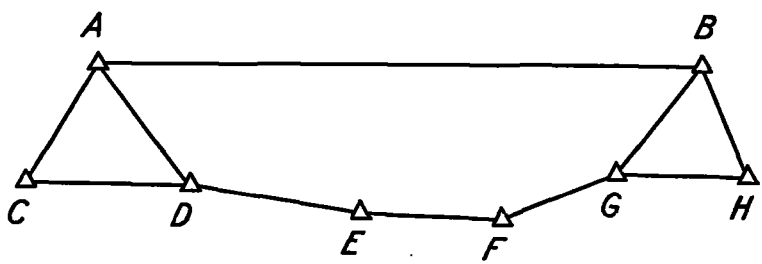


FIG. 6.—Connection between triangulation and traverse by two triangles

Here the directions to the triangulation stations at each traverse station must be connected with some main line of the traverse.

Where a traverse joins an existing traverse line there should be a connection in position and azimuth, and one of the angles of the old traverse should be reobserved to check the recovery of the old stations. If the reobserved angle is very nearly 180° and there is any doubt of the exact recovery of the stations, one line of the old traverse should be remeasured.

MARKING STATIONS

Each station shall be marked with a standard traverse station tablet of copper alloy, so fastened in rock or concrete as to effectively resist extraction, change of elevation, or rotation. (See figs. 8 and 9.) The name of the station and the year established should be stamped upon the mark, preferably before it is set in place.

Traverse stations must often be located where the permanent marking of them is difficult, and for that reason a great variety of settings for the tablets must be permitted. The location of the station, depth of soil or presence of rock ledges, and the availability of materials will usually control the choice of the mark to be used. The precautions to be taken in establishing each kind of mark are briefly stated below.

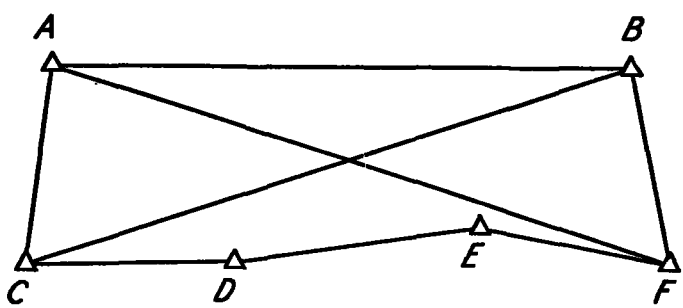


FIG. 7.—Another method of connecting triangulation and traverse

TYPES OF MARKS

1. *In rock outcrop.*—Care should be taken that the rock in which a mark is set is hard and is part of the main ledge, not a detached fragment. The tablet should be countersunk and well cemented in.

2. *In bowlders.*—When set in a bowlder, the tablet should be countersunk and well cemented in. The bowlder must be of durable rock and have a cross section and depth below surface at least equal to the standard concrete mark described on page 10.

3. *In rock ledges below surface.*—When the ledge is only slightly below the surface, a tablet set in the usual manner in the ledge will be sufficient, provided two reference marks are established. Where the ledge is so far below the surface that a surface mark is required, a tablet should be set in the ledge, the ledge carefully brushed or washed off for a space at least 18 inches in diameter, and a concrete surface mark placed above the subsurface mark, the surface mark to be of such size in cross section as to make the volume of concrete equal to that of a mark 14 by 14 by 36 inches. A tablet should be set in the surface mark directly over the subsurface tablet. If the rock ledge in which the subsurface mark is set is very smooth, it

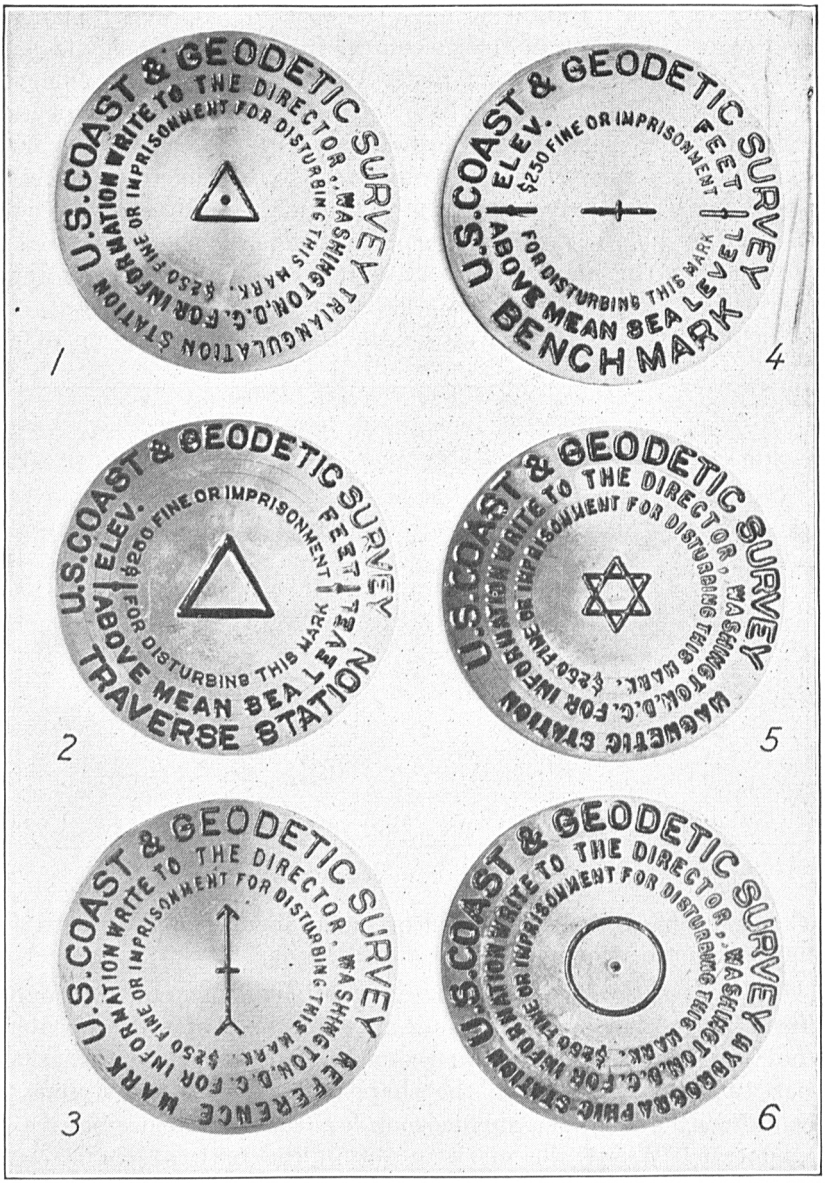


FIG. 8.—Standard marks of the United States Coast and Geodetic Survey

1. Triangulation station mark.
2. Traverse station mark.
3. Reference mark.
4. Bench mark.
5. Magnetic station mark.
6. Hydrographic station mark.

should be furrowed with a chisel to afford better anchorage for the concrete.

4. *In concrete*—(*a*) *Shape.*—The mark should be either a frustum of a cone or of a pyramid or have the form of a post with an enlarged base. If of pyramidal or conical form, the sides should have a batter of at least 1 inch to 1 foot. When a post with an enlarged base is used, the bottom of the base should be 4 inches larger in least horizontal dimension than the post proper, and the base should have a vertical thickness of at least 6 inches. If the concrete is cast in place, the enlarged base can easily be provided for by enlarging the bottom of the hole with the digger. Extreme care should be used to avoid making the mark with a mushroom top or with projecting corners near the surface, which would provide leverage points for frost action and would make easier the malicious destruction of the

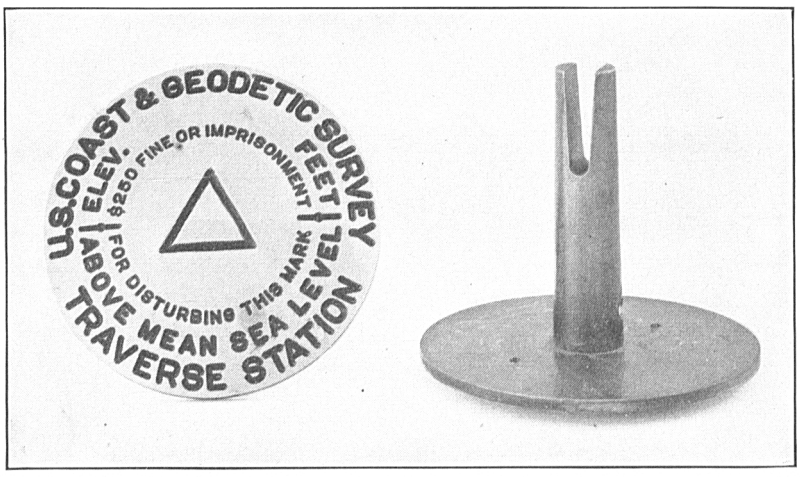


FIG. 9.—Traverse station mark

mark. For this reason a wooden or metal form should be used for the upper part of the mark.

(*b*) *Size and depth.*—The concrete post should extend to a depth of from 30 to 36 inches, depending upon the kind of soil. It should be not less than 14 inches square or in diameter, except that the upper 12 inches may be in the shape of a frustum of a cone or pyramid with the upper surface not less than 12 inches square or in diameter. Where the mark is not in the path of traffic or in soil subject to cultivation, it should project from 2 to 4 inches above the surface. If located where traffic passes over it, the top of the mark should be slightly below the surface.

A standard station-mark tablet, set in a mass of concrete at least 10 inches in diameter and accurately centered under the surface mark, should always be established for an underground mark where

soil conditions permit. The tablet should be stamped with the same designation as the tablet in the surface mark.

The procedure in making the standard concrete mark is as follows: A hole is dug to a depth of 3½ feet or more. It should be 16 inches in diameter for the upper 2½ feet and 10 inches in diameter at the lower end. Concrete made of good cement, sand, and gravel or broken rock is placed in the lower part of the hole to a depth of 6 inches. A standard tablet station mark (fig. 9) is then set in the concrete, with the top of the tablet slightly depressed. This completes the underground mark. A layer of from 4 to 6 inches of sand or dirt is then put into the hole. The hole is then enlarged about 2 inches in radius near the bottom in order that the lower end of the block of concrete for the surface mark will be mushroomed, and then the hole is filled with concrete to within 9 inches of the surface of the ground. Next, a mold or frame 12 inches on a side at the top, 13 inches at the bottom, and 12 inches in depth is set in the hole on top of the concrete and filled in around the outside with dirt tamped firmly. The frame is then filled with concrete level with its top, and a standard station mark tablet (fig. 9) is set in the center of the concrete, with the top of the tablet slightly depressed. The tablet must be centered exactly over the underground mark. The top of the concrete should be smoothed with a trowel and the frame should be left in place to protect the concrete until it becomes firmly set.

Care must be taken not to disturb the position of the tablet in the underground mark when placing the layer of sand or dirt and when pouring the concrete for the surface mark. A piece of thin board should be placed over the lower mark or other suitable means used to insure against any horizontal movement of the tablet due to the impact or pressure of the material above.

The main considerations in making concrete are to have clean materials, to mix them well before adding water, to have the mixture not too wet, and to tamp it well into the form. Each streak of dirt in concrete means a line of cleavage. Where rough aggregate is available, the proportions may very well vary from 1–2–4 to 1–3–5, but the top 12 inches of the mark should be of considerably richer mixture. Where only cement and sand are available, the lower part of the mark should be proportioned 1 part of cement to 3 parts of sand, and the upper part should be 1 part of cement to 2 parts of sand. With a mark of the proper size it will not be necessary to reinforce the concrete with metal rods or wire. To avoid cracking of the concrete due to rapid drying, it should be covered with paper or cloth and with earth or other material for a period of at least 48 hours. In cases where the soil is very dry, the sides of the hole

should be saturated with water before the concrete is poured to avoid too rapid drying by absorption.

All traverse stations which for any particular reason can not be marked with a standard tablet in rock or concrete should be marked by an iron pipe with special cap or by a nail in a post of durable wood in order that the station may be recoverable for several years after its establishment.

Care should be exercised to see that a traverse station which is placed on the extension of one rail of a tangent is exactly on line. If necessary, the station should be located by lining in with a theodolite, especially where it is much higher or lower than the track.

SPECIAL CONDITIONS

Under certain conditions special marks will often be required, and these should conform in size and durability to the marks described above.

1. *Sand.*—In sand which, if used as a mold, would spoil the concrete by absorbing the water from it a sewer tile 8 inches in diameter and 30 inches long may be used. It should be set with the bell end down, filled with concrete, and with the lower end set in concrete. A sheet-iron mold of the same dimensions filled with concrete may be used instead of the tile. A metal tablet should be set in the center of the top of the concrete.

2. *Marsh.*—Where the ground is too soft to hold a mark of the usual type, a post of durable wood should be forced down vertically until it is quite firmly embedded, its top cut off flush with the surface, and a sewer tile at least 6 inches in diameter set into the marsh around the top of the post. The wooden post should first be water-soaked, otherwise subsequent swelling of the wood will crack the concrete and tile. The tile should be filled with concrete and a tablet set in the top.

3. *Land subject to cultivation.*—The subsurface or lower mark should be a tablet in a block of concrete about 10 inches square or 10 inches in diameter and 6 inches thick, set with its top a little more than 3 feet below the surface. The upper mark should be a tablet set in a block of concrete at least 15 inches square or in diameter and 20 inches high, with its top 15 inches below the surface of the ground. About 3 inches of dirt should be placed between the concrete blocks of the upper and lower marks.

REFERENCE MARKS

Reference marks should be established only in special cases. They should be used when the station mark is entirely beneath the surface of the ground and there are no permanent witness marks near it such

as road crossings, etc. Reference marks should be set if the station is at a railroad crossing or junction point or if both of the adjacent stations are 4 or 5 miles distant. In cases where reference marks are required, two should invariably be established for each station. They should be so located as to avoid the probability of both being disturbed by the same cause. Along a railroad track they should usually be placed in the fence lines of the right of way and on opposite sides of the track. They should be so located as to give a good angle of intersection at the station or else be in range with the station. Traverse stations along a beach which are subject to loss by the erosion of the shore line should have two reference marks placed as far back from the shore line as practicable.

The metal tablet for each reference mark should be similar to that of the station mark, except that it should have an arrow which should point to the station. (See fig. 8.) Each reference mark should be stamped with the same name and year as its station mark and with a number, the reference marks being numbered serially in a clockwise direction. It should be set under the same specifications as the station mark, except that the concrete post may be 2 inches smaller in diameter and 6 inches shorter than for the station mark. Subsurface marks need not be set under reference marks.

SIGNAL BUILDING

On first-order traverse it is seldom necessary to build high tripod and scaffold signals, the usual maximum height being about 30 feet. Special Publication No. 93, Reconnaissance and Signal Building, contains detailed instructions, which will not be repeated here, for the construction of various types of signals for use on traverse.

Under certain conditions of terrain, where the traverse line has many short courses, it may be advisable to use tall wooden or steel towers at stations 5 to 10 miles apart, through which the azimuth may be carried. This possibility should be borne in mind when making the preliminary reconnaissance.

A tripod should be placed at each main scheme traverse station to support the direction theodolite used in measuring the horizontal directions. (See figs. 10 and 11.) It should be built to such a height that there is good clearance of the line of sight above all obstructions. It has been found by experience that to build it 4 feet higher than that required to barely clear obstructions will save time in the end and enable the observer to secure better results. As a rule, tripods along a traverse will be 4, 8, 12, or 16 feet in height with those of the lower heights predominating. A small supply of each height of tripod should be made at the beginning of the season.

They may be moved forward by truck and each one used at a number of stations. The scaffolds should be fastened together by bolts, so that they may be taken apart at the corners and laid flat on the truck when moved ahead. Of course, cases will be found where the station is so far from the nearest spot to which a truck may be taken that it will be cheaper to abandon the tripod and scaffold and make new ones at the next station. Where the ground is level between stations, tripods at least 8 feet high should be used. Higher tripods will be needed if the adjacent stations are on the opposite sides of the track and on ground lower than the track. Four-foot tripods should be used only where the ground drops away rapidly near the station. Unless the ground is very firm platforms should be placed around the

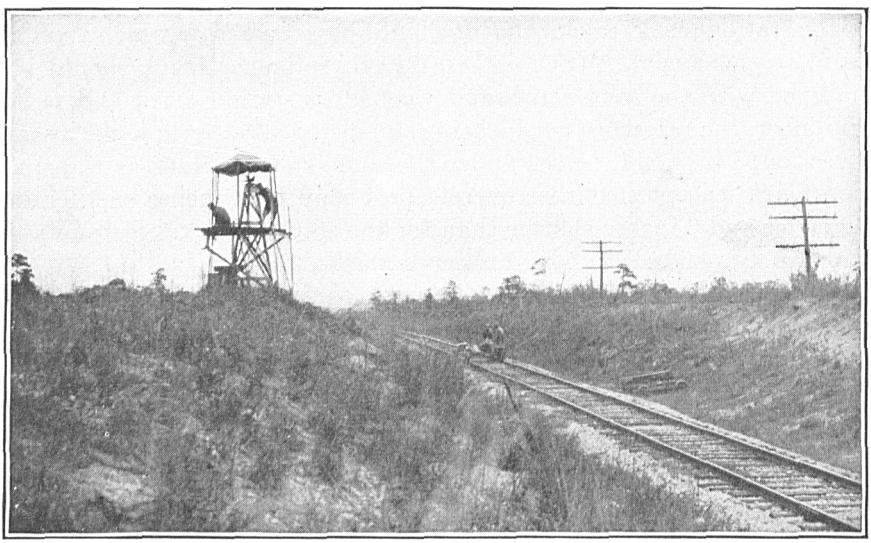


FIG. 10.—Tripod and scaffold for elevating the instrument and observer

tripod just above the ground to avoid disturbance of the theodolite during the observing.

ORGANIZATION OF PARTY

Before deciding upon a general plan of procedure for field work on a contemplated traverse line the chief of party should become as fully informed as possible concerning the conditions to be encountered, especially with regard to railroads and highways, prevailing weather, availability of supplies, and the kind of transportation best adapted to the region. Usually no detailed reconnaissance will have been made and therefore reliance must be placed upon maps, weather reports, and such information as can be obtained from persons familiar with the region. After the chief of party has obtained

a general knowledge of the average conditions to be met it is usually easy to choose the means of transportation which will be most economical. The next step is to decide upon the number of transportation units and the number of employees needed.

It has been found most economical in the past to use motor trucks for transportation, supplemented by motor velocipede cars when the traverse follows a railroad and by boats when the traverse is along a coast. In the past motor velocipede cars alone have been used for transportation on some traverse lines along railroads, but trucks supplemented by motor velocipede cars have been found to be more satisfactory.

The choice of personnel for a traverse party is an important matter. The men must be industrious, alert, congenial, dependable,

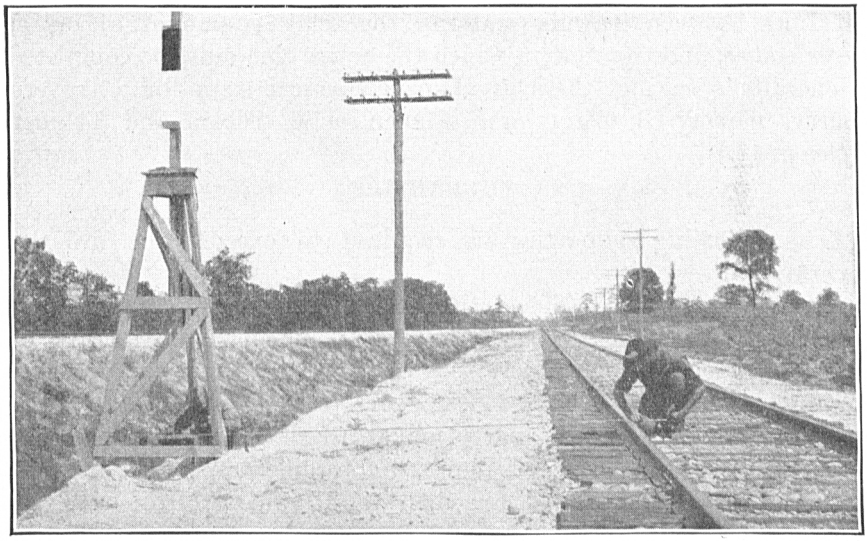


FIG. 11.—Tripod with target in place. Measuring the offset distance

and self-reliant. Young men old enough to have had jobs involving hard manual labor and some responsibility usually give satisfactory service. Men should be selected who will stay with the party until the end of the season. If possible, two or three men should be secured who have had previous experience on a traverse party.

The head truck driver must know how to make all adjustments in the mechanism of the truck, must be skilled at diagnosing the source of any motor trouble, and must be able to make emergency repairs under field conditions. The other truck drivers should at least have sufficient skill to make simple adjustments to the truck mechanism and should be good, careful drivers. The rate of progress of the party depends so much upon the proper care and use of trucks that an unskilled or careless driver should not be kept.

The successful measurement of a traverse depends to a very great extent upon the accuracy, legibility, and clearness of the records of the invar tape measurements. The recorder should be an experienced man. If an experienced and reliable front-contact man is available, the chief of party or some other experienced officer should act as recorder on the invar taping party. The officer acting as recorder can watch the work of each man in the party and correct bad practices. He can make sure that no blunders are committed, check the number of tape lengths, and make all notes necessary for a definite and correct interpretation of the record. The recorders for the observing and wye leveling parties should be able to record rapidly and legibly and should be very rapid and accurate in mental calculations.

The number of officers and men needed on a party for first-order traverse depends upon the amount of traverse to be run, the lengths of lines between traverse stations, the relative amount of taping over stakes, and the time in which the entire line must be completed. Generally speaking, there are two economical sizes for a traverse party, namely, 3 officers and 6 men or 6 officers and 14 men. (See p. 17.)

SUBPARTIES

The following subparties are required to execute the different operations:

1. *Building party.*—The duties of this party are reconnaissance, building and placing the observing stands, and marking the stations. It should consist of one officer, preferably a signalman, and two, three, or four men.

2. *Taping party.*—This party makes all the invar tape measurements and drives the stakes required for tape supports. It should consist of two officers and five men at all times. Ordinarily, one officer should act as recorder and the other as front-contact man. Of the five men, one, an experienced man, should make rear contact, two should handle the two stretchers, one care for the middle of the tape, and the fifth drive the stakes needed for tape supports and act as truck driver.

3. *Leveling party.*—This party runs wye levels over the traverse line or at least over all parts of the line measured over stakes. It should consist of one officer as observer and recorder and one man as rodman. When a motor-velocipede car is used to move the observer and level from one instrument station to the next, there should be an extra man to record and help with the car.

4. *Check-taping party.*—This party makes the check measurements with the 300-foot tape. It should consist of two men, one to make contact at each end of the tape. The recording is done by one of these men.

5. *Angle party.*—This party measures the horizontal angles at the A, B, C loop stations and at the offset and rail stations. It should consist of one officer and one man.

6. *Observing party.*—This party measures the horizontal angles at all main traverse stations. It should consist of one officer as observer, one man as recorder, and one man to post and tend the signal lamps.

If the traverse party consists of three officers and six men, then on the days when invar tape measurements are made the entire party is used, with the exception of one officer and one man (preferably one who has had experience as a recorder) who are available for office work. On other days the party is divided into smaller subparties to complete the other operations. The work can be arranged in such a way under the existing conditions that all operations will progress at nearly the same rate. This size of party has been found to be very economical and efficient because the chief of party can keep in close touch with the work of the party, and there is less lost motion than when a larger party is used. If the time is limited, two small parties working from opposite ends of the line are usually better than one large party.

If the traverse party consists of 6 officers and 14 men, it should be divided into five subparties, each one doing a particular kind of work. These subparties should be as follows: Building party consisting of 1 signalman officer and 3 men; taping party consisting of 2 officers and 5 men; combined leveling and angle party consisting of 1 officer and either 1 or 2 men; check taping party, consisting of 2 men (these 2 men at other times to assist the building or other subparty); and observing party consisting of 1 officer and 2 men. This organization leaves the chief of party free for reconnaissance and general supervision. It might be expected that this sized party would be more efficient than the smaller party described above, because each member is doing the same class of work day after day. It has been found, however, that with a large party there is more lost motion and lack of coordination, and the chief of party can not keep as closely in touch with the different operations. Also with a large party there is apt to be a larger percentage of inexperienced men who must be instructed in their duties for a short season.

Another factor to be considered in choosing between a large and small party is that one subparty will sometimes make more rapid progress than another due to varying conditions along the traverse and it becomes necessary to shift part of the work from one subparty to another. No matter how the shifting is done there will be more lost motion with the larger party than with the smaller party, due partly to the fact that the chief of party can not keep in as close touch with the work. Even if there is an experienced officer in

charge of each subparty there are apt to be some lack of coordination in the field work and unnoticed ambiguities and omissions in the field records.

EQUIPMENT

Two or possibly three 1-ton trucks and two 4-man motor velocipede cars will furnish sufficient transportation for a small party. A large party will require at least four trucks and four velocipedes. The number of men and transportation units will vary slightly on different traverse lines, depending upon the character of the country through which they run.

Usually the traverse party will live in tents or in hotels and will get their meals in the towns and cities along the route of the traverse. In some cases, however, where the towns are far apart, it is necessary for the party to do its own cooking. Each temporary employee is usually furnished with tent shelter, a cot, and bed tarp, but he must furnish his own bedding, cooking utensils, and other outfit.

Part of the outfit for a party is usually obtained from storage and the remainder purchased. If time permits, bids on all equipment to be purchased should be secured sufficiently in advance to have it delivered at the point of outfitting by the date on which the party is to be assembled, as it is essential that all outfit be on hand at that date. In order to facilitate the transportation of the party, the chief of party should consider carefully the need for each article of equipment and should discard or place in temporary storage any surplus outfit or supplies. The packing boxes in which the instruments are shipped from the office to the field should be stored until needed to repack the instruments for shipment to the office at the end of the field season.

There is given below a list of the instruments and other equipment required by a first-order traverse party. There will be some variation in the items and in the number of each required on different traverse lines.

Building-party equipment

Instruments:		Tools and supplies—Continued.	
Binocular	1	Digger, post hole	1
Compass, azimuth	1	Drill, rock	1
Heliotropes, for testing lines	2	Hammer, claw	1
Plummet	1	Hammer, heavy	1
Theodolite, 4-inch, and tripod	1	Hatchet	1
Tools and supplies:		Marks, reference	(*)
Ax	1	Marks, station	(*)
Bag, tool	1	Nails, bolts, etc	(*)
Bucket	1	Saw	1
Cans, 10-gallon, for water	2	Shovel	1
Cement, sand, and gravel	(*)	Spade	1
Crowbar	1	Stamps, steel, set	1

*As needed.

Taping-party equipment

Instruments:	
Awls, marking	2
Balance, pocket spring	1
Balance, spring	3
Clip, attaching, for balances	1
Cutters, glass	(*)
Dividers, pairs	2
Knife	1
Loops, leather	2
Pen, fountain	1
Plummet	1
Scales, decimeter, boxwood	2
Stirrups, wire, for broken grades	2
Stretchers, base, tape	2
Stretchers, rail, tape	2
Strips, copper	20
Tape, 30-meter, standardized steel	1

Instruments—Continued.	
Tape, 50-meter, invar, unstandardized, for staking	1
Tapes, 50-meter, standardized invar	3
Tester, balance	1
Thermometers, standardized, with channel bar holders and cases	4
Tape, adhesive	(*)
Tripods, portable	(*)
Tools and supplies:	
Bag, recorder's	1
Crayon, yellow, lumber	(*)
File or small cold chisel	1
Hammer, claw	1
Hatchet	1
Maul, 12 or 14 pound	1
Saw	1

Check-taping-party equipment

Instruments:	
Pen, fountain	1
Pins, wire	11
Tape, 300-foot steel, with hand grips	1

Tools and supplies:	
Crayon, yellow, lumber	(*)

Leveling-party equipment

Instruments:	
Level, track	1
Level, wye, with tripod	1
Pen, fountain	1
Rod, leveling, graduated in meters and feet	1

Tools and supplies:	
Sunshade	1

Angle-party equipment

Instruments:	
Pen, fountain	1
Plummet, extra	1
Tape, 30-meter steel	1
Theodolite, 7-inch with tripod	1

Tools and supplies:	
Sunshade	1

Observing-party equipment

Instruments:	
Barometer, aneroid	1
Binocular	1
Chronometer, sidereal	1
Flashlights, ordinary 2-cell	3
Flashlights, focusing, 3-cell	3

Instruments—Continued.	
Head, aluminum tripod, with set of springs	1
Lamps, signal, 5½-inch	3
Lamps, signal, for use with flashlights	3

*As needed.

Observing-party equipment—Continued.

Instruments—Continued.	
Pen, fountain	1
Plummet, extra	1
Tape, 30-meter, steel	1
Theodolite, direction, with vertical circle	1
Tripod (if theodolite is small)	1
Tools and supplies:	
Bag, recorder's	1
Batteries, flashlight and signal-lamp	(*)
Tools and supplies—Continued.	
Bulbs, flashlight and signal-lamp	(*)
Hammer, claw	1
Lantern	1
Nails and screws	
Screwdriver	1
Tarpaulin, large, for windshield	1
Tent, observing	1
Umbrella	1

Field-office equipment

Instruments:	
Machine, adding	1
Pens, fountain	2
Typewriter	1

Transportation and camping equipment

Cars, motor velocipede	(*)
Cot for each man	(*)
Lantern for each tent	(*)
Tarpaulin, bed, for each man	(*)
Tents, 9 by 9 feet, 1 for office, 1 for storeroom, and 1 for each two men	(*)
Trucks, 1-ton, with necessary tools and tarpaulin	(*)

MEASUREMENT OF DISTANCES

GENERAL STATEMENT

The final computed lengths in the traverse will depend upon measurements made with 50-meter invar tapes, standardized at the Bureau of Standards before and after use in the field. These tapes usually have 5-meter graduations to permit the measurement of fractional tape lengths, or set-ups, to the nearest 5 meters.

The methods and routine of base measurement as given in Special Publication No. 120 should be followed except as modified by the following statements:

Where the traverse follows a railroad the distances along the tangents will be measured with the tape supported throughout its length on top of the rail. The distances from the points of tangency to the traverse stations (or offset stations) will be measured with the tape supported on stakes. The lengths in the traverse will depend upon one measurement in one direction only unless a blunder has been made or unless a section of the traverse is to be used as a base line from which to start an arc of triangulation. In the latter case instructions for base measurements will govern.

*As needed.

At the beginning and end of the traverse line and at intervals of 40 or 50 miles during the progress of the measurements a section of the traverse 1 or 2 kilometers long should be remeasured by first-order methods, to insure that those making the tape measurements are observing the proper degree of care in their work. This check measurement should be from one traverse station to another and not between kilometer marks or rail stations. It should be an unexpected measurement; that is, no indication should be given the taping party as to where it will be made. The tape used on the check measurement should be one not used on the first measurement of the section. The first check section, near the beginning of the traverse, insures that the taping party is exercising the proper amount of care and the correct methods at the start. The two measurements should agree within 10 mm. $\sqrt{K}$ where K is the distance in kilometers. An inexperienced party should do a considerable amount of practice work before commencing the actual measurements. The chief of party should make sure that the taping party will do the work correctly before allowing them to start the measuring. It is well to make two first-order measurements of the first 8 or 10 sections.

Three or more tapes are required for traverse measurements. One of these should be kept as a standard and used only in making comparisons with the other tapes which are called the working tapes. When the distance between two traverse stations is greater than 1½ kilometers, the measurement should be made in approximate kilometer sections. The end of each section should be marked in such a manner as to be recoverable for one or two weeks should remeasurement be necessary.

TAPE COMPARISONS

At the beginning of the season before any of the working tapes are used, and at intervals throughout the season, they should be compared with the standard tape to detect any change in their lengths. No tape should be used for more than 15 kilometers without being compared. These comparisons should be made on stakes, and metal strips should be used on the tops of the stakes to prevent parallax in marking. Before the comparisons are made all tapes should be carefully unreeled and laid out on the ground, so that they will assume the temperature of the air as closely as possible.

The comparisons may be made by either one of the two following methods. In the first method a distance of several tape lengths is measured with the standard tape and then with each of the working tapes. In the second method a distance of one tape length only is measured several times, first with the standard tape, and then with each of the working tapes. When using the second method, the position of the forward mark on each tape can be read on a decimeter

scale, or on a graduated invar strip similar to those used on portable tripods, fastened to the top of the forward stake, the rear end of the tape being held opposite a fixed mark on the rear stake. A field comparator to be used according to one of the above methods should be established at each camp site.

The comparisons should be entered in the record book, in which should be shown the temperatures read from two thermometers, the method of support, and the amount of the set-ups, setbacks, etc. All of the working tapes should be compared with the standard tape and the results entered in the record.

A tape should be sent to the office for restandardization if it differs from the standard tape by more than 1 part in 200,000 after correc-

FIG. 12.—Forward end of the tape. Applying tension to tape, marking the end of the tape on the rail with a glass cutter, and recording

tions for standardization and temperature have been applied. If the comparisons indicate that the standard tape has changed in length, a new tape to be used as the standard tape should be obtained from the office.

USE OF INVAR TAPES

On each invar tape, near the terminal mark, is a small " x " or " v " or in some cases small dots near one edge of the tape, denoting which end of the graduation marks was used in the standardization. If the " x " or " v " can not be distinguished, that end of the mark should be used which is at the far edge of the tape when the tape is extended in front of the observer with the zero graduation at his left and the 50-meter mark at his right. The tape should always be used

with the 50-meter mark ahead and the zero mark at the rear. Therefore, in marking, the ends of the graduations should be used which are on the left edge of the tape facing in the direction of progress. On some tapes the graduation marks extend only about three-fourths of the way across the tape, and for these the end of the mark at the edge of the tape should be used.

In measuring along the top of a rail the position of the forward end of the tape can be marked on the rail with an ordinary glass cutter. (See fig. 12.) Care should be used to see that the cutting wheel does not become so loose that it will wobble on its bearings. The front contact man should be careful not to cut the tape and injure the graduation mark with the glass cutter when he makes the marks

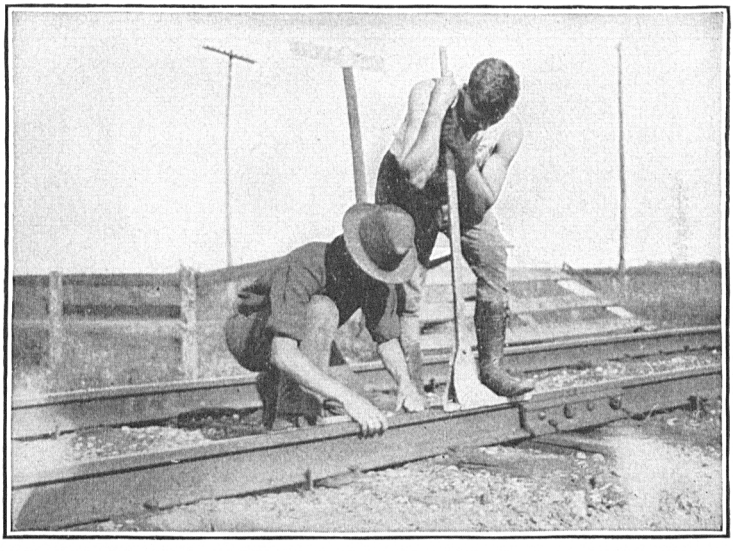


FIG. 13.—Rear end of the tape. Holding the mark on the rear end of the tape coincident with the mark on the rail

on the rail. In measuring over stakes the forward end of the tape can be marked by a knife-cut on the top of the stake. The position of each mark on the rail or on the stakes should be indicated by a chalk mark for the guidance of the rear contact man. The rear contact man must use the same end of the scratch on the rail or knife cut on the stake as was used by the forward contact man. (See fig. 13.) Both contact men should stand on the same side of the tape.

The tape ends are numbered as in base measurement. Great care must be exercised in recording the number of full tape lengths and the lengths of the set-ups. The recording of the temperatures of both thermometers for every full tape length and only one for each set-up or fractional tape length helps to guard against the dropping of a tape length. Another check is to have each tape length numbered and

marked at the forward end on an adjacent tie or on the stake. The forward contact man should call out the number as he marks it, the rear contact man checking it from the mark at his end of the tape, and the recorder checking it by comparing it with his record. The wye level and track level record gives an additional check on the number of tape lengths. The 300-foot tape measurement not only gives a check on the number of tape lengths but will detect an error of a few centimeters in the set-ups.

At kilometer marks, rail stations, and other points where it is necessary to hold the position of a mark on a rail with relation to the ground the mark made by the glass cutter is deepened with a file or chisel. (See fig. 14.) A nail is then driven into each of two ties close to the edge of the rail containing the mark. Marks are then

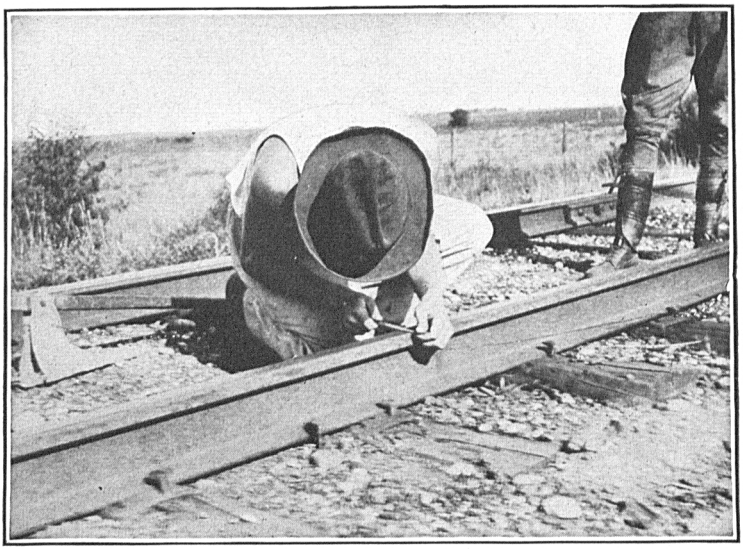


FIG. 14.—Filing a mark on the rail at the end of a kilometer

made with the glass cutter beginning on the rail flange and extending across the heads of the nails. Any lengthwise movement of the rail caused by the passage of a train or temperature changes will be shown by a displacement of the marks on the flange relative to the marks on the nails. On the approach of a train while taping is in progress nails should be driven in and marks made at the last tape end. The amount the rail moves, usually in the direction the train is going, will be measured and recorded as a set-up or setback. Special care should be used not to confuse set-ups and setbacks; if the rail moves in the direction of progress of the measurements, it is a set-up, and vice versa.

No measurement should be made with the invar tape when the rail is wet or damp, because this will introduce a large error due to suction.

A railroad curve often occurs in a deep cut, which makes it necessary to put the traverse station at the top of a high bank; or a traverse station may be at the intersection of two tangents where the intersection is at quite a distance from the track and at a much higher or lower elevation. In these cases staking and taping are difficult. If a saving of time can be made, it is permissible to obtain by triangulation the distance from a stake or a point on the rail to the station, provided the same method is used in going ahead from the station, and two triangles with a common side are thus observed. (See fig. 15.) The base for each of these two triangles is a section of the traverse measured along the track. The reason for specifying two triangles is that a check is thus obtained on the measurement of both angles and length. The three points on the track at the ends of the two bases should be selected to give good angles of intersection at the traverse station.

During the measurement with the invar tape the distances from the initial point of the traverse section to crossroads, railroad stations, water towers, section houses, semaphores, bridges, mileposts, banks

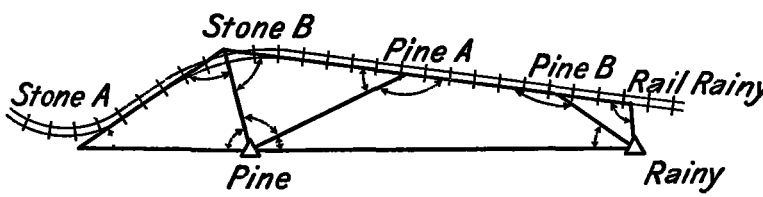


FIG. 15.—Combination of loop and rail station

of rivers, State and county lines, etc., should be recorded in order that the traverse may be properly connected with the alignment surveys of the railroad, and these may then be used as an aid in making maps of the country through which the traverse runs. The distances should be recorded as follows: "Road crossing 24+4," which means that the road crossing is 4 meters beyond the end of the twenty-fourth tape length; or, "center railroad water tank, 15+17, north 9 m.," which means that the tank is at a point 17 meters beyond the end of the fifteenth tape length and 9 meters to the north of the rail.

SUPPORT OF TAPE

When measuring along a railroad, the distances along the tangents should be measured with the tape supported throughout its length on the top of the rail. Between the points of tangency and traverse stations (or offset stations) 2 by 4 inch stakes should be driven in

the same manner as in base measurement to support the ends of the tape. (See fig. 16.) The middle of the tape should be supported by a small stick or rod held by the man at the middle of the tape which should be lined in with the tops of the front and rear stakes by the rear contact man. Where it is impossible, on account of some obstruction or the slope of the ground, to have the middle support on line with the tops of the end stakes, a stake should be driven and a nail driven into the side of this stake at such a height that with the tape held by the wire stirrup described below it will clear all obstructions. To prevent excessive friction due to the middle support being higher than the end supports in such cases, the middle of the tape should be held by a wire stirrup 1 decimeter long suspended from the nail in such a manner that it will swing freely in the direction

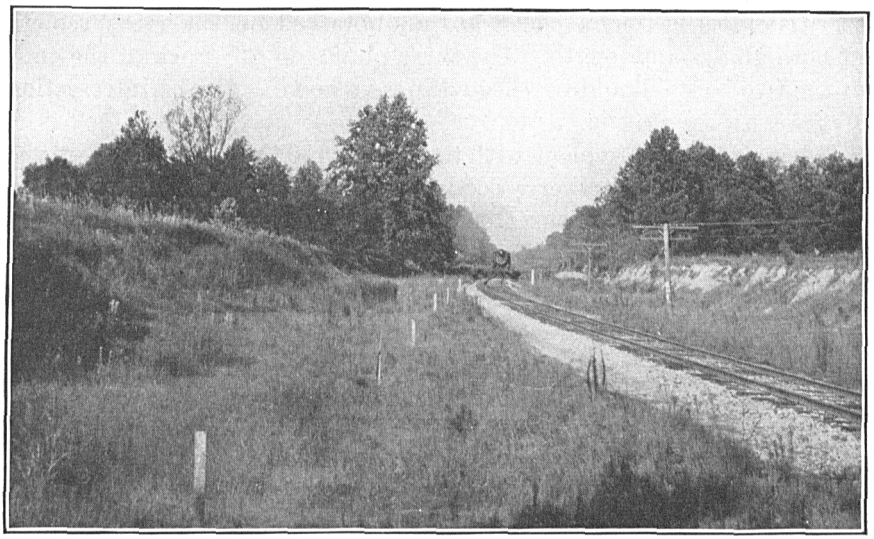


FIG. 16.—Stakes from station to rail tangent

of the tape. The man at the middle of the tape should call the attention of the recorder to the fact that a "broken grade" has been used. During measurements over stakes the recorder should keep a careful watch of the tape throughout its length to see that it does not touch anything between the points of support. If it does, the obstruction should be removed or additional supports provided. Each tape is standardized under three conditions, supported at three points, at five points, and throughout. (See fig. 45, p. 76.) The tape should always be supported under one of these three conditions or a combination of them.

In measuring up to or away from a station the record should indicate clearly whether the tape was supported on the station mark itself or on a bench or table built over the mark. In this connection

the word "tablet" should not be used in the record to designate the station mark, as it is easily confused with the word "table," but the word "mark" should be used instead. For a like reason the designation "bench" should be used instead of "table."

The number and location of all supports should be entered in the record. All broken grades should be plainly indicated, together with a statement concerning the use of the wire stirrup. (See fig. 28, p. 52.)

Where there is a large amount of staking in one locality, it has been found best before the taping is begun to have all the staking done by a staking party. Such a party should consist of four men in charge of an officer or foreman hand. A 50-meter steel tape or an old 50-meter invar tape should be used to locate the stakes. When the tape supports are between or near the rails, it is best to use blocks made of 2 by 4 inch lumber and nail them to the railroad ties. (See fig. 17.) These blocks should be about an inch higher than the rails. The tape will then clear the rails and ties if five supports are used, and yet the blocks will not be an obstruction to passing trains. In setting stakes on the prolongations of tangents the staking party should begin at the station and work toward the rail in either direction. This will bring the minimum number of set-ups on the stakes, and all large set-ups will occur on the tangent where they are more easily measured. Where there is a rail tangent only a few tape lengths long, to make use of which would require an offset station or a loop, it is well to stake direct from one traverse station to the other. This will eliminate the need for measurement of the supplementary angles and will result in a saving of time in both field and office.

Where the staking necessary is small in amount and scattered, it should be done by the invar taping party. The taping can then be done immediately after each stake has been set. The stakes should be distributed beforehand.

Where stakes are used for a considerable distance or where they are much above or below the level of the track, they should be lined in with a theodolite. No stake should be more than 6 inches off the line between the ends of the section or more than 2 inches off the line joining the two adjacent stakes. The slope of no tape length should, as a rule, exceed 10 per cent. When the slope approaches or exceeds that amount, extra care must be taken in determining the difference in elevation of the tape ends. (See p. 40.)

Permission to work along the railroad and to establish marks along the right of way will usually have been secured by the office before work is started and the chief of party apprised of the fact. The chief of party should always keep in touch with the division engi-

neer of the railroad, should conform to any requirements made by him, and should inform him of the progress of the party.

All stakes and tripods on railroad right of way should be removed as soon as possible after the party has finished with them, for often they are a slight hazard to trainmen alighting from or boarding trains at night.

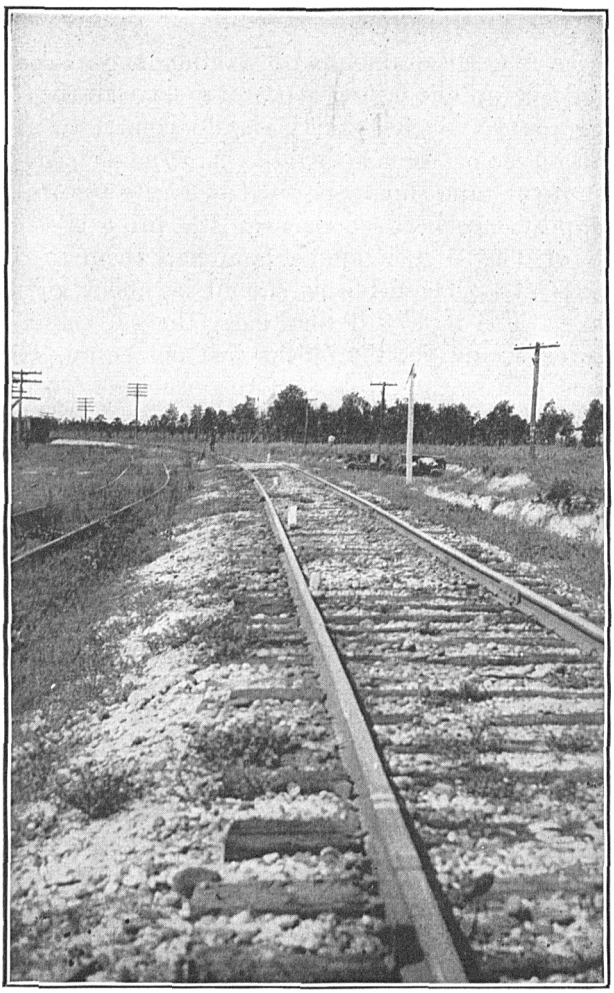


FIG. 17.—Tape supports at the beginning of a curve

TENSION

All invar tape measurements should be made under a tension of 15 kilograms. The tension should be measured by a spring balance attached between the forward end of the tape and the front stretcher. All measurements with a steel tape such as set-ups, offset distances, etc., should be measured under a tension of 5 kilograms. Either a

pocket spring balance or the invar tape spring balance may be used for measuring this tension.

All spring balances used with the invar tapes should be tested with a 15-kilogram weight (see p. 123, Special Publication No. 120) at the beginning and end of each day they are used and a statement to that effect inserted in the record. If the balances are incorrect, they should be adjusted if possible and a statement to that effect inserted in the record. If the indicator can not be adjusted the required amount, the reading produced by the 15-kilogram weight should be recorded. The record should then state whether the balance-dial pointer was held at the 15-kilogram mark during measurements with the tape or at the correct point to produce exactly 15-kilograms tension. The latter practice is preferable as it reduces the amount of computation. (See p. 79.)

The tape stretchers used in taping over stakes are of the same type as those used on base measurement and described in Special Publication No. 120, page 122. For taping along a rail a different type of stretcher is used. It consists of a shoe of galvanized iron about 18 inches long and just wide enough to fit easily over the top of the rail, with uprights of the same material projecting about 6 inches above the rail. These uprights furnish the fulcrum for a lever, to the lower end of which the tape is attached by means of a hook. (See figs. 12 and 13, pp. 22 and 23.) This device applies the tension to the tape and at the same time holds the tape close to the rail.

Care should be taken in applying the tension to the tape on the rail to reduce the friction between the tape and the rail as much as possible. The man at the middle of the tape should hold the tape about 4 feet above the rail until he feels the tension being applied. He should then slowly lower the tape so that the tape reaches the rail at about the time that the tension has been increased to 15 kilograms. If a string is attached to the middle of the tape, the tape can be lowered easily and when the tension is released, it can be raised again quickly to prevent it from catching under the rail spikes. (See fig. 18.)

TEMPERATURE

Two thermometers should be attached to the invar tape, one at each end, 1 meter inside the zero and 50-meter graduations, the distance being measured from the mark to the nearer end of the thermometer. These thermometers should be of the same weight as the ones used during the standardization of the tape, usually 45 grams. Special centigrade thermometers in metal holders will be furnished by the office on application. (See p. 124, Special Publication No.

120.) They should be attached by adhesive tape to the invar tape in such a manner that good contact with the tape will be insured. Every day before using, and oftener if necessary, the readings of the two thermometers on the tape should be compared to detect discrepancies or breaks in the mercury column.

The readings of both thermometers should be recorded for each full tape length and of one thermometer for all set-ups with the invar or steel tapes.

CARE OF TAPES

Great care should be exercised in the use of tapes. Kinks are usually made by catching the tape under ties or spikes along the railroad track, by dragging the tape along the ground, or by careless reeling and unreeling. The tape should never be allowed to come

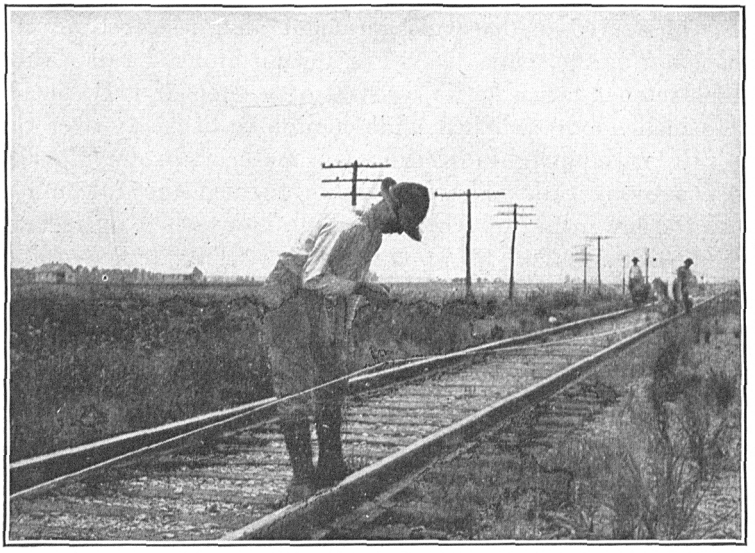


FIG. 18.—Placing the tape on the rail. As the tension is applied the man at the middle of the tape lowers it gradually to the rail

in contact with the ground while being carried forward. (See figs. 19 and 20.)

If a kink should be made in a tape, do not straighten it out. A note should be made in the record book giving the exact time the kinking occurred and at the first opportunity a field comparison should be made with the standard tape by one of the methods described on page 21. If a tape becomes so badly kinked or injured that it can not be used, it should be sent to the office with a letter of explanation giving details as to the condition of the tape and the date of injury or injuries.

Tapes should be cleaned and oiled often enough to prevent corrosion. They should also be cleaned occasionally with gasoline to remove grease and tar which would increase the friction of the tape on the rail, and also, by increasing the weight of the tape, affect the catenary correction over stakes.

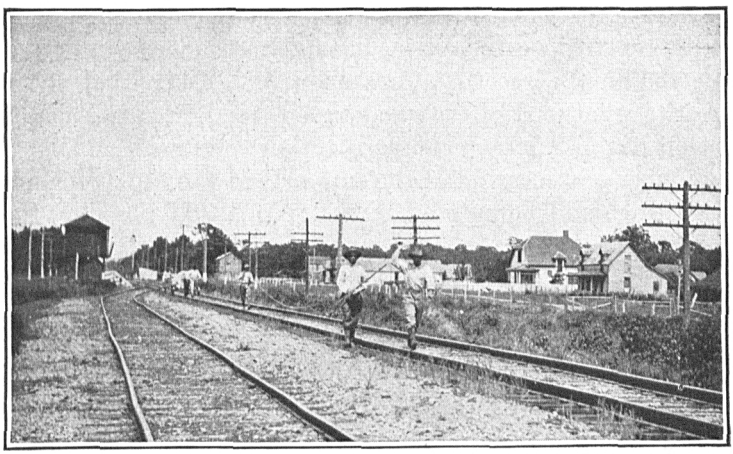


FIG. 19.—Moving the tape forward. The tape is carried free from the ground and never allowed to drag

SETBACKS, SET-UPS, AND OFFSET DISTANCES

To avoid gross errors, due to the erroneous recording of a set-up as a setback, or vice versa, setbacks should not be greater than 1 deci-

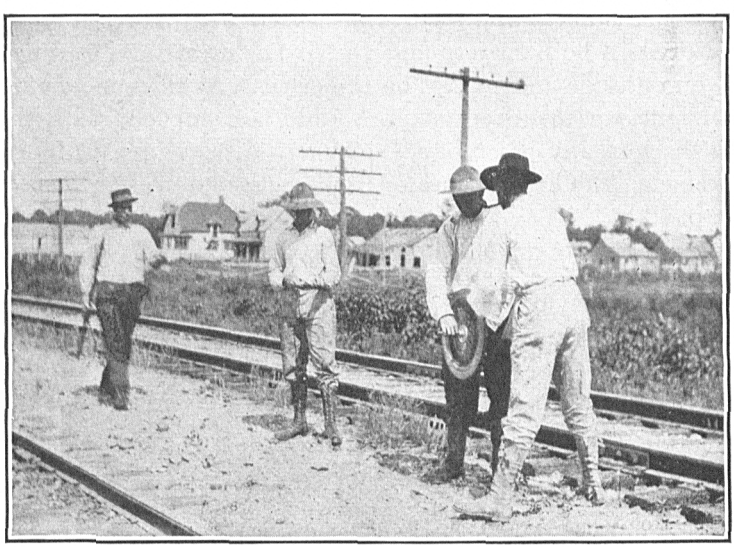


FIG. 20.—Reeling up the tape

meter, the amount that may be measured with a pocket decimeter scale. Any larger variation from a full tape length should be measured as a set-up, or plus correction to the measured length.

To measure a fraction of a 50-meter tape length, the best procedure, unless the distance is so short as to be more easily measured entirely with a decimeter scale or a steel tape, is to make use of the 5-meter graduations on the invar tape and measure as large a part of the distance as possible in this way. The remainder should then be measured with a standardized pocket steel tape. The number of the steel tape, the temperature, tension, and method of support should be indicated in the record. Care should be taken that the record is clear as to what part of the invar tape is used, because each 5-meter graduation has a different standardization correction.

The number and location of the supports of the tape when measuring a set-up should be entered in the record. If possible, the tape should be supported at the same points as when it was standardized. All set-ups greater than 1 decimeter should be entered on a separate line in the record. Set-ups and setbacks less than 1 decimeter should be entered in the record on the same line as a full tape length.

Distances from offset and rail stations to the traverse stations should be measured with a steel tape in the same manner as set-ups and recorded in the remarks column of the record. They should be measured horizontally whenever possible to eliminate corrections for inclination. (See fig. 11, p. 15.) The record should state clearly whether the horizontal or inclined distance was measured. If the inclined distance is measured, the difference of elevation should be determined by the wye leveling party.

All offset distances and set-ups measured with a steel tape should be measured in both meters and feet by using a tape graduated in meters on one side and in feet on the other. At the end of the day's work the measurements in meters should be compared with those in feet to disclose any discrepancy. If any discrepancy is found, the measurement should be repeated and corrected in the field. (See fig. 28, p. 52.)

INVAR TAPE RECORD

The invar tape measurements should be recorded in Form 590, Traverse Measurements (see fig. 28, p. 52), and in addition to the data indicated by the headings the following data should be given, because they are essential to the completeness of the record:

Personnel of the party, with duties of each.
Weather.
Statement of thermometer comparison.
Statement of comparison of spring balances.
Note as to which rail of tangent was used.
Number of steel tape used in measuring set-ups.
Portion of invar tape used in measuring set-ups, with location of points of support.
Each set-up over 1 decimeter in separate line in record.

One temperature (only one) for each set-up over 1 decimeter.

Distance to rail and offset stations.

Statement as to whether offset distances are horizontal or inclined measurements.

Distance from beginning of section to road crossings, etc.

Record of broken grades.

Sketch of each section of the traverse showing railroad, traverse stations, and route of tape measurement.

Tabulation of abbreviations used, with meanings.

Statement of route followed by traverse, giving name of railroad and indicating points where change is made to another railroad or to streets or highways.

CHECK MEASUREMENT OF DISTANCES

A single check measurement will be made of each section of the traverse with a 300-foot tape to detect blunders. Small errors will not be detected by this check. The measurement may be made under any condition of the weather and should be made from traverse station to traverse station along the route used by the invar tape with no reference to kilometer sections. Each section from a traverse station to an A station, from an A station to a B station, etc., should be considered as a separate section of the traverse in this measurement and should have a separate page in the record.

Along a tangent the 300-foot tape should be supported on the ties of the railroad track as close to the rail as possible without catching in the railroad spikes. The position of the forward end of the tape should be indicated on the inner flange of the rail by a mark with a sharply pointed piece of lumber crayon. The location of this mark should be indicated by a conspicuous mark made near it with the crayon on the inner flange of the rail and by the number of the tape end marked also on the flange of the rail. The check measurement should be made along the base of the same rail as that previously used for supporting the invar tape. The crayon marks used to indicate the location of the tape ends for the invar measurement will not be confused with the marks made on the check measurement if the latter are made on the inner flange of the rail only. Between the tangent points and the traverse stations the tape should follow the line of stakes but should not be supported by them. Instead, it should be stretched on the ground, and if necessary a plumb bob should be used as in ordinary chaining where the tape does not lie close to the ground near the tape ends. To mark the position of the forward end of the tape when measuring on the ground long iron or heavy wire pins pointed at the end should be used.

A moderate tension only should be used with the 300-foot tape. It is believed that about 5 kilograms is sufficient, and with this light tension two men can do the measuring. A heavy tension would

require a tape stretcher at each end of the tape. The length of the tape under the standard pull and temperature must be determined in the field by comparison with an invar tape. The temperature should be recorded at least once for every section. One thermometer will be sufficient, and this need not be attached to the tape.

To avoid errors in the number of 300-foot tape lengths, the forward contact man numbers the tape end on the inner flange of the rail, calling out the number as he marks it. The rear contact man checks this number by comparison with the number on the flange at his position. Between the traverse stations and the points of tangency the number of tape lengths is counted by the rear contact man by collecting as he moves forward the wire pin which marks each tape end, the first pin being placed at the traverse station. On reaching the point of tangency from a traverse station the rear contact man should give the front contact man the pins he has collected, including the one picked up at the traverse station. With this system the first number written on the rail flange is checked by the number of pins delivered to the front contact man.

Likewise the wire pins collected by the rear contact man in the taping from the point of leaving the tangent to the next traverse station should be given to the front contact man at the end of the section. At the point of leaving the tangent the rear contact man, who also acts as recorder, should record the number of the last tape end on the tangent, and then at the end of the section he should record the number of pins collected. In addition to these two entries he should record as a set-up the fraction of the tape length from the last pin to the traverse station. In measuring this set-up the front contact man should hold the zero end of the tape, which should always be ahead, on the mark or bench and the rear contact man can read directly the amount of set-up at the last pin. (See fig. 29, p. 53.)

A comparison between the check measurements of the sections and those made with the invar tape should be made immediately after the completion of a day's work, so that if any discrepancy is disclosed the necessary remeasuring may be done before the party has left the vicinity.

The party making the check measurement should have no knowledge of the length obtained with the invar tape. If the length obtained with the 300-foot tape, after corrections for temperature and standardization have been applied, differs from the length obtained with the 50-meter invar tape by more than 1 part in 5,000 in any section over 500 meters in length or by more than 1 part in 2,500 for sections under 500 meters in length, a second measurement with the 300-foot tape should be made unless the 300-foot measurement has

been made over very rough ground, in which case the lack of agreement between the two measures may be allowed to exceed somewhat the amounts stated. If this second measurement agrees closely with the first one made with the 300-foot tape, then a second measurement should be made with the 50-meter invar tape. If necessary to make a second measurement with the invar tape, kilometer sections of 20 full tape lengths supported on the rail need be remeasured only if the error can not be found elsewhere.

MEASUREMENTS ALONG HIGHWAYS AND CITY STREETS

Practically the same methods should be used for traverse measurements along paved streets and improved highways as for the measure-

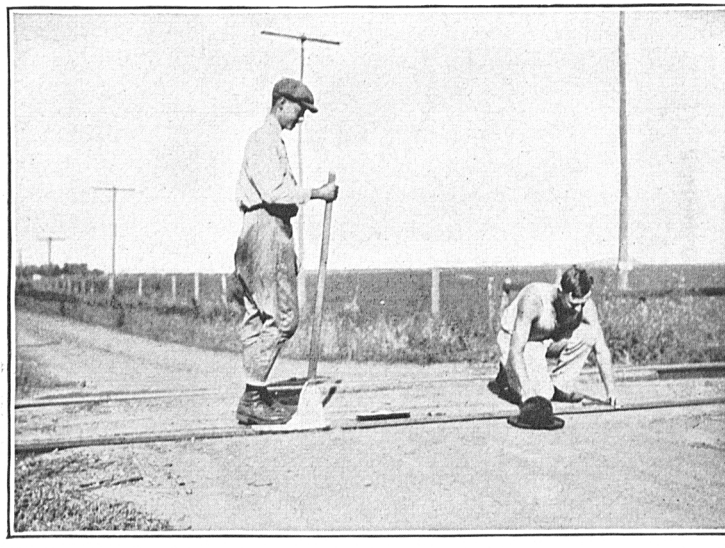


FIG. 21.—Tape stretcher at a road crossing. This type of stretcher can be used readily on road crossings where the rails are practically flush with the highway

ments along a railroad. The tape may be supported throughout its length on the pavement or sidewalk or it may be supported on stakes driven along the side of the highway or on portable tripods.

If the surface of the pavement is smooth and has a uniform grade, it is ordinarily advisable to use the pavement as a support for the tape. In order to avoid traffic, the line to be taped should be chosen if possible to run near the curb or edge of the sidewalk, either of which is usually sufficiently straight so that the tape ends can be lined in without an instrument. The pavement at a distance of about 1 foot from the curb has been found to be the most practical location for the line, not only to avoid the traffic but also to miss the wash of sand found close to the curb. This location is often prohibited by

the large number of parked automobiles, and the measurements should then be made along the sidewalk or in the street.

For marking tape ends white adhesive tape 1 inch wide may be used. A piece of this tape about 3 inches long should be stuck to the pavement and the forward mark on the tape transferred to it with a hard pencil. On a street paved with asphalt the tape ends may be marked directly on the pavement with a knife. Each tape end should be numbered on the pavement with yellow lumber crayon so that it may be easily found by the rodman of the wye level party.

The same tape stretchers that are used for taping on the rail may be used on the pavement. (See fig. 22.) To give a flat surface

FIG. 22.—Taping along the sidewalk

against the pavement, a piece of board may be put between the flanges which fit over the rail.

If movable tripods are used, the tape ends may be marked on copper strips attached to the wooden marking tables at the top of the tripods unless the marking tables are equipped with graduated invar strips. (See figs. 23, 24, and 25.)

The check measurement with the 300-foot tape should be made in the usual way.

LEVELS

FIRST-ORDER LEVELS

The elevation of each traverse station must be determined in order that the measured lengths may be reduced to sea level, and in addition the difference of elevation of consecutive tape ends must be

determined in order that the corrections for inclination may be computed. The elevations of the traverse stations should be determined

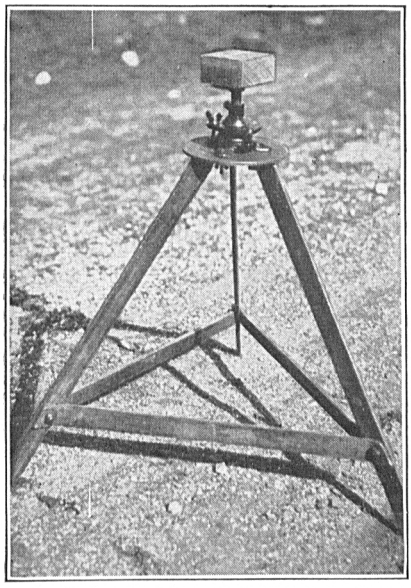


FIG. 23.—Movable iron tripod for traverse measurement

The wooden marking table, which carries a strip of copper on which the mark for the tape end is made, can be placed on grade by the ball-and-socket base and then clamped in position.

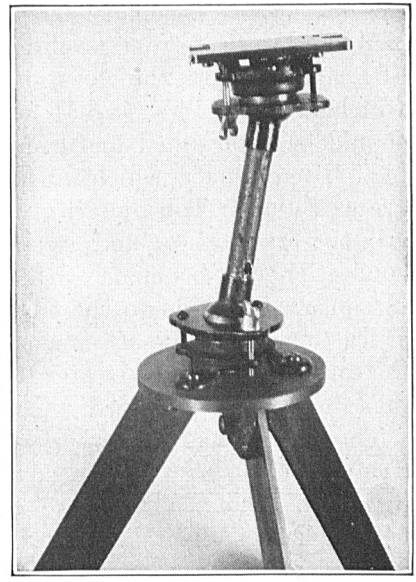


FIG. 24.—Movable iron tripod with double ball and socket

This tripod permits the marking table to be adjusted over a point as well as placed on grade.

by first-order leveling, which should be done either at the same time or shortly after the traverse measurements are made except in cases where the traverse follows a line of first-order leveling already com-

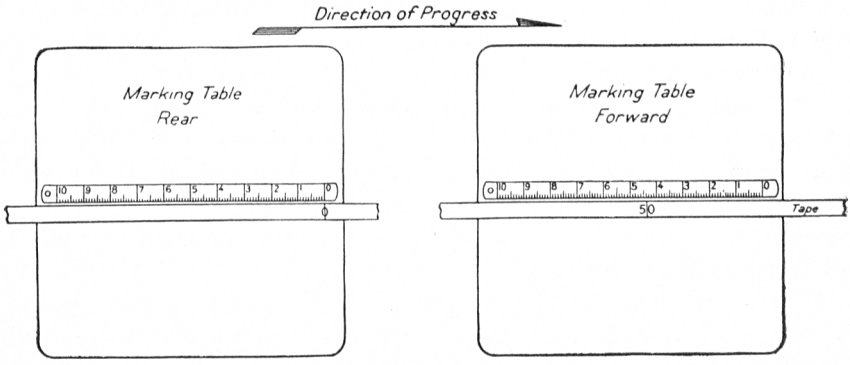


FIG. 25.—Method of using graduated invar strips on marking table

The marking tables of movable tripods for traverse measurement are frequently fitted with these strips. With the arrangement as shown, and the rear or zero mark of the tape held opposite the zero mark of the strip on the rear marking table, the reading of the forward mark on the tape would always be recorded as a set-up, or additive quantity.

pleted. The first-order leveling will be carried on in accordance with the general instructions for such leveling contained in Special Publication No. 140 (now in press), except as they may be modified by the instructions herein.

When the first-order leveling is done at the same time or shortly after the traverse, the elevations of a sufficient number of points to which the wye level and the track level work has been connected should be determined to furnish control for the less accurate leveling. The points to which the first-order leveling should be connected are as follows: Top of rail opposite each railroad station, milepost, and traverse station, and each traverse station mark itself to which connection can be made without much loss of time. If for some reason a connection to the traverse measurements can not be made at least once per mile at some one of the above points, the elevation of the top of rail opposite water tanks and at bridges or highway crossings should be determined.

The elevation of the top of rail at the specified points may be determined by using them as turning points or by reading extra foresights on them. The record should show by the letters "F" or "B" whether the reading was taken in front of or back of the instrument. If the point to be determined is used as a turning point, only one connection need be made providing the section checks, but if it is determined by extra foresights one foresight must be taken from each of two instrument stations.

The traverse stations which have been marked in a permanent manner and are easily accessible should be used as bench marks on the line of levels.. Enough additional bench marks should be established by the leveling party to give the required number of bench marks per mile. Reference marks should not be used as bench marks because it has been found that there is too much chance for confusion where there are two bench marks as close together as are the station and reference marks.

Where for any reason a line of levels leaves the railroad track—as, for example, to connect with bench marks in a city—the point of leaving the track should be indicated in the record. Where the line again returns to the track, a turning point should be chosen as close as possible to the last turning point used before leaving the track and a note made in the record, so that a continuous profile of the track may be obtained.

When a traverse station has the same name as a railroad station, care should be taken to distinguish in the record between the readings on the rail opposite the railroad station and readings opposite the traverse station.

WYE LEVELS

Where the taping is over stakes, the difference of elevation of consecutive tape ends should be determined by wye levels. Where the tape is supported on the rail, the difference of elevation of the tape ends should be determined by wye leveling or by the track level if that instrument is being used. The wye leveling should be done with a leveling rod graduated in meters on one side and in feet on the other. Readings should be made on both sides of the rod for each tape end, and if this is done a single running is sufficient. If a rod graduated only in meters (or feet) is used, a double running of the line is necessary.

Even where first-order leveling is to be done later the difference of elevation of tape ends along the tangents should be determined with either a wye level or a track level. This not only increases the speed of the first-order leveling party by materially decreasing the number of elevations to be determined by that party but also simplifies the computation of the inclination corrections and results in a considerable saving of time. If wye leveling is used, it should be done in the same manner as over stakes. Rod readings should be taken at each tape end unless special instructions are given to take them at every other tape end only.

The differences in elevation between the traverse stations and the rail or offset stations should also be determined for use in reducing the measurements of the offset distances to the horizontal. If there is a bench over the traverse station mark, the difference in elevation between it and the mark should be determined. Extreme care should be taken that rod readings are taken at all broken grades.

For traverse measurements along paved streets or highways wye levels should be run over the line in the same manner as along a railroad. If portable tripods are used, the levels may be run either over the tripods or over points on the pavement where the tripods stood. In the latter case these points will have been marked by the invar taping party and the height of the tripod at each tape end measured and recorded.

Before the wye leveling is begun on a section an abstract of the taping record should be made in the wye level record book. This is necessary in order to show at what points rod readings are required and thus elminate the danger of omitting broken grades, benches, etc.

The error of the inclination correction for a single tape length should not exceed 0.2 millimeter. The correction varies directly as the square of the difference of elevation and inversely as the distance, and therefore the leveling must be more accurately done on steep grades and for fractional tape lengths than elsewhere. Tables of the inclination corrections for 50-meter tape lengths, for 25-meter lengths,

and for the intermediate 5-meter lengths for various differences of elevation are given on pages 103 to 111. An inspection of these tables

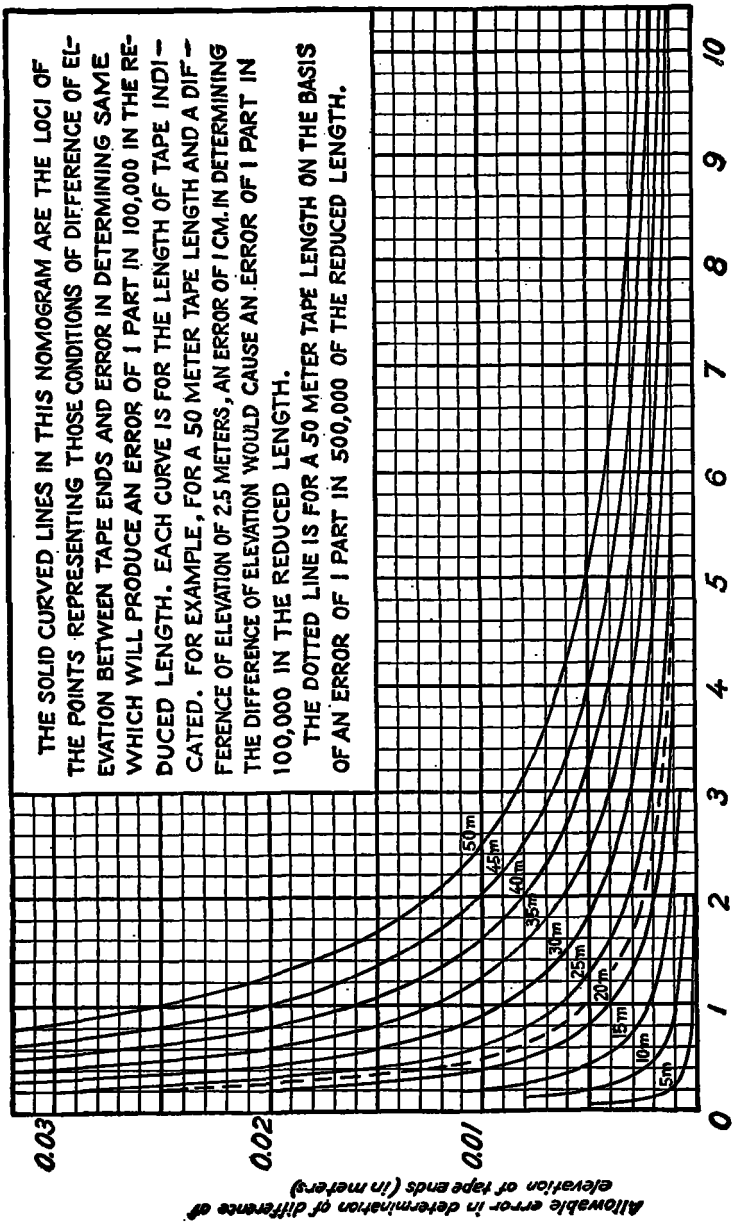


FIG. 26.—Nomogram for effect upon the reduced length of errors in the relative elevations of the ends of a tape

and of the nomogram (see fig. 26) will indicate the accuracy required in the leveling.

At the end of each day's work with the wye level the rod readings in feet should be converted to meters and compared with the readings

in meters. If any material difference is found, the correct value should be determined by releveling.

TRACK LEVELS

An instrument called the "track level" has been developed by the Coast and Geodetic Survey for use in determining the inclination corrections where the tape is supported on the rail. (See fig. 27.) The track level is supported on the rail at two points, about 6 feet apart, designated as *A* in figure 27. The bubble *B* is mounted on a movable arm, pivoted at *P*, which has a graduated arc and vernier *V*. The arm is about 30 inches long and is not supplied with a clamp

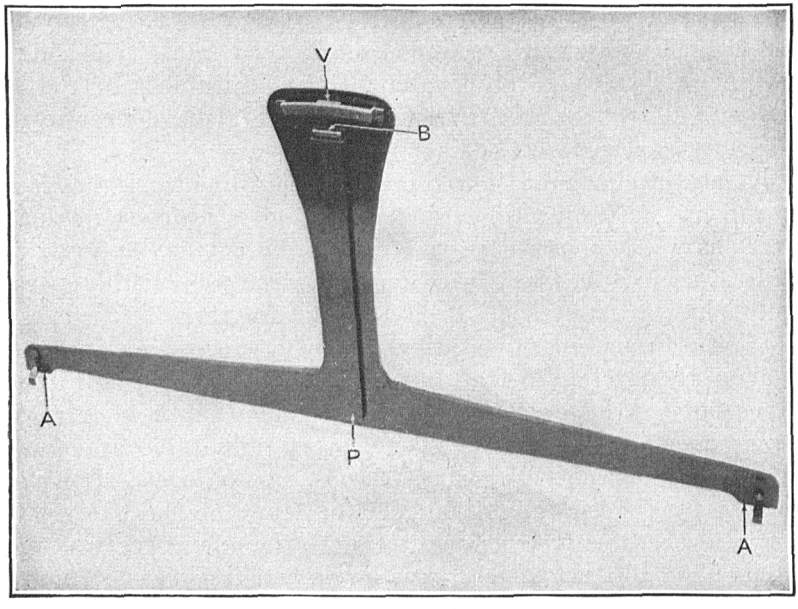


FIG. 27.—Track level

and slow-motion screw but is held in position by friction only. The scale is graduated to 10 minutes, and the vernier reads to minutes. With such a long arm the bubble can be centered very quickly and about as accurately as with a short arm and slow-motion screw, and the graduations are of such a size as to be easily read with the naked eye. On the back is mounted a hinged leg, which serves as a support for the instrument while the operator records the observation.

With this instrument the inclination of each tape length is determined by placing the track level on the rail near the middle of the tape, moving the arm until the bubble is centered, and then reading the angle of inclination. The track level need not be placed exactly

in the center of the tape length but should be placed near the middle of a rail to avoid an incorrect grade, due to the rail being bent near its ends.

The track level should have one end marked "Forward end," and this end should be kept ahead during all measurements to avoid confusion in sign in the differences of elevation. The observer in making the readings will then have to stand on the outside of the track when the tape is supported on one rail and between the rails when it is supported on the other rail. The level should be adjusted at least once a day and oftener if necessary. The track level is in adjustment if the angle reading is the same numerically, although of opposite sign, when the instrument is used in the direct and reversed position on the same two points. The adjustment should be tested by taking reversed readings once every mile. The chief of party should keep a careful watch of the adjustment of the level and should inspect the record frequently to see if the observations are consistent on even grades.

The track level should be used only on main line track that is well kept and has uniform grades, since it will give incorrect inclination corrections where consecutive rails have different inclinations. The successful use of the track level depends largely upon the operator, and the chief of party should select a man for this duty who is not only careful in making observations but who will use good judgment in placing the level on the rail in such a position that it will indicate the true slope of the tape. The track level should be used only where connections can be made at least once every mile to elevations determined by first-order levels, railroad levels, or wye levels. It is better to use the track level on long tangents only and on short tangents to run wye levels directly from one station to the other.

A complete abstract of both wye levels and track levels should be made for the whole line on Form 635, "Abstract of wye levels." (See fig. 43, p. 72.) This not only gives a continuous profile of the line, but also when compared with the invar tape record checks the number of tape lengths and the designation of all points and insures that no broken grades, etc., have been omitted.

If the wye and track levels can not be connected to first-order leveling bench marks, they should be connected to any available bench marks, such as those established by the railroads, United States Geological Survey, or other organizations. This will furnish elevations for sea-level reduction and also give a check on the accuracy of the levels until first-order levels are available.

ANGLE MEASUREMENTS

MAIN TRAVERSE STATIONS

In general, a direction instrument of high order should be used in measuring the angles at the traverse stations through which the azimuth of the traverse is to be carried. A repeating theodolite should be used at these stations only in cases where conditions prevent the use of a direction theodolite:

If a direction theodolite is used, the angles will usually be measured in eight positions of the circle chosen so as to space the micrometer readings uniformly around the graduated circle for a complete set of observations. With a small direction theodolite it may be necessary to use 12 positions. For each position or initial setting of the horizontal circle a pointing is made on each station around the horizon in a clockwise direction with the telescope direct (or inverted) and then in the reverse direction with the telescope inverted (or direct).

The initial settings for 8, 12, and 16 positions for both 2 and 3 micrometer theodolites are as follows:

Initial settings of direction theodolite for 8 positions of circle

[One division of circle=5 minutes]

3-micrometer theodolite					2-micrometer theodolite				
Position No.	Setting				Position No.	Setting			
	°	′	″			°	′	″	
1	0	00	40		1	0	00	40	
2	15	01	50		2	22	01	50	
3	30	03	10		3	45	03	10	
4	45	04	20		4	67	04	20	
5	67	00	40		5	90	00	40	
6	82	01	50		6	112	01	50	
7	97	03	10		7	135	03	10	
8	112	04	20		8	157	04	20	

Initial settings of direction theodolite for 12 positions of circle

[One division of circle=5 minutes]

3-micrometer theodolite					2-micrometer theodolite				
Position No.	Setting				Position No.	Setting			
	°	′	″			°	′	″	
1	0	00	40		1	0	00	40	
2	15	01	50		2	15	01	50	
3	30	03	10		3	30	03	10	
4	45	04	20		4	45	04	20	
5	65	00	40		5	60	00	40	
6	80	01	50		6	75	01	50	
7	95	03	10		7	90	03	10	
8	110	04	20		8	105	04	20	
9	130	00	40		9	120	00	40	
10	145	01	50		10	135	01	50	
11	160	03	10		11	150	03	10	
12	175	04	20		12	165	04	20	

Initial settings of direction theodolite for 16 positions of circle

[One division of circle=5 minutes]

3-micrometer theodolite		2-micrometer theodolite	
Position No.	Setting	Position No.	Setting
	° ′ ″		° ′ ″
1	0 00 40	1	0 00 40
2	15 01 50	2	11 01 50
3	30 03 10	3	22 03 10
4	45 04 20	4	33 04 20
5	64 00 40	5	45 00 40
6	79 01 50	6	56 01 50
7	94 03 10	7	67 03 10
8	109 04 20	8	78 04 20
9	128 00 40	9	90 00 40
10	143 01 50	10	101 01 50
11	158 03 10	11	112 03 10
12	173 04 20	12	123 04 20
13	192 00 40	13	135 00 40
14	207 01 50	14	146 01 50
15	222 03 10	15	157 03 10
16	237 04 20	16	168 04 20

For theodolites with two micrometers the tables of initial settings were computed by the formula:

$$I=\frac{360}{mn}$$

where I is the increment in degrees between settings of the circle, m is the number of micrometers, and n is the number of positions to be observed. For theodolites with three micrometers the formula is

$$I=\frac{360}{2mn}$$

In this connection the difference between two-micrometer and three-micrometer instruments in reversing should be noted. With two micrometers the reversal of the instrument merely interchanges the positions of the micrometers on the circle, but with three micrometers the reversal of the instrument brings the positions of the micrometers halfway between their positions with the instrument direct, thus giving altogether six equally spaced readings on the circle.

In the above tables for the three-micrometer theodolites it will be noticed that in order to make the settings easier to remember and to spread them over a greater part of the circle a multiple of the increment is used which is increased after every four positions by the increment itself. For example, with 12 positions the increment is $\frac{360}{2\times3\times12}$ or 5. A multiple of the increment (15°) is used to obtain all positions except the fifth and ninth, where 20° (15° plus the in-

crement itself) is used. The same system is used in determining the settings for 8 and 16 positions in order to make them all consistent. The settings for eight positions differ slightly from those given in Special Publication No. 120, where the increment itself was added after the fourth position instead of 15° plus the increment. Exactly the same distribution of the micrometer readings over the circle is obtained in both cases. In fact, the settings may be given in many different ways, all of which will give the same distribution of the micrometer readings around the circle.

The increment of the minutes and seconds for each group of four settings is determined by dividing the value of the smallest graduation of the circle by four. The first setting of each group is one-half of this increment. For a theodolite with a circle graduated to 10 minutes the settings in minutes and seconds would be (rounding off the values to 10″) 01′–20″, 03′–50″, 06′–20″, and 08′–50″ for each group of four settings.

The settings given in the tables are those actually to be made with the finder microscope of a three-micrometer theodolite or with the A microscope of a two-micrometer instrument. Since the telescope is reversed between the settings for any two consecutive positions, the given settings require the changing of the circle almost 180° in orientation for each new position, and this tends to maintain the circle at a uniform temperature, even though temperature conditions may not be the same on all sides of the instrument.

OBSERVATIONS WITH REPEATING THEODOLITE

When the measurement of a main angle of the traverse is made with a 7-inch repeating theodolite, a sufficient number of observations should be made to obtain the same degree of accuracy as can be obtained by measuring the angle in eight positions with a high-grade direction theodolite. Usually three sets of observations on each angle and the angle closing the horizon, each set consisting of six repetitions of the angle with the telescope direct and six repetitions of the explement with the telescope reversed, will give the required accuracy. The circle should be read and recorded at the initial and at the first, third, and sixth repetitions. The initial reading for each set should be on a different part of the circle. These initial settings should be obtained by the same formula as that used for a direction theodolite (see p. 44), m in this case being the number of verniers or micrometers and n the number of sets to be observed. Thus, for three sets with a 7-inch repeating theodolite, graduated to 10 minutes and with two verniers, the initial settings would be 0° 02′ 00″, 60° 05′ 00″, 120° 08′ 00″.

INSTRUCTIONS FOR MAKING OBSERVATIONS

Observations at the main traverse stations should be made only at night or on very cloudy days. In either case lights should be used for signals. Observations at night should not be started until a half hour after sundown and should be made only under favorable conditions. A steady signal does not always mean good observing conditions, for there may be considerable lateral refraction of the line at such a time and practically none when the signal appears to jump about or is tremulous. Excellent observations can be obtained on a signal that is moderately unsteady when a number of repetitions of the angle or direction is made. The amount of unsteadiness that will still permit good observations to be obtained can be determined only by experience. The traverse station to the rear, in relation to the direction of progress of the traverse, should invariably be used as the initial except when an azimuth is being observed at the same time. (See p. 49.)

The observations with a direction theodolite on a station for any one position of the circle should be rejected, and the observations for that position repeated if it differs from the mean of all positions by more than 5 seconds. For any direction the mean of all positions of the circle should have a probable error rarely to exceed 1.5 seconds. If a repeating theodolite is used, any set which gives a horizon closure of more than 3 seconds per angle or any angle which differs by more than 3 seconds from the mean of all the sets should be rejected.

The geodetic azimuth of the traverse line as carried through by the angle observations at the traverse stations should rarely differ from the astronomic azimuth by more than one second times the number of stations between azimuth stations. This accuracy may be obtained if care is used in selecting stations and observing conditions.

It is very important that directions should be observed to prominent objects distant from the railroad, such as church spires, large chimneys, cupolas, etc., especially when the positions of these objects may be determined by observations from two or more stations. These observations on intersection points may be made in the daytime, using a direction theodolite with two positions of the circle or using a 7-inch repeating theodolite and taking one set of three direct and three reverse. An adjacent traverse station, preferably the one to the rear to avoid the use of two different initials at one station, should be used for the initial on these observations. Horizontal directions to reference marks should be observed with one position of the circle, either at night at the same time that the directions to the main stations are observed by sighting on flashlights or in the daytime when the directions to the intersection points are observed.

Supplementary stations, placed near towns for the benefit of local engineers and surveyors, should be occupied and observed upon in the same manner as the main angle stations even though the azimuth of the traverse is not carried through them. The closure of the figures thus formed should be determined in the field as a check upon the observations.

One source of error in angle measurements is in the use of short lines. No line shorter than one-half mile should be used if it is possible to avoid it. If signal lamps are used, no phase should be encountered. On short lines flashlights may be used to advantage instead of signal lamps. The instrument and the objects sighted upon should be accurately centered. They should not be placed over eccentric points unless this is absolutely necessary. If the instrument or object is eccentric, the eccentric distance and direction must be carefully measured and recorded. The distance and direction from the eccentric instrument to the station, or from the station to the eccentric object, should be entered on the list of directions and should be referred to the same initial station as the other directions from that station. Confusion is caused by recording the eccentric as "2.5 centimeters right." A sketch should be made in the horizontal direction record book and also on the list of directions showing directions to the center, to the eccentric object, and to a main station. (See Special Publication No. 120, p. 94, for proper method of recording eccentricity.)

Precautions should be taken to avoid lateral refraction. If it is necessary to have a line of sight pass close to some object, a condition which sometimes can not be avoided, the observations should be made when the wind is blowing across the line of sight toward the object. Stations alternated from one side of the track to the other will tend to lessen any accumulation of lateral refraction errors.

Sighting on the wrong object will be prevented if signal lamps tended by light keepers are used at stations where, on account of the presence of other lights in the vicinity, the signal light is hard to identify. If a tended light is used, it should not be observed upon until some code signal has been received from the light keeper.

SUBSIDIARY STATIONS

Where the loops are small (see p. 6), the stations designated A, B, C, etc., may be occupied with a 7-inch repeating theodolite, one set of six repetitions with the telescope direct and reversed being measured on the interior angle and a similar set on the exterior angle. They may also be occupied with a small direction theodolite, four positions of the circle being used.

Where the loops are long and the intermediate stations permanently marked (see p. 6), they should be occupied with a direction

theodolite or with a 7-inch repeating theodolite, the same accuracy being required as at main traverse stations.

All loops must be closed, because a concluded angle will hide any errors in angles that may have been made. The angles at main traverse stations required to close loops should be measured at the same time that the main angles are measured. For this purpose a light should be plumbed over the intermediate station. A definite allowable closing error for loops can not be set because generally the lines in the loops vary considerably in length, many of them being very short. The chief of party must depend largely upon his own judgment, but the closing error should seldom exceed three seconds times the number of angles in the loop.

The practice of sighting along a rail on a long tangent when occupying an A station should be avoided, since any slight deviation of the tangent from a straight line will increase the error of closure of the loop, and the adjustment of the loop will throw the discrepancy where it does not belong. An extra A station should be put in along the tangent if necessary, so that all pointings will be on stations and none on rail tangents. (See fig. 15, p. 25.)

The danger of error in sighting along a rail tangent and the importance of always computing in the field the closing error of the angles in the loops are well illustrated in the following incident. On a recent traverse the error of closure of the angles in one loop was not computed in the field. When the computation of this loop was made in the office, it was found that the angles failed to close by nearly five minutes. An examination of the record book showed that at two of the stations in this loop the pointings had been made on a rail tangent instead of the station.

At rail and offset stations the offset distances are so small in comparison to the distances between stations and the angles at the rail and offset stations are so nearly 90° that only the angles at the rail and offset stations themselves need be observed. Here the direction method may be used with a 7-inch repeating theodolite and two positions of the circle as described in Special Publication No. 26, paragraphs 66 to 68, or the repetition method may be used with two sets of repetitions. If the same rail or offset station is used both in coming up to and leaving a traverse station, the angle on each side of the line to the main traverse station should be measured. Angles must always be measured in a clockwise direction. At rail or offset stations the pointing may be made upon the rail of the tangent or upon the line of stakes along which the measurement has been made, but the sights should be taken as far up the tangent or line of stakes as possible.

AZIMUTH STATIONS

Owing to the fact that errors in angle observations on a traverse line tend to accumulate, it is necessary to determine frequent astronomic azimuths by observations on Polaris.

Astronomic azimuths are divided into three groups according to accuracy, and these are designated first, second, and third order azimuths. A first-order azimuth is an azimuth determined with a direction instrument with two sets of 16 positions and must have at least 22 acceptable positions with not less than 8 of them in one set. The two sets should be entirely separate and observed on different nights. At first-order azimuth stations the astronomic longitude will be determined later. A second-order azimuth is one determined with one set of 16 positions of which at least 10 must be acceptable. A third-order azimuth is usually observed with a repeating theodolite. The limiting probable errors of first, second, and third order azimuths are 0″.30, 0″.50, and 2″, respectively.

The location of the first-order azimuth stations will be specified in the special instructions for each particular piece of work. In general, the second-order azimuth stations will be established at intervals of about 10 to 15 traverse stations. Only main traverse stations should be used for azimuth stations.

When the geodetic azimuth is carried through long lines forming loops as described on page 6, the stations through which it is carried will be used in determining the interval between the azimuth stations. The interval between azimuth stations of either first or second order should not exceed 50 miles unless instructions to the chief of party specify otherwise.

An astronomic azimuth is determined by observations upon Polaris at any hour angle, referred to some main traverse station as the azimuth mark. The azimuth observations are usually made during the measurement of directions to the traverse stations. The time required to make the observations upon Polaris is approximately equal to that required to make the observations upon two traverse stations. The station last sighted upon before pointing on Polaris should be used as the azimuth mark, in order that the instrumental changes shall be as small as possible between the times of pointing upon the mark and upon the star. If a traverse angle is being measured at the same time that observations for azimuth are being made, it is advantageous to use for the initial the station to the right of north. This will make the station to the left of north the azimuth mark, and Polaris will be at a convenient angle from the mark.

TIME DETERMINATIONS

Since observations for azimuth are made upon Polaris at any hour angle, the correction to the chronometer time should be known within one second. An error of one second in the time would cause an error of about 0″.3 in the computed azimuth of Polaris near culmination in latitude 30° and about 0″.6 in latitude 60°.

The chronometer correction is sometimes obtained by comparison with the time signals from the Naval Observatory sent out by radio or over commercial telegraph lines, but this method is apt to prove unsatisfactory for the following reasons. Because of temperature and winding errors the daily rate of the chronometer obtained by successive comparisons with the time signals may be very different from the actual rate during the interval from the signal to the mean epoch of the time of observing. Transporting the chronometer to the traverse station and back causes an additional variation in its rate.

Observations upon the stars near the time of the azimuth observations will, in general, prove the more accurate and satisfactory means for obtaining the chronometer correction, and of the many methods available observed altitudes of both east and west stars near the prime vertical will prove the most advantageous with the instruments usually at hand. With this method no star catalogue or observing list is needed, and any star near the prime vertical whose altitude at the time is greater than 30° can be used, even though it shows for only a few minutes through a broken field of clouds. For routine of observing azimuth and time see Special Publication No. 120.

FIELD RECORDS AND COMPUTATIONS

GENERAL STATEMENT

On account of the number of different operations, the multiplicity of details, and the chances for errors and blunders, it is advisable to make a field computation of a traverse as close behind the field work as possible. In this way any discrepancies or omissions may be found and corrected before the party has left the vicinity where they occur. It is sometimes desirable to have an extra officer or a mathematician attached to the party who can devote his entire time to keeping the computations up to date. A complete computation, including the geographic positions and geodetic and astronomic azimuths, can then be made in the field.

If no extra officer or mathematician is available, the field records and abstracts should be kept up to date in the field as closely as possible and sent to the office at least every 10 days even if the different volumes are not full. In this way the office will usually be able

to make a computation close behind the field work and inform the field party quickly of any discrepancies revealed by the computation.

Abstracts of all records must be made and checked in the field and the records and abstracts sent to the office by registered mail on different days. In this way if any portion of the records or abstracts is lost a duplicate of the essential data will be available.

A detailed outline of the necessary records, abstracts, and computations which must be made in the field and the checks to be applied follow.

MEASUREMENT OF DISTANCES

The record of the invar tape measurements will be entered in "Traverse measurements," Form 590. (See fig. 28.) Before the records are sent to the office the following operations should be completed:

1. Temperature means computed.
2. All measurements which were taken in both meters and feet compared by converting distances in feet to meters.
3. Set-ups and setbacks summed up.
4. Necessary data entered on traverse sketches.
5. Forms 589 and 635 filled out in part.

The computation of the measured distances should be made on Form 589, "Computation of traverse line." (See fig. 44, p. 74.) The columns of this form under the following headings should be filled out and checked before it is sent to the office:

1. Section.
2. Date.
3. Direction of measurement.
4. Tape number.
5. Tape lengths.
6. Meters.
7. Temperature.
8. Set-up and setback.

The record of the check measurements with the 300-foot tape will also be entered in Form 590. Different volumes should be used for the invar and check measurements. Before the records of the check measurements are sent to the office the length of each section should be corrected for temperature and standardized length and converted from feet to meters. These distances in meters, together with the uncorrected distances obtained with the invar tape, should be entered in the record book so that a comparison between the two measurements may be easily made. (See fig. 29.) The distances, expressed in meters, as determined by the 300-foot tape should also be entered on the traverse sketches.

LEVELS

If first-order levels are run over a traverse line, the observations should be recorded in Form 257, "Spirit level observations." The computation should be made on Form 45, "Computation of first-

order levels," in accordance with instructions in Special Publication No. 140 (now in press), and should show the connections with the wye and track levels. These computations should be checked before they are sent to the office.

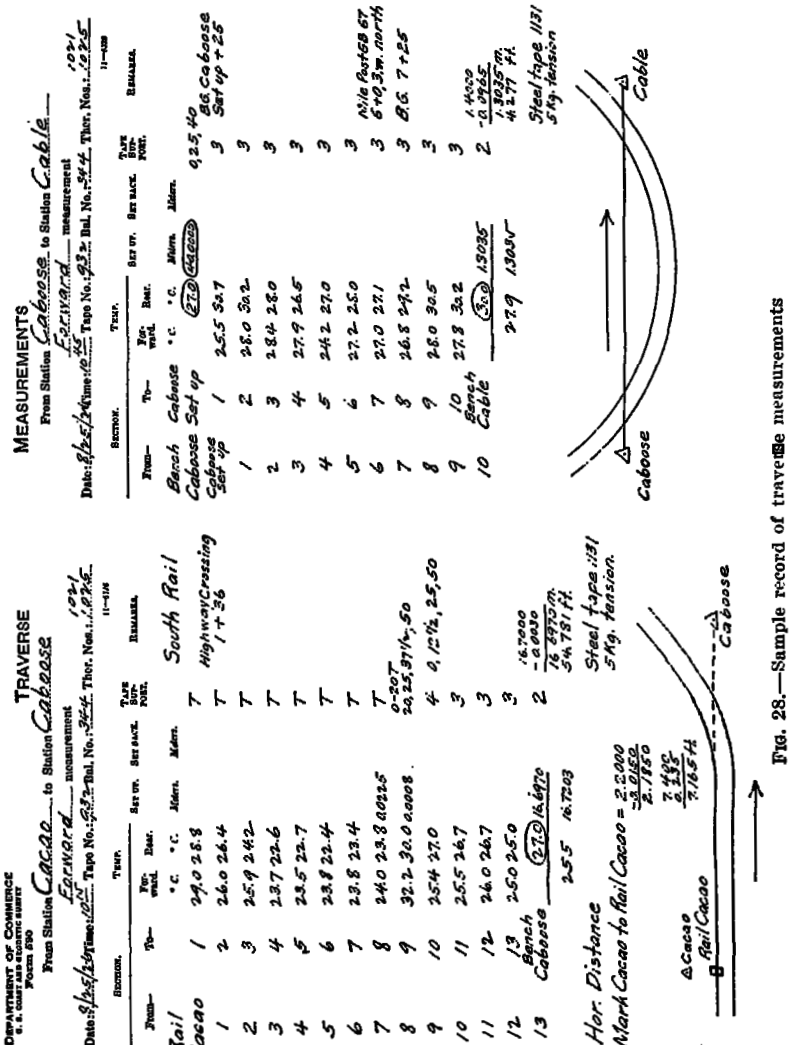
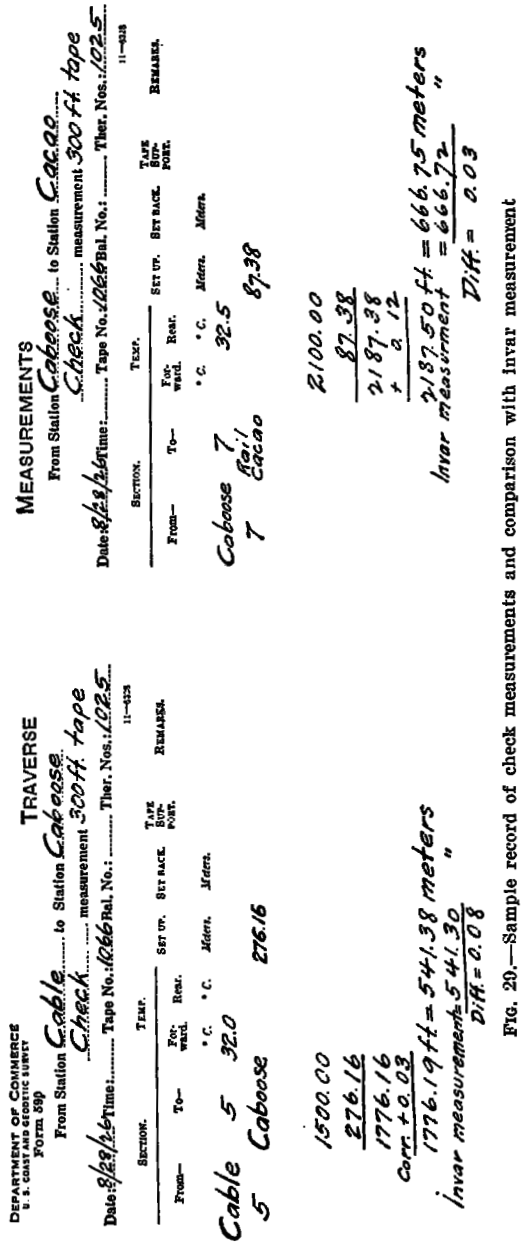


Fig. 28.—Sample record of traverse measurements

All wye and track level observations used in obtaining the inclination corrections should be entered in Form 634 "Wye leveling." If both kinds of leveling are done on the same section of the traverse, spaces should be left in the record when the first type of leveling is done, so that the other can be entered later to make the record continuous. (See fig. 30.)

The leveling records should be checked and then abstracted on Form 635, "Abstract of wye levels and computation of inclination



DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
FORM 599

TRAVERSE

From Station Cable to Station Caboose
Check measurement 300 ft. tape
Date: 8/29/26 Time: Tape No. 1066 Bal. No.: Ther. Nos.: 1025

SECTION. From—	To—	TEMP. Forward. °C.	TEMP. Rear. °C.	SET UP. Meters.	SET BACK. Meters.	TAPE BOTTOM POINT.	REMARKS.
Cable 5	5 Caboose	32.0		276.16			

1500.00
276.16
1776.16
corr. +0.03
1776.19 ft = 541.38 meters
Invar measurement = 541.30 "
Diff. = 0.08

MEASUREMENTS

From Station Caboose to Station Cacao
Check measurement 300 ft. tape
Date: 8/29/26 Time: Tape No. 1066 Bal. No.: Ther. Nos.: 1025

SECTION. From—	To—	TEMP. Forward. °C.	TEMP. Rear. °C.	SET UP. Meters.	SET BACK. Meters.	TAPE BOTTOM POINT.	REMARKS.
Caboose 7	7 Rail Cacao	32.5		87.38			

2100.00
87.38
2187.38
+ a 12
2187.50 ft = 666.75 meters
Invar measurement = 666.72 "
Diff. = 0.03

FIG. 29.—Sample record of check measurements and comparison with invar measurement

corrections." The first three columns of this abstract should be filled out in the field. The first two columns are taken from the invar tape record and should be checked against the leveling record.

In this way the number of tape lengths is checked and the omission of broken grades, extra set-ups, etc., may be prevented. The third

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DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
FORM 634

WYE

From Caboose To Cable

FORWARD RUNNING

Date 8/26/26 Instrument 95 Rods 167.6

Point.	Backsight. Meters	Foresight. Meters	Difference. Meters	Remarks.
Bench Caboose	1.17			
Caboose set up B.G. Caboose set up + 25		0.47	+0.70	
1		0.61	-0.14	
2		1.24	-0.63	
3		1.04	+0.20	
4	1.22	1.80	-0.76	
5		0.28	+1.52	
6		0.31	+0.91	
7		0.77	-0.46	
B.G. 7 + 25		1.54	-0.77	
8		0.39	+1.15	
9		0.40	-0.01	
10		2.02	-1.62	
Bench Cable		0.27	+1.75	
Mark Cable		0.24	+0.03	
		1.27	-1.03	

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LEVELING

From Caboose To Cable

FORWARD RUNNING

Date 8/26/26 Instrument 95 Rods 167.6

Point.	Backsight. feet.	Foresight. feet.	Difference. feet.	Remarks.
Bench Caboose	3.85			
Caboose set up B.G. Caboose set up + 25		1.56	+2.29	+0.70
1		2.02	-0.46	-0.14
2		4.09	-2.07	-0.63
3		3.42	+0.67	+0.20
4	4.00	5.91	-2.49	-0.76
5		0.92	+4.99	+1.52
6		1.02	+2.98	+0.91
7		2.50	-1.48	-0.45
B.G. 7 + 25		5.07	-2.57	-0.78
8		1.29	+3.78	+1.15
9		1.32	-0.03	-0.01
10		6.63	-5.31	-1.62
Bench Cable		0.89	+5.74	+1.75
Mark Cable		0.79	+0.10	+0.03
		4.17	-3.38	-1.03

Differences in ft. converted to meters

FIG. 30.—Sample record of wye leveling

column of the abstracts should also be checked before they are sent to the office. If a track level is used, the differences of elevation

corresponding to the angles of inclination should be entered in this column. (See table on p. 102.) The best available elevations should be carried through the levels and checked on all available bench marks. (See fig. 43, p. 72.)

ANGLE MEASUREMENTS

All angles measured with a repeating theodolite should be entered in Form 250, "Observations of horizontal angles." All records should be checked, and "Lists of directions," Form 24A, should be made out and checked before they are sent to the office. All angles at rail and offset stations and at loop stations should be entered on the traverse sketches.

All observations made with a direction theodolite should be entered in Form 251, "Horizontal directions." The record books should be checked, and "Abstract of directions," Form 470, and "List of directions," Form 24A, should be made out and checked before they are sent to the office. (See pp. 88, 90, and 94 of Special Publication No. 120.) It is important that the degrees and minutes entered on the abstract of directions be checked from the observations of several different positions of the circle.

Azimuth observations should be recorded in Form 251, "Horizontal directions." (See p. 88, Special Publication No. 120.) The record should be checked and then abstracted on Form 380, "Computation of azimuth, direction method." (See p. 148, Special Publication No. 14.) The abstract should be filled out and checked to such an extent that the azimuth could be computed if the original observations were lost.

If time is determined by comparisons with Naval Observatory time signals, either radio or wire, a copy of the comparisons should be made and checked. If time is determined by observations on stars with a vertical circle, the observations should be entered in Form 252, "Double zenith distances." (See p. 103, Special Publication No. 120.) The record should be checked and an abstract made out and checked on Form 381A, "Computation of time, observations on a star with a vertical circle." (See p. 55, Special Publication No. 14.) This form should be filled out and checked to such an extent that if the original should be lost the time could be computed from the data on the abstract.

Abstracts of azimuth and time observations should be sent to the office within one week after the observations are made. The observer should scale off the latitude and longitude of the station from the best available map and include these with the records. A description of the azimuth station giving the distance and direction to the nearest town should also be included, but this description is not to be con-

fused with the more complete description which is to be forwarded with the descriptions of all other stations.

TRAVERSE SKETCHES

Traverse sketches, similar to Figures 31 to 35, should be made out for each section of the traverse line and should include all necessary data for projecting the measured lengths onto the traverse lines. The sketches should be made on horizontally ruled computing

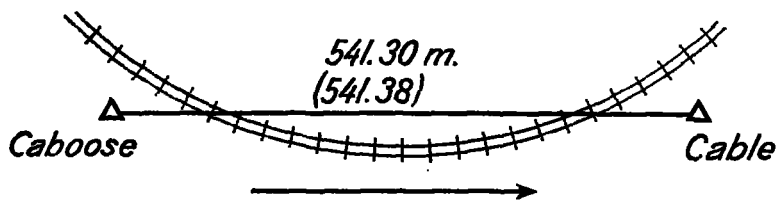


FIG. 31.—Traverse sketch, direct measurement

paper, and there should be only one sketch on a page. The following data should be included on each sketch:

1. Direction of progress (shown by arrow).
2. Relation of railroad tracks to traverse stations.
3. Distances as taken from invar tape record without correction for temperature, standardized length, inclination, or sea level.
4. Distances determined by 300-foot tape, expressed in meters and corrected for temperature and standardized length, inclosed in parentheses and written below the invar distance.
5. Offset distances expressed in meters with statement whether distances were measured horizontally or inclined.
6. Angles at loop stations and at offset and rail stations.
7. Summation of loop angles with closures.

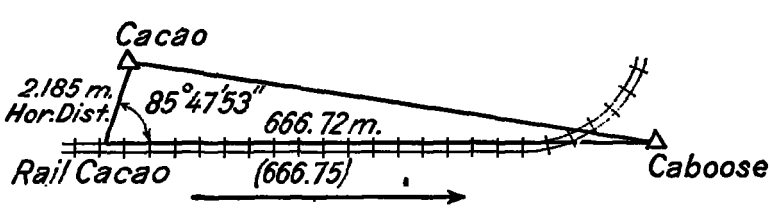


FIG. 32.—Traverse sketch, one offset station

The importance of these sketches can not be over emphasized. It has been found by experience that they are of utmost value to the officer in charge of the field work in determining whether all the necessary data have been obtained and whether the required accuracy has been secured. They are also of great assistance to the mathematicians in the office. The office computation of the projection is usually made on the same page with the sketch, and the sketch should

therefore be neatly drawn in ink and be placed near the top of the page.

DESCRIPTIONS OF STATIONS

All stations of the traverse except A, B, C stations, whether marked in a permanent or in a temporary manner, should be described in such a way that they may be recovered easily. The descriptions should include the distance from the nearest city or town, milepost, and highway crossing, and the distance to the fence line,

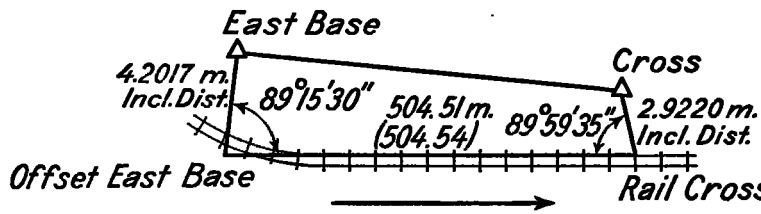


FIG. 33.—Traverse sketch, stations on same side of track

to the nearest rail of the track, and to any other objects which would be of assistance in recovering the station. The observing party usually occupies more than one station in a single night, and it is often impossible at that time to measure distances to reference marks and other objects or to write good descriptions of the stations. It is usually necessary, therefore, for the observing party or one of the other parties to visit the stations in the daytime in order to make the measurements and write the descriptions. Distances to near-by objects should all be measured and not paced or estimated. Dis-

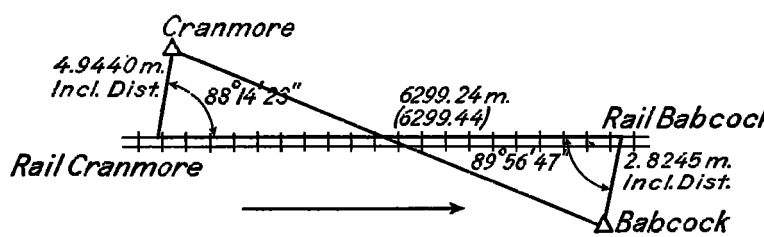


FIG. 34.—Traverse sketch, stations on opposite sides of track

tances which can not be easily measured by the party writing the descriptions should be taken from the invar tape record book.

Preliminary descriptions should be written in the horizontal direction record book or a blank book. Using these data and data taken from the invar tape record book the final descriptions should be typewritten on cards, Form 525, "Descriptions of triangulation station." (See fig. 36.) The writer of the descriptions should have in mind that the descriptions will later be published and therefore should be so written that the minimum amount of editing will be

necessary in preparing them for the printer. The station and reference marks should be described by notes, as given below.

Standard Notes

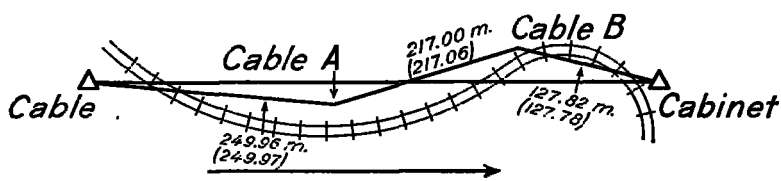
SURFACE MARKS

Note 1.—A standard disk station mark set in the top of (*a*) a square block or post of concrete, (*b*) a concrete cylinder, (*c*) an irregular mass of concrete.

Note 2.—A standard disk station mark wedged in a drill hole in outcropping bedrock (*a*) and surrounded by a triangle chiseled in the rock, (*b*) and surrounded by a circle chiseled in the rock, (*c*) at the intersection of two lines chiseled in the rock.

Note 3.—A standard disk station mark set in concrete in a depression in outcropping bedrock.

Note 4.—A standard disk station mark wedged in a drill hole in a bowlder.



Cable-Cabinet	0	00	00.0
	0	09	08.7
Cable-Cable A	0	09	08.7
	180		
	176	26	57.8
Cable A-Cable B	356	36	06.5
	180		
	188	53	29.0
Cable B-Cabinet	5	29	35.5
	180		
	354	30	25.6
Cabinet-Cable	180	00	01.1

FIG. 35.—Traverse sketch, loop

Note 5.—A standard disk station mark set in concrete in a depression in a bowlder.

Note 6.—A standard disk station mark set in concrete at the center of the top of a tile (*a*) which is embedded in the ground, (*b*) which is surrounded by a mass of concrete (*c*) which is fastened by means of concrete to the upper end of a long wooden pile driven into the marsh, (*d*) which is set in a block of concrete and projects from 12 to 20 inches above the block.

UNDERGROUND MARKS

Note 7.—A block of concrete 3 feet below the ground containing at the center of its upper surface (*a*) a standard disk station mark, (*b*) a copper bolt projecting slightly above the concrete (*c*) an iron nail with the point projecting above the concrete, (*d*) a glass bottle with the neck projecting a little above the concrete, (*e*) an earthenware jug with the mouth projecting a little above the concrete.

Note 8.—In bedrock (*a*) a standard disk station mark wedged in a drill hole, (*b*) a standard disk station mark set in concrete in a depression, (*c*) a copper

bolt set in cement in a drill hole or depression, (*d*) an iron spike set point up in cement in a drill hole or depression.

Note 9.—In a bowlder 3 feet below the ground (*a*) a standard disk station mark wedged in a drill hole, (*b*) a standard disk station mark set in concrete in a depression (*c*) a copper bolt set with cement in a drill hole or depression. (*d*) an iron spike set with cement in a drill hole or depression.

Note 10.—Embedded in earth 3 feet below the surface of the ground (*a*) a bottle in an upright position, (*b*) an earthenware jug in an upright position, (*c*) a brick in a horizontal position with a drill hole in its upper surface.

REFERENCE MARKS

Note 11.—A standard disk reference mark with the arrow pointing toward the station set at the center of the top of (*a*) a square block or post of concrete, (*b*) a concrete cylinder, (*c*) an irregular mass of concrete.

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
Form 525

TRAVERSE
DESCRIPTION OF TRIANGULATION STATION

NAME OF STATION: Door
CHIEF OF PARTY: J.S.Silby

STATE: Wisconsin COUNTY: Walworth
YEAR: 1920 LOCALITY: Darien

Surface-station mark,	Note,*	1a
Underground-station mark,	Note,*	7a
Reference mark, No. 1	Note,*	11a
Reference mark, No. 2	Note,*	11a
Witness mark,	Note,*	
Witness mark,	Note,*	
Height of signal above station mark		meters.
Height of telescope above station mark		meters.

DISTANCES AND DIRECTIONS TO REFERENCE MARKS AND PROMINENT OBJECTS

OBJECT	DISTANCE	DIRECTION ° ′ ″	AZIMUTH ° ′ ″
Dodge		00 00 00.0	75 15 09.1
Reference Mark 1	17.46m. (57.28ft.)	340 52 00	56 07 09
Reference Mark 2	21.94m. (71.98ft.)	94 01 10	169 16 19

Detailed description:

About 2 miles west of Darien, on the south side of the Chicago, Milwaukee & St. Paul Railway track, 80 yards west of the road leading north from Allen Grove, 125 yards west of the railroad bridge, and 8.74 meters (28.67 feet) south of the south and nearest rail.

The reference marks are near the right of way fence lines, No. 1 is on the same side of the track as the station and No. 2 is on the opposite side of the track.

Described by E.C.S. Marked by J.S.B.

NOTE.—The initial direction must be to a main scheme station. *Refers to pages 48 and 49, Special Publication No. 28. G P O 11—6781

FIG. 36.—Sample description of traverse station

Note 12.—A standard disk reference mark with the arrow pointing toward the station (*a*) wedged in a drill hole in outcropping bedrock, (*b*) set in concrete in a depression in outcropping bedrock, (*c*) wedged in a drill hole in a bowlder, (*d*) set in concrete in a depression in a bowlder.

Note 13.—A standard disk reference mark with the arrow pointing toward the station, set in concrete at the center of the top of a tile (*a*) which is embedded in the ground, (*b*) which is surrounded by a mass of concrete, (*c*) which is fastened by means of concrete to the upper end of a long wooden pile driven into the marsh, (*d*) which is set in a block of concrete and projects from 12 to 20 inches above the block.

WITNESS MARKS

Note 14.—A conical mound of earth surrounded by a circular trench.

Note 15.—A tree marked with (*a*) a triangular blaze with a nail at the center and each apex of the triangle, (*b*) a square blaze with a nail at the

center and each corner of the square, (*c*) a blaze with a standard disk reference mark set at its center into the tree.

Recovery descriptions

Whenever a traverse or triangulation station established during some previous season is recovered or searched for, Form 526, "Recovery note," must be made out and transmitted to the office. Any deficiency in accuracy in the original description, any change in the marking of the station or in the surroundings, and any additional information which will make the station more readily recovered in the future should be recorded on the recovery note. If the station is looked for but not found, the recovery note should describe in some detail the completeness of the search in order that the office may know whether or not to mark the station as "lost" in the records. If the evidence seems conclusive that the station is lost, a definite recommendation should be made by the field officer on the recovery form that the station be listed as lost in the office records.

ADDITIONAL COMPUTATIONS

If a complete computation is made in the field, the same methods should be used as described under "Office computations" on pages 69 to 87. All record books should be checked by the officers making the observations. All abstracts should be made out by the extra officer or mathematician detailed to the computations and checked by the officers who made the observations, or vice versa. The remaining computations should be checked by the officers doing the field work.

If it is not possible to make a complete computation in the field, but it is desired to ascertain whether the geodetic and astronomic azimuths are in agreement, the following method will give an approximate check: The distances may be computed to the nearest tenth of a meter using the number of tape lengths and the summation of set-ups without any corrections for temperature, standardized length, inclination or elevation above sea level. Offset projections need be made only where the offset distance is large and the angle at the offset station differs considerably from 90°. Loop projections should be computed using five place logarithms and angles to the nearest second.

Geographic positions should be computed with these distances, using five place logarithms and angles to the nearest second. These computations can be made very rapidly and will permit a comparison of the geodetic with the astronomic azimuths, thus giving a good check on the accuracy of the measurement of the horizontal directions.

SEASON'S REPORT

When the field work is completed on a line of traverse, the chief of party should forward to the office a season's report similar to that described on pages 109 to 111, Special Publication No. 120. This report must be accompanied by statistics of field work on the form provided and also by a progress sketch on which is shown each new station established and also each old station recovered. The progress sketch should be on tracing vellum and should have a projection and a title.

TRAVERSE ALONG BEACH OR HIGHWAY

This publication is devoted primarily to traverse along railroads, but the same general methods should be used along a beach or highway. The tape should be supported on stakes or on portable tripods. In measuring traverse along a beach it is often necessary to carry the measurements across inlets or streams by means of triangulation. This may be done by using a section of the traverse as a base and carrying the length through one or more quadrilaterals. If a check is obtained by a connection to a line of the traverse on the other side of the inlet, a chain of single triangles will suffice.

TRAVERSE OVER ICE

In special cases, where the cost of first-order triangulation along a lake or river would be very high, it may be possible to substitute a traverse measured over ice. The traverse stations should be permanently marked on small islands or points of land during the preceding summer, and the horizontal directions should also be observed at the same time, leaving only the invar taping, check taping, leveling, and loop angle measurements for winter work. The check-taping and loop-angle measurements should be done as under ordinary conditions. The theodolite, however, should be cleaned to remove nearly all the oil from the bearings to prevent sticking in extreme cold weather. Usually the best time to do the work is early in the winter, as soon as the ice is safe and before the heavy snows.

Portable tripods should be used to support the tape ends in making the measurements with the invar tape. The legs of the tripods should be movable, similar to the legs of a theodolite tripod and 3½ feet or more in length, depending upon the depth of the snow. (See figs. 37 and 38.) The tripod head should have a double ball-and-socket joint surmounted by a marking table with a graduated invar decimeter scale of the same thickness as an invar tape. (See fig. 25, p. 37.) The tripod should be set on line with the feet of the tripod resting on the ice and the zero mark of the scale forward.

The taping is done by the rear contact man holding the rear end of the tape on the zero mark of the scale at his tripod and the front contact man reading the scale on the forward tripod opposite the mark at the forward end of the tape. This reading should be recorded as a set-up in each case.

The staffs of the front and rear tape stretchers should be graduated in meters and feet, respectively. The height of each tripod above the ice can then be measured first in meters and then in feet and the readings recorded to give the inclination corrections, the ice being considered level. Wye levels need be run only when the taping leaves the ice.

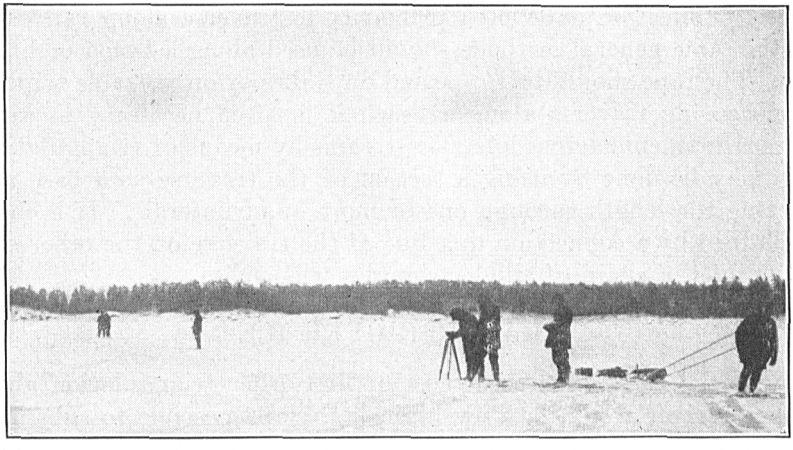


FIG. 37.—Traverse over ice

TRAVERSE IN CITY SURVEYS

The subject of geodetic control for city surveys has been covered in Special Publications Nos. 91 and 120. The main control for a city survey should be first-order triangulation. Traverse is used for the intermediate control and to furnish starting points for the detailed surveys.

The first-order traverse system of a city should be composed of two sets of lines. The first set, which should be included in the first adjustment, should be closely connected with the main-scheme triangulation and should divide the area into blocks 3 or 4 miles across. Each line of this set should be measured twice with two different tapes and the two measurements should agree within 10 mm. $\sqrt{K}$ where K is the distance in kilometers. The second set should divide these blocks into smaller blocks about 1 mile square, and the lines of this second set should be included in a second adjustment in which they are made to fit those of the first set. Traverse within the 1-mile blocks should be of a lower order of accuracy.

Long, narrow loops should be avoided, and when the distance between two traverse lines is less than 15 per cent of the distance around the loop containing those lines a connecting traverse line should be run across the loop.

The chief function of the triangulation is to provide proper control for the first-order traverse, and for that reason the connections between the two systems should be as strong as can be made economically. A traverse line should contain not more than 15 angle stations between connections to first-order triangulation stations, and the connections to the triangulation should be in both position and azimuth. Where it is impossible to make a direct connection, the connection should be made by means of two triangles with a common side. Where two lines of first-order traverse cross, an angle

FIG. 38.—Traverse over ice, making front contact

station should invariably be placed at the intersection to give a connection in azimuth as well as in position.

LOCATION OF STATIONS

The first-order traverse stations should be spaced about 500 yards apart along the traverse lines. Often two first-order traverse stations on the same line, but not adjacent, are intervisible, in which case the azimuth can be carried through the long line, avoiding the shorter lines of sight. This should be done, however, only where the lines are very short because it necessitates extra work in both the field and office and does not materially strengthen the results when all lines are of nearly average length. Care should be taken that no considerable portion of a supplemental loop makes an angle of more than 25° with the line of the main scheme upon which it will be projected.

Before the traverse reconnaissance is started information must be obtained as to where the traverse stations should be located to be of most use for subordinate control lines and detailed surveys. With this exception the reconnaissance will be guided by the topography of the streets. An attempt should be made to locate the traverse stations at street corners wherever practicable, since this makes it easy for the city to tie in its street corner monuments and to turn angles to the direction of any intersecting street.

It has been found best in most cases to have the traverse lines follow along the sidewalk, for then the only interference will be caused by pedestrian traffic and the traffic at occasional street crossings. Moreover, the sidewalk usually forms a very stable and satisfactory support for the taping tripods. (See figs. 39 and 40.)

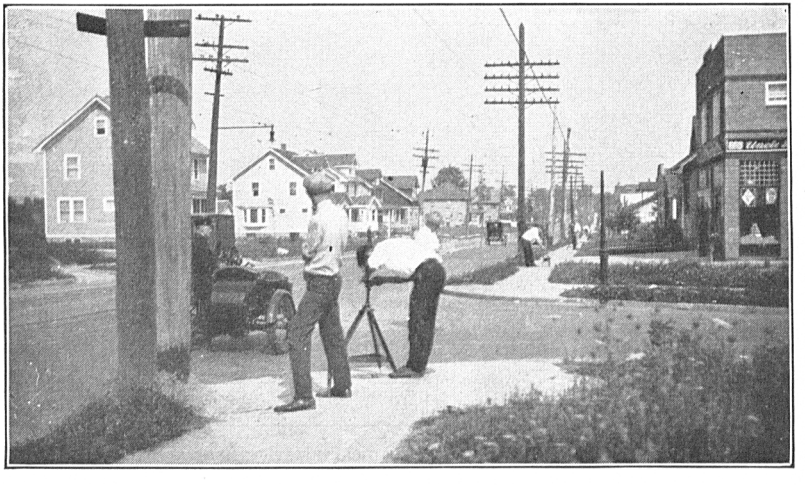


FIG. 39.—Traverse in city surveys, taping along sidewalk

The traverse stations should be located in the sidewalk or between the inside edge of the walk and the property line. These are usually the only locations in a city street where manholes, electric conduits, water and sewer pipes, etc., are not placed to any great extent.

MARKING OF STATIONS

All city traverse stations should be marked in a permanent manner except in special cases. The stations should be marked according to Coast and Geodetic Survey specifications, except that no underground or reference marks are necessary. Where the marks are in sidewalks or pavements they should be set about 8 inches below the surface and a manhole about 16 inches in diameter placed over them. (See fig. 41.)

If extra stations are established in making a connection with triangulation or another traverse line, they should be temporarily marked by a hole in the center of a small copper bolt set in sulphur or lead in a drill hole in the sidewalk or pavement.

TAPE MEASUREMENTS

In city surveys the invar tape measurements are made in the same manner as in first-order traverse with the few exceptions noted below. Before the invar taping is started the approximate location of each tape end should be determined with an old 50-meter invar or steel tape stretched flat on the pavement or sidewalk and the points marked by spikes driven into the pavement or by crosses cut in the concrete sidewalk. These points should also be marked with white

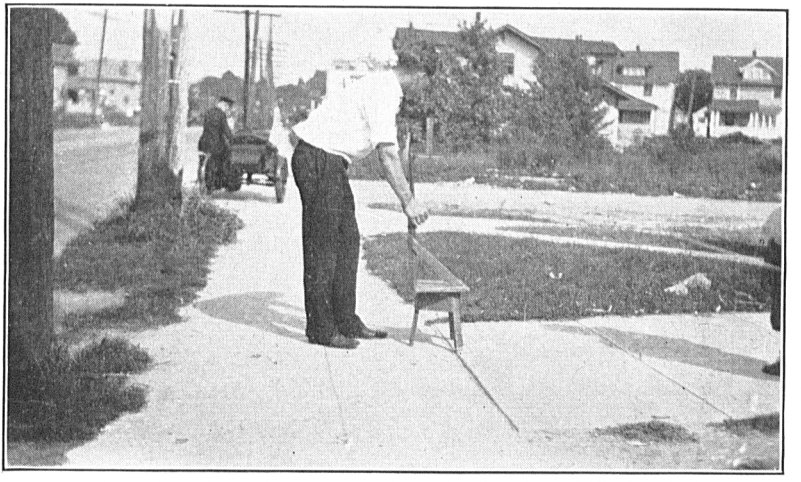


FIG. 40.—Traverse in city surveys, center support for tape

paint, so that they may be easily recovered by the taping and leveling parties.

For the invar tape measurement the tape should be supported on portable iron tripods. (See fig. 41.) These tripods weigh about 30 pounds each. The marking table of each tripod should be faced with wood and have a copper marking strip nailed to it. The tape ends are marked on the strips by means of an awl. The strips may be used over and over if they are dipped in a solution of ammonium sulphide after being used.

The marking table should have a small hole through which the zero mark on the strip may be accurately transferred when necessary to a traverse station set below the street level. (See fig. 41.) This hole is also used in plumbing the tripod over the marked points on the pavement. The invar taping party should measure and record

the heights of the tops of the marking tables above the marked points on the pavement.

LEVELING

Wye or first-order levels should be run over the route of the traverse and touch on all traverse stations and bench marks and on all the marked points indicating the positions occupied by the portable tripods. These levels when used with the heights of tripods determined by the invar taping party give the data required for computing the inclination corrections for the measurements made with the invar tape.

FIG. 41.—Traverse in city surveys, tripod being plumbed over mark

ANGLE MEASUREMENTS

The angle measurements on the first set of traverse lines should be made with such an accuracy that the correction per angle to close a loop will not greatly exceed $2''.5\ \sqrt{a}/a$ where a is the number of main angle stations. This accuracy will usually be obtained by observing the angles with a 6 or 8 inch direction theodolite reading directly to 1 or 2 seconds and using 12 positions of the circle. The theodolite may be supported on its own portable tripod except where a higher support is needed.

The angle measurements on the second set of traverse lines should be made with such an accuracy that the correction per angle to close

a loop will not greatly exceed $3''.5\sqrt{a}/a$ where a is the same as above. With a direction theodolite eight positions of the circle will usually be sufficient to give this accuracy.

All angle observations should be made at night on a special type of signal lamp. (See fig. 42.) This lamp consists of a flashlight in a small box with the center of the reflecter directly over the bolt in the base of the box by which the box is fastened to the tripod, the bolt being placed directly over the traverse station mark. There is an opening about 1 inch in diameter in the end of the box for the light to shine through. A thin sheet of white paper should be placed over the hole in the box to eliminate any eccentric appearance of the reflector, and then the hole should be carefully lined in between the bolt which holds the signal lamp to the light stand and the observer's station to avoid eccentricity. The flashlights should be wired so that 1.5-volt dry cells may be used instead of flashlight batteries.

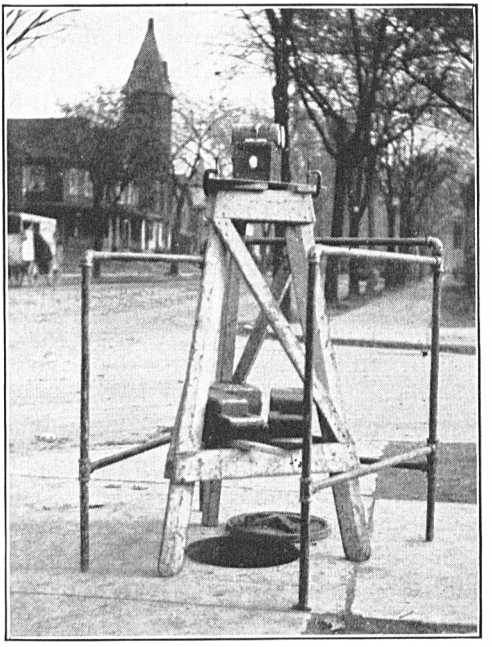


FIG. 42.—Traverse in city surveys, signal lamp and tripod

The signal lamp should be supported on a tripod constructed of 1 by 4 inch and 2 by 4 inch lumber, with a platform near its base on which a weight of about 150 pounds may be placed without interfering with the plumbing of the lamp. (See fig. 42.) For plumbing the lamp a thin brass or iron plate is used which has a hole in the center the exact size of the bolt in the base of the signal lamp. A brass plug which fits exactly is first inserted in this hole, and a plummet line is threaded through a small hole in the center of this plug. The plate is then shifted until the hole is plumbed over the mark. The plate is secured in this position by means of three clamps in the top of the tripod. The plug and plummet line are finally removed and the bolt in the base of the lamp placed in the plumbed hole and fastened by a winged nut beneath the plate. A small level should be used on top of the lamp while it is being centered to make sure that the reflector is not tilted off center. These

or similar precautions are necessary to make certain that there is no eccentricity of the light.

At connections to triangulation stations where two triangles with a common side are used angles should be measured as at regular traverse stations, and stride level readings should be made if there is much difference in elevation between the traverse and triangulation stations, the directions being later corrected for the inclination of the horizontal axis of the telescope.

SECOND-ORDER TRAVERSE

In general, second-order control will be used instead of first-order control for lines or arcs not more than 150 miles long which are joined at both ends to lines or arcs of previously adjusted first-order control. Second-order traverse will be used in place of second-order triangulation in those areas where the configuration of the ground, presence of heavy timber, or extensive swamps would make triangulation excessively expensive. The accuracy to be obtained on second-order traverse has already been given on page 2.

The methods for executing first-order traverse should be used on second-order traverse with the following modifications: The angles should be measured by the same methods, but a direction theodolite which can be used on its own portable tripod is preferable. No first-order azimuths need be observed unless called for by specific instructions. Second-order azimuth stations should be established at intervals of about 20 to 25 traverse stations. The discrepancy between astronomic and geodetic azimuths should not be more than 1.5 seconds times the number of stations through which the geodetic azimuth is carried. Where the tape is supported throughout its length on a rail of a railroad track, differences of elevation between points of decided changes in grade should be determined by wye levels, and the differences for each tape length should be determined by the track level.

Part II.—OFFICE COMPUTATION

GENERAL STATEMENT

In computing traverse it must be remembered that there are practically no automatic mathematical checks on any part of the computations like there are on triangulation. The discovery of errors and inaccuracies in the computations must depend upon a duplicate computation or upon an ordinary check by another man. There is nothing very involved or difficult in traverse computations, but there are many different operations, many corrections to be applied, and many chances for errors and omissions, and therefore very careful inspection and close attention to details are required to make sure that the computations are accurate and complete.

The office computation of the measured lengths should start from the original field records and observations and be entirely new, the field computations being used in the office only as an extra check. All abstracts should either be very carefully checked or else made out new and compared with the field abstracts. The comparison of the office computation with the field computation gives a very valuable check and is the best method available of discovering errors and omissions.

The various operations necessary in making a traverse computation are as follows:

(*a*) Checking the abstracts and lists of directions of the horizontal angles and directions from the original record books.

(*b*) Computation of inclination corrections and mean elevations of sections from the wye-level and track-level observations.

(*c*) Computation of measured lengths, including the corrections for temperature, tape standardization, catenary, set-ups and setbacks, inclination and reduction to sea level.

(*d*) Projection computation at rail and offset stations.

(*e*) Closure of loops and projection on line joining ends.

(*f*) Computation of preliminary geographic positions.

(*g*) Computation of astronomic azimuths.

(*h*) Least-squares adjustment of the latitude, longitude, and azimuth discrepancies.

(*i*) Computation of final geographic positions.

HORIZONTAL ANGLES AND DIRECTIONS

In the record books containing the observations of horizontal directions all computed values and means should be carefully checked

and, if the field abstracts of directions are used, they should be carefully compared with the record books, the degrees and minutes of each direction being checked from the observations of several different positions of the circle. In the field the degrees and minutes are often taken out from the first position only, and an error made in reading or recording the observations on the first position is thus carried into the abstract.

By making use of the tables published on pages 115 and 116 a check may be obtained on the observed seconds of direction-theodolite observations by such a different method of computation as practically to eliminate the possibility of blunders remaining undetected. First, add on an adding machine all the micrometer readings on the initial station as negative quantities (strike a subtotal if there are more than two stations in the set), then add all the micrometer readings on the second station as positive quantities. If the total now in the machine is negative, add 480 or 720, depending on whether the instrument has two or three micrometers, and strike a total. The addition of 480 or 720 is not necessary if the total is positive. With the total as argument, enter the proper table, depending on the number of micrometers on the instrument and the corresponding tabular value will be the observed seconds of the second direction, referred to a zero direction for the initial.

This method gives the result without dropping extra decimal places for six intermediate results as is done when the values are computed by the usual method in the record books. For this reason the result computed by this method will not always exactly check the value computed by the ordinary method. However, it will seldom vary more than one or two tenths of a second from the value computed in the record book unless there is a blunder in one computation or the other. If the discrepancy is more than, say, two-tenths of a second both computations should be checked to eliminate any blunder. The object of this method of computation is not so much to secure great accuracy in the last decimal place as to arrive at the result by such a different routine that blunders will be detected. Mistakes of 1 second, 5 seconds, or even 10 seconds have frequently been caught by this method. If there are no blunders, the mean of the various observations will be little affected by slight variations of one or two in the last decimal place of individual observations.

Where there are more than two stations in a set the subtotal mentioned above can be used instead of adding again all the micrometer readings on the initial when computing the seconds of the extra directions.

If the mean value of the seconds for any one position of the circle differs by five seconds or more from the mean of all the positions, it should be rejected. If there is more than one value for any one

position and none of them differ by five seconds or more from the mean of all the positions, then the mean should be used as the value for that position in computing the mean of all the positions.

All eccentric reductions should be carefully checked, especial care being taken to make sure that the corrections to reduce to center have been applied to the directions with the proper signs. (See pp. 96 and 97 of Special Publication No. 120 for methods of making eccentric reductions.)

The lists of directions should be checked from the abstracts and record books and should give all directions at the station, including those to intersection stations and reference marks. All directions should be given to tenths of seconds except those to indefinite objects such as mountain peaks, which should be given to seconds only, and those to near-by objects such as witness and reference marks, which should be given to the nearest 10 seconds only.

In the record books containing the observations of angles measured with a repeating instrument all computed values and means including the corrections to close the horizon, the means of the different sets, and the eccentric reductions, should be checked and the lists of directions should then be checked from the books. Any set having a horizon closure of more than three seconds per angle or any measure of an angle which differs by three seconds or more from the mean should be rejected.

INCLINATION CORRECTIONS AND MEAN ELEVATIONS

Usually a new abstract of the wye-level and track-level observations should be made out in the office and the field abstract used only as a check on the office abstract. The abstract should be prepared directly from the wye-level, track-level, and invar-taping record books on Form 635. (See fig. 43.) The designation of the points which are placed in the first column of this form should be the same in both the leveling and taping records. The distances in the second column are obtained from the invar-taping record, great care being taken to make sure that all partial tape lengths and broken grades are noted. The differences of elevation in the third column are taken from the wye-level and track-level record books. Before these differences are entered on the form they should be checked in the wye-level records, the differences in feet being reduced to meters if a rod graduated in both meters and feet was used. Great care should be taken to enter the correct sign of the differences on the form. If a track level is used, the differences of elevation corresponding to the angles of inclination are obtained from the table on page 102.

The inclination corrections in millimeters should then be computed for each tape length and entered in the fourth column of the form.

For 50-meter tape lengths and for parts of a tape length 5, 10, 15, 20, 25, 30, 35, 40, and 45 meters in length these corrections can be obtained directly from the tables on pages 103 to 111. The corrections for other lengths and also for differences of elevation outside the limits of the tables must be computed. This can be done by the use of the formula

$$C = -\frac{h^2}{2l} - \frac{h^4}{8l^3} - \frac{h^6}{16l^5} - \cdots\cdots$$

where l is the inclined length and h the difference of elevation of the two ends. The correction may also be obtained, of course, by solving

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
Form 035

ABSTRACT OF WYE LEVELS
AND
COMPUTATION OF INCLINATION CORRECTIONS

POINT	DISTANCE	MEAN DIFFERENCE OF ELEVATION	INCLINATION CORRECTION	ELEVATION	MEAN ELEVATION	REMARKS
	Meters	Meters	mm.	Meters	Meters	
Bench Caboose				319.90		
Caboose Set up	40	+0.70	6.1			
B.G.	25	−0.14	0.4			
1	25	−0.63	8.0			
2	50	+0.20	0.4			
3	50	−0.76	5.8			
4	50	+1.52	23.1		321	
5	50	+0.91	8.3	321.70		
6	50	−0.46	2.1			
7	50	−0.77	5.9			
B.G.	25	+1.15	26.5			
8	25	−0.01	0.0			
9	50	−1.62	26.2			
10	50	+1.75	30.6			
Bench Cable	1.304	+0.03	0.3	321.77		
Mark Cable	0	−1.03	0.0			
			143.7			

FIG. 43.—Sample abstract of wye levels

the right triangle, of which the inclined length is the hypotenuse and the difference of elevation is one of the legs. Only the first term of the above formula need be considered for slopes less than 5 per cent. For steep slopes and short lengths it is well to obtain the correction by computing the right triangle. Barlow's tables of squares will be found useful in this connection.

If tables of natural functions and multiplying machines are available, the inclination correction may be easily computed by the formula

$$C = l\ (1 - \cos A) = l \text{ vers } A$$

where l is the inclined length and A is the angle of inclination. The value of sin A is obtained by dividing the difference of elevation by the inclined length. Then, in the table of natural functions this value of sin A can be found and on the same page will be found the corresponding value of cos A. Subtract this from 1 and multiply by l to obtain the inclination correction.

It is very important that the correct length be used in computing the inclination corrections for the partial tape lengths and broken grades. The most frequent mistake in computing inclination corrections is due to using 50-meters as the length for these parts of tape lengths. The sum of the inclination corrections for each section of the traverse is entered on Form 589, in the column headed "Inclination."

The mean elevation of each section of the traverse is also computed on Form 635. This is done by starting with the elevations of one end of the section and adding (algebraically) on the adding machine the differences of elevation of the tape ends. A sufficient number of subtotals are obtained so that the mean of them will give the approximate mean elevation of the section. For fairly uniform slopes the mean of the elevations at each end of the section and at each kilometer mark will give the mean elevation of the section accurately enough. If a section is only a kilometer or less in length, the mean of the elevations of the two ends of the section will be sufficient. If the profile of the traverse is broken, additional elevations should be computed. The elevations carried ahead by adding the differences obtained from the wye-level and track-level observations should be checked with the elevations determined by the first-order leveling as often as possible. If a large discrepancy in elevation is thus found, it may be necessary to correct the differences of elevation of the tape ends before computing the inclination corrections. This is often necessary when the track level is used. If first-order levels are not available, a comparison of elevations should be made at all bench marks to which ties were obtained. A profile of the railroad can often be secured and used to advantage in checking the elevations.

COMPUTATION OF MEASURED LENGTHS

Form 589 (see fig. 44) should be used for the computation of the measured lengths. Here, again, it is well to make an entirely new office computation and to use the field computation only as a check. The first seven columns on this form should be filled out directly from the invar-taping record, the temperature in the seventh column being the mean of the thermometer readings for all the tape lengths in the section. The column headed "Set-up, setback" is also filled out from the record book. Each value in this column is the algebraic

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
FORM 252

COMPUTATION OF Green Bay to La Cresse ~~BASE~~ Traverse LINE

SECTION	DATE 1926	DIR. OF MEAS.	TAPE NO.	UNCORRECTED LENGTH: Tape lengths	UNCORRECTED LENGTH: Meters	TEMP. °C	CORRECTIONS: Temp. Meters	CORRECTIONS: Tape and Catenary Meters	CORRECTIONS: Set-up Set-back Meters	CORRECTIONS: Inclination Meters	CORRECTIONS: Sea level Meters	REDUCED LENGTH Meters	ADOPTED LENGTH Meters	(v) mm.	(vv) mm.
Rail Cacao to	Aug. 25	F	932	13	650	25.5	+0.0007	+0.0039	+0.0233	-0.0259	-0.0334	666.6667	666.667		
Bench Caboose	" "		1131			27.0	+0.0014	-0.0003	+16.6970						
Bench Caboose to	" "	F	932	10	500	27.9	+0.0018	-0.0238	———	-0.1437	-0.0272	541.1100	541.110		
Bench Cable	" "		"		40	27.0	+0.0001	-0.0009	———						
			1131			30.0	+0.0002	0.0000	+1.3035						

FIG. 44.—Sample computation of traverse line

sum of all the set-ups and setbacks on the section, the set-ups being plus and the setbacks minus.

The first correction to be computed, the temperature correction, C_T, is obtained as follows:

$$C_T = k\ (T_o - T_s)\ 50\ n,$$

in which k is the expansion coefficient, T_o is the mean of the observed temperatures for the section, T_s is the temperature at which the tape was standardized, and n is the number of tape lengths in the section. The value of T_o is given in the column headed "Temperature" and the value of T_s is given in the standardization data for the tape. (See fig. 45.) The expansion coefficient is the change in length per meter for each degree centigrade change in temperature and is also given with the standardization data. Sometimes the expansion of the 50-meter tape for each degree centigrade change in temperature is given instead of the coefficient with the standardization data, and the factor 50 must then be omitted from the formula above. The number of tape lengths is given on Form 589 in the column headed "Tape lengths." For tapes with a positive coefficient of expansion the temperature correction is plus or minus, according to whether the mean observed temperature is greater or less than the standard temperature. There are a few tapes which have negative coefficients of expansion and for these the corrections have the opposite sign.

The correction in the column headed "Tape and catenary" is obtained from the standardization data for the tape or by computing the catenary correction and combining it with the tape correction when the tape is supported in an unusual manner. The tape correction is the difference between 50 meters and the length of the tape as given in the standardization data for the corresponding method of support. The correction for a tape supported at three points, at five points, and throughout can be obtained directly from the standardization values. (See fig. 45.) For a tape supported with any combination of these the correction is obtained by combining the proper fractional parts of these corrections. Where the tape is supported in an unusual manner—as, for instance, in the crossing of a stream or gully where it is impossible to have a support at the middle of the tape—the correction must be computed by the following catenary formula:

$$C_c = -\frac{n}{24}\left(\frac{w}{t}\right)^2 l^3$$

where n is the number of sections into which the tape is divided by the equidistant supports, l the length of the section in meters, w the weight of the tape in grams per meter, and t the tension in grams.[1]

[1] For numerical example, see Spec. Pub. No. 120, p. 127.

This correction is the amount the tape is shortened due to the sag of the tape between supports and must be combined with the standardization correction of the tape when supported throughout to obtain the correction of the tape for that particular method of sup-

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DEPARTMENT OF COMMERCE

Bureau of Standards

Certificate

FOR

50-METER INVAR TAPE

Maker:

B. S. No. 3229
U.S.C. & G. S.No.926

SUBMITTED BY

United States Coast and Geodetic Survey,
Washington, D. C.

THIS CERTIFIES that the above-described tape has been compared with the standards of the United States and found to have the length given below when under a horizontal tension of 15 kilograms and when supported at the 0, 25, and 50 meter points:

(0 to 50 meters) = 49.99595 meters, at 26.4 °C.

When supported at the 0, 12.5, 25.0, 37.5, and 50 meter points:

(0 to 50 meters) = 49.99887 meters, at 26.4 °C.

When supported on a horizontal surface, throughout its entire length (value computed from observations taken on the tape when supported at 3 and at 5 points)
(0 to 50 meters) = 49.99989 meters, at 26.4 °C.

For the first and second of the above conditions thermometers weighing 45 grams each were attached at the points 1 meter inside the terminal marks during the test.

The above comparisons were made on the section of the lines near the end on the edge of the tape marked with a small "x" or "v" near the graduation.

The above values are correct within 1 part in 300,000 ; the probable error does not exceed 1 part in 1,000,000.

Coefficient of Expansion = 0.00000104 per degree Centigrade.
Weight per meter = 25.7 grams.

Test completed. December 18, 1926

Test No. Twl 48928

George K. Burgess, Director.

Washington, D. C. Dec. 22, 1926

FIG. 45.—Sample certificate of standardization

port. A frequent mistake is to use the catenary correction without regard to the standardization correction of the tape when supported throughout. The algebraic sum of the corrections for all the tape lengths in the section is entered in the column headed "Tape and

catenary," the sign depending on whether the length of the tape is greater or less than 50 meters.

To assist in computing the catenary correction, the value of $\frac{1}{24}\left(\frac{w}{t}\right)^2$ in the above formula has been computed and tabulated for tapes of different weights. (See p. 112.) The catenary corrections for sections of the tape 5 meters or a multiple of 5 meters in length for tapes of different weights have also been computed and tabulated. (See p. 112.) It is necessary to apply the catenary correction for partial tape lengths measured over stakes for which the 5-meter marks on the invar tapes were used because the corrections for the 5-meter intervals are not given in the standardization data except for the tape supported throughout.

If the same tapes are used to measure a large amount of traverse, it will usually save time to make up tables for the temperature and tape corrections. For the temperature correction table compute the change in length per tape length per tenth of a degree change in temperature. Then lay out a table having 10 columns, the top argument being in tenths of degrees and the side argument in degrees. The side argument should cover the range over which the observed temperatures may extend. A zero is first placed in the table for the temperature at which the tape was standardized, and then the rest of the table is filled out by simply adding for each tenth of a degree change in temperature, both backward and forward from the zero point, the corresponding correction per tape length as already computed, the correction having a minus sign ahead of the zero point and a plus sign beyond it. In using the table the temperature correction is obtained by entering the table with the mean observed temperature for the section as an argument and multiplying the corresponding tabular value by the number of tape lengths in the section.

For the tape correction table referred to above the corrections for the various methods of support can be computed for the usual number of tape lengths in a section. For traverse along a railroad the table of corrections for the throughout support should be made to cover about 100 tape lengths, for the three-point support 20 tape lengths, and for the five-point and combination supports five tape lengths. These tables can be made quickly by two men, one to operate an adding machine and the other to operate a typewriter, the results being transferred directly from the adding machine to the typewriter. In this way several carbon copies can be made, and each man engaged in the computation of the traverse can be furnished with a copy of the tables.

In the column headed "Set-up, setback," the algebraic sum of all the set-ups and setbacks in the section may be entered, but if this is

done the temperature and the tape and catenary corrections must include the corrections for all partial tape lengths, the computation of the entire section being made on the one line. It is better, however, to enter the corrections for the full tape lengths and the summation of the small set-ups and setbacks on one line and to enter on a separate line each large set-up and the temperature and the tape and catenary corrections for it. This simplifies the checking of the computation.

The correction entered in the column headed "Inclination" is the sum of the inclination corrections for the section as computed on Form 635. This correction is always minus.

The correction in the column headed "Sea level" is computed by the formula

$$C = -S\frac{h}{r} + S\frac{h^2}{r^2} - S\frac{h^3}{r^3} + \cdots\cdots$$

in which S is the length of the section, h is the mean elevation of the section, and r is the radius of curvature of the earth's surface for that section. The first term of the formula is all that need be used to give sufficient accuracy. S is obtained from the columns headed "Meters" and "Set-up, setback," and h is obtained from Form 635, it being necessary to know these values only to the nearest meter. The value of r varies with the latitude and azimuth and is obtained from the table on page 117. It is not necessary to use a new value for r for each section of the traverse, but for each portion of the traverse having the same general direction a mean latitude and azimuth can be estimated and the corresponding mean r used. The computation should be made with five-place logarithms. (See p. 147, Special Publication No. 120.) The sign of the sea-level correction is always minus, provided the measured lengths are above sea level.

The algebraic sum of the uncorrected lengths and all the different corrections explained above gives the length of the section to be entered in the column headed "Reduced length." If the section was measured more than once, the mean of the different measures is entered in the column headed "Adopted length." The discrepancy between two measurements of a section should not exceed 10 mm. $\sqrt{K}$, where K is the length of the section in kilometers. All the corrections on Form 589 should be computed to four decimal places, but the adopted length is rounded off to three decimal places and only three places are used in the remaining computations. The columns headed "(v)" and "(vv)" are for use in computing the probable error of the measurement of a base line and are left blank in a traverse computation.

CORRECTION FOR CHANGE IN TENSION

If the tension applied to the tape during the measurements is not exactly 15 kilograms, it is necessary to correct for the variation in tension. This correction can be computed by the following formula:

$$\text{Change in length} = \Delta L = +\frac{1}{12} n w^2 l^3 \frac{\Delta t}{t^3}.$$

This formula is obtained from the catenary formula (see p. 75) by differentiating with respect to t and the various terms have the same meaning as in the catenary formula.[2]

For a tape not supported throughout, a variation in tension changes the effective length of the tape in two different ways. It changes the sag of the tape, and it changes the amount the tape is stretched. The sag part of the length change is computed by the formula above, but the stretching part can best be determined by experiment, because the modulus of elasticity of invar varies greatly with the percentage of nickel in its composition and also with the temperature. Five 50-meter invar tapes tested at the Bureau of Standards showed a mean change in length due to stretching of 0.43 millimeter for a 500-gram change from a tension of 15 kilograms.

COMPUTATION OF SAG OF TAPE

The sag of the tape or the vertical distance from the lowest point of the catenary to the line joining the adjacent points of support can be computed accurately enough for all practical purposes by the formula

$$\text{Amount of sag} = y = \frac{wl^2}{8t}$$

where w, l, and t represent the same quantities as in the catenary formula.[3] (See p. 75.)

CORRECTION FOR CHANGE OF WEIGHT OR POSITION OF THERMOMETERS

The invar tapes are standardized at the Bureau of Standards with a thermometer weighing 45 grams fastened to each end of the tape 1 meter inside the terminal marks. The thermometers used in the field should have the same weight and should be fastened in the same position on the tape as in the standardization. A formula to be used in computing a correction where these conditions have been inadvertently varied in the field has been developed by Walter D. Lambert, mathematician, division of geodesy, which gives the change

[2] For numerical example, see Spec. Pub. No. 120, p. 128.
[3] For numerical example, see Spec. Pub. No. 120, p. 129.

in length caused by a change in the weight of the thermometers or a change in their position on the tape. This formula is

$$S-S_0=\left(\frac{a^2-h^2}{2c^2}\right)\left(l+\frac{l^2}{2a}\right),$$

where S is the length of the catenary with the thermometer attached, S_0 is the length without the thermometer, a is one-half the distance between supports, h is the distance from the center of the catenary to the point at which the thermometer is attached, $c=\frac{T}{m}$, in which T is the tension and m is the weight per linear unit of the catenary and $l=\frac{p}{m}$, in which p is the weight of the thermometer and m is the same as above.[4] This formula has been confirmed by experiments conducted at the Bureau of Standards. (See Scientific Papers of the Bureau of Standards, No. 534.)

PROJECTION OF RAIL AND OFFSET STATIONS

The computations on Form 589 give the actual measured lengths, but these are seldom between the traverse stations themselves. It is necessary, therefore, to make additional computations to obtain the distances between the traverse stations. The connection to the traverse station at the end of a measured length is made by observing the angle at the rail or offset station between the measured line and the traverse station and by measuring the offset distance. The offset distance, if measured as an inclined distance, must be reduced to the horizontal before being used in the computation.

A number of different cases occur in making projection computations, and each projection is a separate problem. It is therefore very essential that a diagram, similar to those shown in Figures 46 to 48, be made for each projection computation, as much confusion will thus be avoided and gross errors eliminated. As the offset distance is always small compared with the distance between stations, no attempt is made to draw these diagrams to scale, but the offset distances are very much exaggerated and the angles distorted. The essential point is to show clearly whether the angle used in the computation is greater or less than 90°.

It will be noticed that these diagrams are very similar to the sketches made by the field party. (See figs. 32 to 34, pp. 56 and 57.) It is sometimes possible to use the field sketch and make the projection computation on the same page. If this is done, the data should be carefully checked from the record books and the corrected lengths, as computed on Form 589, should be substituted for the uncorrected

[4] For numerical example, see Spec. Pub. No. 120, p. 132.

lengths. It is usually better, however, to make new diagrams directly from the data in the record books and check them by comparison with the field sketches. Blunders are often discovered in this way.

The projection computation is made by multiplying the offset distance by the sine and cosine of the angle at the rail or offset station to obtain the two sides of the right triangle, the hypotenuse of which is the offset distance. The shorter side is then added to or substracted from the measured length, depending on whether the angle at the offset station between the measured line involved and the traverse station is greater or less than 90°. This corrected length then forms the long side of another right triangle, the short side of which is the longer leg of the small right triangle already computed and the hypotenuse of which is the desired distance between the traverse stations. If there is an offset station at each end of the measured line, the small offset triangles must first be computed at both ends of the line. There are then two small corrections to be applied to the measured length, and the other side of the long right triangle is either the difference or the sum of the longer legs of the two small right triangles, depending on whether the traverse stations are on the same or opposite sides of the measured line. This long right triangle is solved by dividing the short leg by the long leg to obtain the tangent of the angle designated c and then dividing the long leg by the cosine of angle c to obtain the hypotenuse, which is the distance between the traverse stations. Angle c is always very small, and it is not necessary to take out the value of the angle. Find in the logarithm tables the log tan c and then on the same page in the corresponding column and line under the heading of cosine will be found log cos c. The logarithm of the cosine changes very slowly for such small angles and can be obtained readily with little interpolation. It is well to take the cologarithm of the cosine and add it to the logarithm of the distance instead of substracting the logarithm of the cosine.

The sample computations on the diagrams (figs. 46 to 48) show the various steps and the arrangement of the work. The construction lines and the names of the various quantities are not necessary after one becomes familiar with the computation. The most frequent mistakes in projection computations are misplaced decimal points or wrong signs for the small corrections to the measured lengths. The importance of the diagrams in preventing these mistakes is easily seen, since a glance at a diagram will show whether the corrections are to be added or subtracted and also whether the short leg of the long right triangle is the sum or the difference of the long legs of the small right triangles. If tables of natural functions and multiplying machines are available, the best way of insuring against

errors in the projection computations is to have two computations made, one with logarithms and the other with natural functions.

CLOSURE AND PROJECTION OF LOOPS

As explained on pages 6 and 7, it is often desirable to carry the azimuth through long lines extending past several intermediate sta-

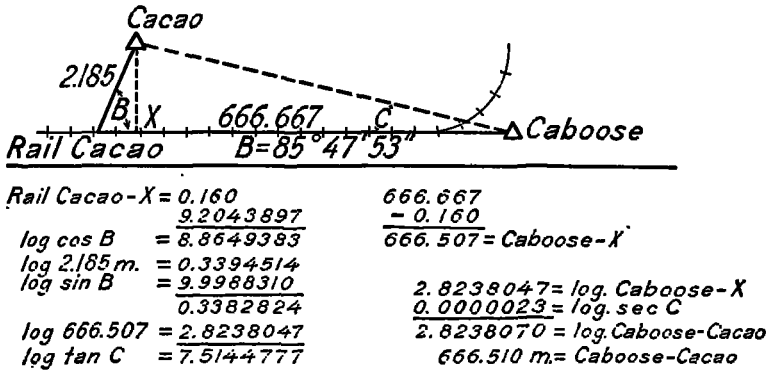


FIG. 46.—Sample projection computation, one offset station

tions and forming loops with the intermediate stations. The lengths of these long lines must be determined by projecting the measured lengths onto them.

The first step in the computation is to make a diagram of the loop. (See fig. 49.) The error of closure of the angles in the loop should

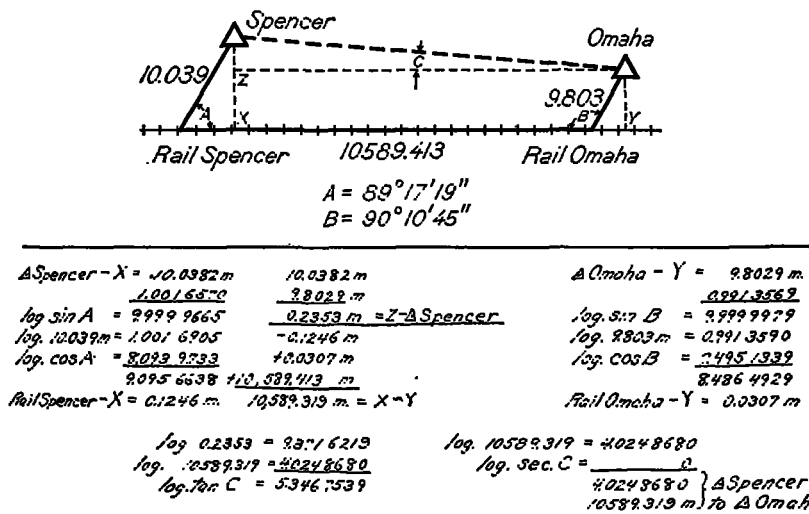
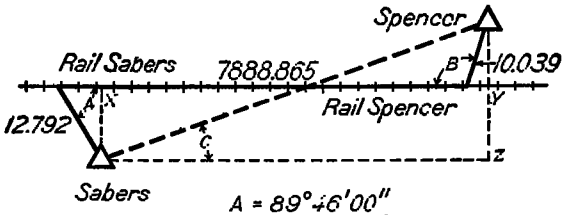


FIG. 47.—Sample projection computation, stations on same side of track

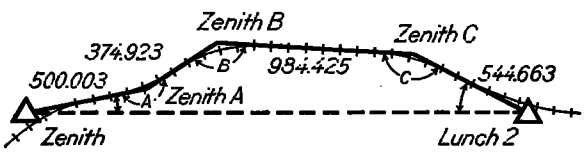
be determined and distributed among the angles before making the projection. The error of closure is the difference between the sum of the angles in the loop and the proper number of right angles (number of sides minus two multiplied by two). This error is dis-



A = 89°46′00″
B = 90°42′11″

ΔSabers − X = 12.7919 m.	12.7919 m	log.22.8301 = 1.3585078	ΔSpencer − Y = 10.0382 m.
1.1069349	10.0382 m	log.7888.936 = 3.8970185	1.0016578
log. sin A = 9.9999964	22.8301 m	log. tan C = 2.4614893	log. sin B = 9.9999673
log. 12.792 m = 1.1069385	+0.1232 m		log. 10.039 m = 1.0016905
log. cos A = 7.6098530	−0.0521 m		log. cos B = 8.0888561
8.7167915	+0.0711 m	log.7888.936 = 3.8970185	9.0905466
Rail Sabers − X = 0.0521 m	7888.865 m	log. sec C = 18	Rail Spencer − Y = 0.1232 m.
	7888.936 m	3.8970203	
		7888.969 m.	ΔSabers. to ΔSpencer

FIG. 48.—Sample projection computation, stations on opposite sides of track



Zenith = 1°16′32.8″
Zenith A = 187°57′58.4″
Zenith B = 173°43′55.2″
Zenith C = 164°01′21.2″
Lunch 2 = 13°00′18.7″

Zenith − Lunch 2	0°00′00.0″		00.0″		1.046 9662	−11.129	
(1)	358 43 27.2	+1.3	28.5		8.347 4936		
Zenith − A	358 43 27.2		28.5	Zenith − A	2.698 9726		
(2)	172 02 01.6	+1.2	02.8		9.999 8924		
	180				2.698 8650		499.879
A − B	350 45 28.8		31.3		1.779 6680	−60.210	
(3)	186 16 04.8	+1.3	06.1		9.205 7260		
	180			A − B	2.5739420		
B − C	357 01 33.6		37.4		9.994 3263		
(4)	195 58 38.8	+1.2	40.0		2.568 2683		370.057
	180				1.709 8132	−51.264	
C − Lunch 2	13 00 12.4		17.4		8.714 8693		
(5)	346 59 41.3	+1.3	42.6	B − C	2.994 9439		
	180				9.999 4151		
	179 59 53.7		60.0		2.994 3590		987.095
					2.088 3745	+122.567	
					9.352 2467		
				C − Lunch 2	2.736 1278		
					9.988 7155		
					2.724 8433		530.673
						−0.036 m	2387.724 m
							3.377 9841

FIG. 49.—Sample loop closure and projection

tributed equally among the angles, and then the azimuth of each line with respect to the line on which it will be projected is computed by using these corrected angles. A better method is to determine the azimuth of each line to start with and determine the closing error of the angles in this way and then apply a correction to each angle to obtain the corrected azimuths. To do this, start at one end of the loop, assume the azimuth of the long line to be 0° 00′ 00″.0, and then compute the corresponding azimuth of each of the other lines with respect to the long line. The azimuth of each line is obtained by adding to the azimuth of the preceding line 180° plus the angle between the two lines measured in a clockwise direction. The amount that the back azimuth of the long line as thus computed through the angles differs from 180° 00′ 00″.0 will be the closing error of the angles of the loop. When this error is distributed among the angles, the corrected azimuths can be obtained by merely correcting the seconds of the preliminary azimuths, the degrees and usually the minutes remaining unchanged. (See fig. 49.)

The length of each measured line in the loop is next multiplied by the sine and cosine of the azimuth of that line as determined in the previous computation. The product of the length and the cosine gives the projected length of the line on the long line, and the sum of these projected lengths for all the measured lines gives the length of the long line. The product of the length and the sine gives the departure of the line or the difference between the perpendicular distances from the long line of the two ends of the measured line, the sign depending upon the azimuth. The sum of the plus perpendiculars for all the measured lines should equal the sum of the minus perpendiculars, and this gives a valuable check on the accuracy of the field measurements and the office computations. (See fig. 49.) A discrepancy of some size between the sums of the plus and minus perpendiculars indicates that a mistake has been made either in the computations or in the measurement of the angles or distances. Another valuable check on the loop can be obtained by starting at one end of the long line and computing the geographic position of the other end through both the long line and the short lines. The discrepancy between the two positions should be approximately equal to the discrepancy in the sums of the perpendiculars.

It is possible, of course, to make a least-squares adjustment of each loop, and thus make the sums of the perpendiculars exactly equal as well as eliminate the closing error of the angles. This has been tried on a number of different loops and has been found to give a length for the long line which differs so slightly from the length determined as described above as not to justify the additional work, except where one of the lines is used to make a connection with triangulation. An adjustment of a loop is given on pages 97 to 101.

Sometimes in triangulation it is necessary to measure a broken base. Such a base must be computed very much like a traverse loop, and as great accuracy is desired the adjustment should be made by least squares.

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
FORM 596.

POSITION COMPUTATION, TRAVERSE.

				°	′	″
α	Black	to	Babe	247	42	42.7
∠		&		+179	40	32.3
α	2 Black	to 1	Blossom	67	23	15.0
Δα					-04	00.2
				180	00	00.0
α′	1 Blossom	to 2	Black	247	19	14.8

Do not write in this margin.

	°	′	″				°	′	″
φ	44	23	12.308	2	Black	λ	88	28	08.476
Δφ		-01	42.471	s =	8214.717	Δλ		+05	42.912
φ′	44	26	29.837	1	Blossom	λ′	88	33	51.388

½(φ+φ′)	44° 27′ 21.1″	log s	3.914 5926	log s²	7.829 19		
		log cos α	9.584 8926	log sin² α	9.93052	log h²	4.0200
		log B	8.510 5086	log C	1.396 02	log D	1.3925
h	+102.3278″	log h	2.009 9938	log 2d term	9.15573	log 3d term	6.4125
2d and 3d terms	+ 0.1434			2d term	0.14313	3d term	0.00026
−Δφ	+102.4712						

log s	3.914 5926		
log sin α	9.965 2612		
log A′*	3.509 0048	log Δλ	2.535 1821
log sec φ′	0.146 3235	log sin ½(φ+φ′)	9.845 3211
log Δλ	2.535 1821	log (−Δα)	2.380 503
Δλ	+342.″91151	−Δα	+240.″16

*Use φ′ as the argument for taking out A′.

FIG. 50.—Sample computation of traverse position

COMPUTATION OF PRELIMINARY GEOGRAPHIC POSITIONS

After the lengths of the lines connecting the main traverse stations have been determined the geographic positions of the stations and the azimuths of the lines should be computed. This computation is made on Form 596 (see fig. 50), which is simply half of the form used for the computation of geographic positions in triangulation. The computation is described in Special Publication No. 138, and

the explanation will not be repeated here. A traverse position, unlike a triangulation position, has no automatic check, and consequently must be computed in duplicate. It is not safe for one man to check another's computation, and even when the two computations are made entirely independently the same mistake may be made in both. The best method of making certain that there are no errors in the position computations is to have one computation made by logarithms and the other by natural functions.

The geographic positions are computed by starting with the fixed position and azimuth at one end of the traverse and computing the positions and azimuths in order through the traverse until a check is obtained on a fixed position and azimuth at the other end. At each azimuth station the geodetic azimuth should be compared with the astronomic azimuth, and if the discrepancy is too large (see p. 46) the computations should be examined to locate, if possible, the cause of the large discrepancy. If no errors are found in the computations, it is necessary to reobserve the angles until the error is found. The error may all be found at a single station, due usually to the first observations having been made on the wrong object, or it may be found to result from an accumulation of small errors caused by unfavorable observing conditions or by a lack of skill on the part of the observer.

Usually the azimuth discrepancy along a traverse line tends to accumulate in one direction and causes a rather large discrepancy in latitude and longitude at the end. If the discrepancy in position is too large to be eliminated by the latitude and longitude equations without making a preliminary solution, the accumulated azimuth discrepancy between each two azimuth stations should be divided equally among the angles through which the geodetic azimuth was carried between the two stations before the least-squares adjustment is made. The geographic positions must now be recomputed, using the corrected angles. The geodetic and astronomic azimuths should now check, at least within a few tenths of a second, and the discrepancy in position is very likely to be much smaller than before.

COMPUTATION OF ASTRONOMIC AZIMUTHS

The computation of the astronomic azimuths from the observations upon Polaris at any hour angle should be made as described in Special Publication No. 14. On page 55 of that publication is given an example of the computation of the chronometer correction from observations on stars near the prime vertical. These observations are taken in two sets of two stars each, one before and the other after the azimuth observations. In each set the mean chronometer correction is obtained by taking the mean for each star and then the mean of

the two stars. The mean epoch of the set is computed in the same way. The rate of the chronometer is computed by using the mean corrections and the mean epochs of the two sets. With this rate the correction to the chronometer reading for each azimuth observation can be computed.

On pages 148 to 150 of Special Publication No. 14 is given an example of the computation of azimuth and an explanation of the method. The level factor, $\frac{d}{4}\tan h$ is usually computed by using the approximate formula for the altitude of Polaris, $\cos h = \frac{\sin t \cot \delta}{\tan A}$. In a set of 16 observations it is only necessary to compute the values of this factor for 4 or 5 observations, those for the remaining observations being interpolated.

In the azimuth computation the logarithms of sine t and cosine t may be taken from Shortrede's Logarithms of Sines and Tangents without first converting t from time to arc. Although the interpolation in the logarithm tables is slightly more difficult when time is used as the argument than when arc is so used, the elimination of one step in the computation results in a saving of time and decreases the chances for error. It will be noted that each column in Shortrede's tables covers four seconds of time, and that there is a wide space to indicate the end of one second and the beginning of the next. Otherwise the arguments are given at the top and left-hand side of the page for time in much the same manner as for arc.

LAPLACE AZIMUTHS

A Laplace station is a station of triangulation or traverse at which both the astronomic azimuth and the astronomic longitude have been determined. A Laplace or true geodetic azimuth is an observed astronomic azimuth corrected for the prime vertical component of the deflection of the vertical. This deflection is the angle formed at the point of observation by the actual plumb line direction with the normal to the reference spheroid used in computing the triangulation or traverse. The Laplace equation, used for computing the true geodetic azimuth from the astronomic azimuth, is

$$\alpha_G = \alpha_A + (\lambda_A - \lambda_G) \sin \phi_G$$

where α_G is the geodetic azimuth, α_A the astronomic azimuth, λ_A the astronomic longitude, λ_G the geodetic longitude, and ϕ_G the geodetic latitude. All Laplace or true geodetic azimuths are held fixed in the adjustment of triangulation and traverse.

For a traverse line located in a region in which the deflections of the vertical are small and of the same sign it is not necessary to

determine Laplace azimuths. In such a region the observed astronomic azimuths may be held fixed in the adjustment of the traverse. Laplace stations are necessary, however, in regions where the deflections are large or where they vary considerably in size and sign. It is not necessary to make each azimuth station on the traverse a Laplace station, but the observed astronomic azimuths between the Laplace stations should be corrected by interpolated values of the Laplace correction. In planning a traverse line a study should be made of the deflections in the region through which the traverse will pass in order to decide whether or not Laplace stations are required and, if they are, to determine their number and location.

LEAST-SQUARES ADJUSTMENT

The least-squares adjustment of a traverse must ordinarily eliminate both the discrepancies in azimuth (see p. 86), which are due mainly to errors in measuring the angles, and the discrepancy in geographic position, which may be due to errors in either the angles or the measured lengths or a combination of them. It must be remembered that in a traverse, unlike triangulation, there is no mathematical relation between the measured lengths of the sections and the angles between them. The angles and lengths are entirely independent quantities, and there is no way of telling how much of the discrepancy in the closing position is caused by errors in the angles and how much by errors in the measured lengths. It is therefore very difficult to adjust a traverse satisfactorily and to distribute the discrepancies so that the angles and lengths receive their proportionate share of the corrections.

The adjustment of each traverse is a problem which must be studied out by itself. Sometimes the proper method can be determined at once, but in other cases it is necessary to experiment and try different methods in order to find a satisfactory one. The chief factor involved is the direction of the discrepancy in position with relation to the direction of the traverse. If a traverse line has one general direction over its entire length and most of the discrepancy in position is in that same direction, then the major portion of this discrepancy must ordinarily be eliminated by corrections to the measured lengths. If most of the discrepancy, however, is in a direction at right angles to the general direction of the traverse, the larger part of the discrepancy, and in some cases all of it, can be eliminated by corrections to the angles. The problem, however, is not as simple as this in most cases. For example, a traverse adjusted several years ago extends north and south in general direction, and the discrepancy in latitude was very small in comparison to the discrepancy in longitude. It was thought, therefore, that the discrepancy could be easily

eliminated by corrections to the angles. When this was tried the angles received very large corrections. After considerable study it was found that the corrections to the angles to eliminate the azimuth and longitude discrepancies had increased the latitude discrepancy very much. After applying corrections to the lengths to eliminate the latitude discrepancy the azimuth and longitude discrepancies were eliminated by small corrections to the angles.

A method of adjusting a traverse has been devised by the members of the division of geodesy as a practical means for the elimination of the discrepancies without too great an expenditure of time and labor. This method, with modifications to fit different conditions, has been successfully used a number of times. A development of the method is given below.

The corrections to the lengths are expressed in units of the sixth place of decimals of the logarithms, and the corrections to the angles are expressed as usual in seconds of angular measure. In order to have a proper relation between the part of the discrepancy put on the lengths and the part put on the angles, a system of weighting must be determined experimentally.

MATHEMATICAL DEVELOPMENT OF ADJUSTMENT EQUATIONS

In considering the condition equations for the distribution of the latitude and longitude discrepancies, it must be remembered that they are developed from the changes which will occur in the formulas for the computation of geodetic positions due to small changes in length and azimuth. These formulas are given fully in U. S. Coast and Geodetic Survey Special Publication No. 8, entitled "Formulae and tables for the computation of geodetic positions."

The first term, and the only one here considered, of the formula for the difference of latitude is

$$\Delta\phi = -S \cos \alpha \, B, \tag{1}$$

and for the difference of longitude, is

$$\Delta\lambda = S \sin \alpha \, A' \sec \phi', \tag{2}$$

where S is the distance between the points, α is the azimuth from the fixed to the new point, ϕ' is the latitude of the new point, and B and A' are factors depending on the latitude of the stations and the dimensions of the reference spheroid.

In Figure 51 let *1* and *5* be fixed in both latitude and longitude and let the azimuths of the lines *1* to *A* and *5* to *B* be fixed. A traverse is run from *1* to *5*, all distances and angles being measured. From the data thus obtained the preliminary latitude and longitude

of each point is computed and also the preliminary azimuth of each line. There will be, of course, a small discrepancy between the fixed latitude and longitude of *5*, the final point, and the latitude and longitude as derived from the computation.

Now let the computed latitude and longitude be represented by ϕ_1 and λ_1 for the first point, ϕ_2 and λ_2 for the second point, and so on to ϕ_n and λ_n for the final point. Let the length of the first course be represented by S_1, the second by S_2, and so on to S_n for the final course. Let V_{s1} be the change in the logarithm of the distance S_1, V_{s2} the change for S_2, and so on to V_{sn} for S_n.

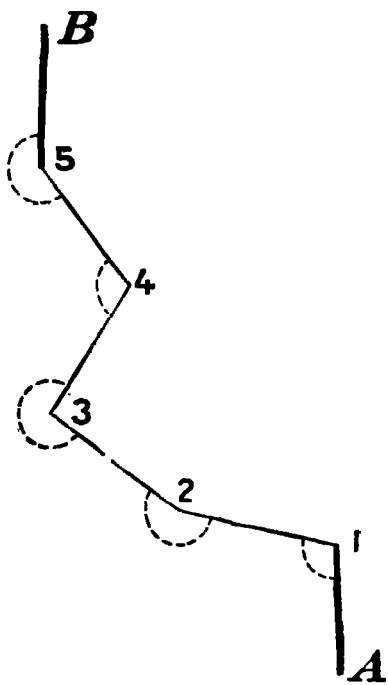


FIG. 51.—Traverse between fixed points 1 and 5

Knowing the number to which a given logarithm corresponds, the change in the number due to a *small* change in the logarithm, can be found by multiplying the number by the change in the logarithm and dividing by M, the modulus of the common system of logarithms.

Let us now consider the change in the first term of the latitude formula, equation (1), which will be brought about by a change in the distance S. If we take the first course of the traverse, that is from *1* to *2*, where the change in the logarithm of the length is V_{s1}, it is evident that the change in the logarithm of the first term will also be V_{s1}. Now, the number corresponding to the first term of the latitude formula may be expressed closely enough for this purpose by $\phi_2-\phi_1$. If this be multiplied by V_{s1} and divided by $10^6\,M$ it will show in seconds of latitude the change caused by V_{s1}. Ten to the sixth power is here introduced, since the sixth place of the logarithm has been arbitrarily taken as the unit.

Then the change in latitude

$$=\frac{\phi_2-\phi_1}{10^6\,M}(V_{s1}). \tag{3}$$

In a similar way the change in longitude due to a change of V_{s1} in the logarithm of the length S_1,

$$=\frac{\lambda_2-\lambda_1}{10^6\,M}(V_{s1}) \tag{4}$$

The change in the length of the line from *1* to *2* will affect the geodetic position of the final point by exactly the same amount as it affects the geodetic position of *2*. Hence, the effect on the geodetic position of the final point, of a change in each length, will be simply the sum of the individual changes of position caused by these length changes.

Next, we must consider the effect on the geodetic position of *2*, of a small change in the observed angle at *1*, and also the effect of this change on the position of the final point.

Let V_{c_1} be the small change in seconds in the observed angle at *1*, V_{c_2} the change in the angle at *2*, etc.

Due to the small change V_{c_1} the point *2* will rotate about *1* to some point *II*, Figure 52. Then introducing arc 1″ to reduce to circular measure, the distance *2* to $II = S_1\ V_{c_1}$ arc 1″.

Now, let α=the azimuth of the line *1* to *2*; then $90° + \alpha$=the azimuth of the line *2* to *II*.

From the first term in the latitude formula, equation (1), the change in latitude due to a change V_{c_1}

$$= -S_1\, V_{c_1} \text{ arc } 1'' \cos (90° + \alpha)\, B_1$$

$$= +V_{c_1} B_1 \text{ arc } 1''\, S_1 \sin \alpha.$$

But from the longitude formula, equation (2),

$$\lambda_2 - \lambda_1 = S_1 \sin \alpha\, A' \sec \phi'$$

or

$$S_1 \sin \alpha = \frac{\lambda_2 - \lambda_1}{A' \sec \phi'}.$$

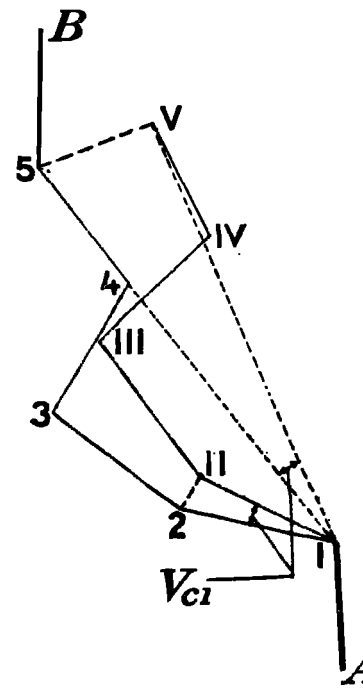


FIG. 52.—A change of the first angle of a traverse as it affects the position of the final point

Or, substituting above, the change in latitude due to V_{c_1} may be expressed as

$$\frac{B_1 \text{ arc } 1''}{A_2 \sec \phi_2} (\lambda_2 - \lambda_1)(V_{c_1}). \tag{5}$$

In equation (5) and thereafter the subscripts after B, A, and $\sec \phi$ refer to the points (see fig. 52) upon the latitude of which these functions depend.

In the same manner a change in longitude due to the small change V_{c_1} in the azimuth

$$= +S_1\, V_{c_1} \text{ arc } 1'' \sin\ (90° + \alpha) A_2 \sec \phi_2,$$

$$= +S_1\, V_{c_1} \text{ arc } 1'' \cos \alpha\, A_2 \sec \phi_2.$$

But from the latitude formula, equation (1), neglecting the small terms as before,

$$\phi_2-\phi_1=-S_1 \cos \alpha\ B_1,$$

or

$$S_1 \cos \alpha=-\frac{\phi_2-\phi_1}{B_1}.$$

Or, substituting this expression in the above equation, the change in longitude may be expressed as

$$=-\frac{A_2 \sec \phi_2 \text{ arc } 1''}{B_1}(\phi_2-\phi_1)\ (V_{c_1}). \tag{6}$$

Now equations (5) and (6) represent the changes in latitude and longitude which take place in point 2 due to a small change in the azimuth, but a change in the azimuth of the first course affects the azimuth of each succeeding course, and consequently changes the geodetic position of each point on the traverse. The effect on the final point will be expressed by substituting $(\phi_n-\phi_1)$ for $(\phi_2-\phi_1)$ and $(\lambda_n-\lambda_1)$ for $(\lambda_2-\lambda_1)$.

Then the change in position of the final point due to the change in length and azimuth of the first course will be, for the latitude, the sum of equations (3) and (5) or

$$\frac{\phi_2-\phi_1}{10^6\ M}(V_{s_1})+\frac{B_1 \text{ arc } 1''}{A_n \sec \phi_n}(\lambda_n-\lambda_1)\ (V_{c_1}),$$

and for the longitude, the sum of equations (4) and (6) or

$$\frac{\lambda_2-\lambda_1}{10^6\ M}(V_{s_1})-\frac{A_2 \sec \phi_2 \text{ arc } 1''}{B_1}(\phi_n-\phi_1)\ (V_{c_1}).$$

The change in the position of the final point for a change in the length and azimuth of each course may be determined in the same way. Then if $\phi_{n'}$ and $\lambda_{n'}$ are the fixed latitude and longitude of the final point, the equation for the latitude will be

$$0=(\phi_n-\phi_{n'})+\left[\frac{\phi_2-\phi_1}{10^6 M}(V_{s_1})+\frac{\phi_3-\phi_2}{10^6 M}(V_{s_2})+\ldots\frac{\phi_n-\phi_{n-1}}{10^6\ M}(V_{s_n})\right]$$

$$+\left[\frac{B_1 \text{ arc } 1''}{A_n \sec \phi_n}(\lambda_n-\lambda_1)\ (V_{c_1})+\frac{B_2 \text{ arc } 1''}{A_n \sec \phi_n}(\lambda_n-\lambda_2)\ (V_{c_2})+\ldots\ldots\right.$$

$$\left.\frac{B_n \text{ arc } 1''}{A_n \sec \phi_n}(\lambda_n-\lambda_{n-1})\ (V_{cn})\right]. \tag{7}$$

For the longitude of the final point the equation will be

$$0=(\lambda_n-\lambda_{n'})+\left[\frac{\lambda_2-\lambda_1}{10^6\,M}(V_{s_1})+\frac{\lambda_3-\lambda_2}{10^6\,M}(V_{s_2})+\ldots\frac{\lambda_n-\lambda_{n-1}}{10^6\,M}(V_{s_n})\right]$$

$$+\left[-\frac{A_n\sec\phi_n\text{ arc }1''}{B_1}(\phi_n-\phi_1)\,(V_{c_1})\right.$$

$$-\frac{A_n\sec\phi_n\text{ arc }1''}{B_2}(\phi_n-\phi_2)\,(V_{c_2})\ldots\ldots$$

$$\left.-\frac{A_n\sec\phi_n\text{ arc }1''}{B_n}(\phi_n-\phi_{n-1})\,(V_{c_n})\right]. \tag{8}$$

It is close enough to take the differences in latitude and longitude to minutes and decimals. If this is done the equations should be divided by 60, since as they now stand the differences in position are in seconds. The minute and second symbols after the parentheses in the following equations show whether the difference indicated within the parenthesis is expressed in minutes or seconds. Multiplying equations (7) and (8) by $10^6\,M$ and changing from seconds to minutes, we have

$$0=+\frac{10^6\,M}{60}(\phi_n-\phi_{n'})''+[(\phi_2-\phi_1)'(V_{s_1})+(\phi_3-\phi_2)'(V_{s_2})+\ldots.$$

$$+(\phi_n-\phi_{n-1})'(V_{s_n})]+10^6\,M\left[\frac{B_1\text{ arc }1''}{A_n\sec\phi_n}(\lambda_n-\lambda_1)'(V_{c_1})\right.$$

$$+\frac{B_2\text{ arc }1''}{A_n\sec\phi_n}(\lambda_n-\lambda_2)'(V_{c_2})+\ldots..$$

$$\left.+\frac{B_n\text{ arc }1''}{A_n\sec\phi_n}(\lambda_n-\lambda_{n-1})'(V_{c_n})\right], \tag{9}$$

and

$$0=+\frac{10^6\,M}{60}(\lambda_n-\lambda_{n'})''+[(\lambda_2-\lambda_1)'(V_{s_1})+(\lambda_3-\lambda_2)'(V_{s_2})$$

$$+\ldots.(\lambda_n-\lambda_{n-1})'(V_{s_n})]+10^6\,M\left[-\frac{A_n\sec\phi_n\text{ arc }1''}{B_1}(\phi_n-\phi_1)'(V_{c_1})\right.$$

$$-\frac{A_n\sec\phi_n\text{ arc }1''}{B_2}(\phi_n-\phi_2)'(V_{c_2})-\ldots.$$

$$\left.-\frac{A_n\sec\phi_n\text{ arc }1''}{B_n}(\phi_n-\phi_{n-1})'(V_{c_n})\right]. \tag{10}$$

The following substitutions may be made in equations (9) and (10)

$$a_1 = +10^6 M \frac{B \text{ arc } 1''}{A_n \sec \phi_n}$$

$$a_2 = -10^6 M \frac{A_n \sec \phi_n \text{ arc } 1''}{B}$$

$$\frac{10^6 M}{60} = 7238.24.$$

The B factor changes so slowly for any traverse that the mean latitude may be taken as an argument. The latitude of the final point is used as the argument for A_n and sec ϕ_n. The quantities designated as a_1 and a_2 may thus be computed and used as a constant for each of the terms affected. A table of the values a_1 and a_2 for various latitudes is given on Form 496 (see below), but it is better to compute the values for each traverse, especially if the traverse has a considerable extent in latitude. If the table is used, the latitude of the final point should be used as the argument.

The final latitude equation becomes

$$\begin{aligned} 0 = &+7238.24(\phi_n - \phi_{n'})'' + [(\phi_2 - \phi_1)'(Vs_1) + (\phi_3 - \phi_2)'(Vs_2) + \ldots\ldots \\ &+ (\phi_n - \phi_{n-1})'(Vs_n)] + a_1[(\lambda_n - \lambda_1)'(Vc_1) + (\lambda_n - \lambda_2)'(Vc_2) + \ldots\ldots \\ &+ (\lambda_n - \lambda_{n-1})'(Vc_n)]. \end{aligned} \tag{11}$$

The corresponding equation for the longitude is

$$\begin{aligned} 0 = &+7238.24(\lambda_n - \lambda_{n'})'' + [(\lambda_2 - \lambda_1)'(Vs_1) + (\lambda_3 - \lambda_2)'(Vs_2) + \ldots\ldots \\ &+ (\lambda_n - \lambda_{n-1})'(Vs_n)] + a_2[(\phi_n - \phi_1)'(Vc_1) + (\phi_n - \phi_2)'(Vc_2) + \ldots\ldots \\ &+ (\phi_n - \phi_{n-1})'(Vc_n)]. \end{aligned} \tag{12}$$

COMPARISON OF VARIOUS ADJUSTMENT METHODS

In forming the equations it is well to start at one end of the traverse and number all the angles and lengths consecutively, the angles being designated by odd numbers and the lengths by even numbers. Form 496, which is the form used in forming latitude and longitude equations in the adjustment of triangulation, can be used by simply leaving blank the columns on the form which are not needed in the traverse adjustment. A sample of this form, together with a detailed explanation of the method of solving equations, will be found in Special Publication 138. A sample of the equations used in adjusting a traverse by the method outlined above and the corrections to the angles and lengths resulting from the least-squares solution of these equations will be found in Special Publication No. 79, pages 80 to 86.

The chief objection to this method of adjusting traverse is the difficulty of dividing the discrepancy between the angles and lengths. It is necessary to use a system of weighting which can be determined only by trial, and the equations, therefore, have to be solved several times. Different weights are tried until one is found which does not cause excessive corrections to either the angles or the lengths. Another objection to the method is that some of the lengths receive much larger proportional corrections than others, although the lengths are all measured with equal accuracy.

As stated on page 86, the azimuth discrepancies are sometimes arbitrarily distributed among the angles before the least-squares adjustment is made. After the positions have been recomputed with the corrected angles the equations for the least-squares adjustment must be formed from the corrected angles and positions. The numerical terms in the azimuth equations do not then represent the actual azimuth discrepancy but only that remaining after the approximate discrepancy has been distributed. The total correction to each observed angle is a combination of the correction derived from the least-squares adjustment with that applied to eliminate the approximate azimuth discrepancy. On pages 62 to 67 of Special Publication No. 86 will be found the equations and the resulting corrections to the angles and lengths for a traverse adjusted in this manner.

It is often possible to adjust a traverse without correcting the measured lengths and at the same time not have to apply excessive corrections to any of the angles. It is usually advisable to do it in this way when possible, since the angles are weaker than the lengths especially if the traverse is measured along a railroad. The observing conditions along a railroad are unusually poor, as the heated air over the railroad always causes considerable refraction, and it is often necessary to have the line of sight pass close to buildings and other objects. The smoke from passing trains and from factories also makes the observing difficult. In adjusting a traverse by correcting only the angles the azimuth discrepancies should first be approximately eliminated, as described on page 86. The latitude and longitude equations should be formed by means of the equations given on page 94, except that the parts giving corrections to the lengths should be omitted. The equations and resulting corrections to the angles for two traverses adjusted by this method will be found in Special Publication No. 101, pages 153 to 159.

If it is necessary to let the measured lengths take care of part of the discrepancy in order to avoid excessive corrections to the angles, the following method of adjustment is probably better than the method described on the preceding pages. The azimuth discrepancies should first be approximately eliminated and the positions recomputed

as described on page 86. The component of the position discrepancy which is in the general direction of the traverse should then be determined and expressed as a proportional part of the total length of the traverse. Each of the measured lengths should then be corrected by this proportional amount. This is easily accomplished by simply increasing or decreasing the logarithm of each measured length by this proportion expressed as a logarithm. The positions should then be recomputed, using these corrected lengths, and the remaining discrepancy in position should be eliminated by correcting the angles as described on page 95. This method requires an additonal computation of the positions which, however, is usually easier and quicker than determining the weights to be used when the corrections to both angles and lengths are obtained from the same adjustment as described on pages 89–95. This method also has the advantage that the measured lengths, all determined with the same accuracy, are corrected by the same proportional amount.

Another method of adjusting traverse is by the use of plane rectangular coordinates. This method is especially useful in city surveys where the area covered by the survey is of limited extent and the results desired are the plane coordinates of the traverse stations instead of geographic positions. The city survey, as a whole, is usually controlled by triangulation, the traverse being used to control the intermediate areas between the triangulation stations. The traverse lines are therefore short and connect directly with the triangulation stations or with other traverse lines which have already been adjusted between the triangulation stations. The triangulation is first adjusted by least squares, and the plane coordinates of each triangulation station, referred to one station selected as the origin, are computed. The traverse lines are then adjusted, as follows: Starting at the triangulation station at one end and using the fixed bearing to another triangulation station, the bearing of each line of the traverse is computed, the observed angles at the traverse stations being used as plane angles. A check is obtained at the triangulation station at the other end of the traverse, and the discrepancy in bearing is distributed equally among the angles.

The latitude and departure of each line of the traverse and the plane coordinates of each traverse station are next computed, using the corrected angles. The differences between the fixed coordinates of the second triangulation station and its coordinates as computed through the traverse from the first station are then distributed by correcting the latitude and departure of each of the traverse lines in proportion to the length of the line. The resulting coordinates computed with these corrected latitudes and departures are the adjusted coordinates of the traverse stations, but it is necessary to compute the bearing and length of each of the lines by solving the right-

angled plane triangle the legs of which are the corrected latitude and departure of the line.

The development of another method of adjusting a short traverse between two fixed points will be found in a publication (now in press) entitled "Joint Report Upon the Survey and Demarcation of the Boundary Between the United States and Canada, from the Source of the St. Croix River to the Atlantic Ocean." The azimuth of each traverse line with relation to the fixed line is first computed and then the length of each is multiplied by the cosine of its azimuth to give its length projected on the fixed line and by the sine of its azimuth to give its length projected on a line perpendicular to the fixed line. The error of closure of the angles and the discrepancy in the algebraic sum of the perpendicular distances (this sum should equal zero) are eliminated by corrections to the angles. The discrepancy between the length of the fixed line and the sum of the projections of the traverse lines on the fixed line is eliminated by correcting each measured length by the same proportional amount. This method is very similar in effect to that explained on page 95. It should be very useful for adjusting city-survey traverses and in traverse loops where the intermediate stations are permanently marked and it is necessary to adjust them between the main stations.

ADJUSTMENT OF TRAVERSE LOOP

The following example will serve to illustrate a convenient method of adjusting a traverse loop or a broken base in case an adjustment is deemed advisable. This method was devised by R. N. Ashmun, chief mathematician, International Boundary Commission, United States and Canada.

The azimuth of each line with respect to the line White Lake to Peter (see fig. 53) and the closure of the angles in the loop are determined as described on page 84. The azimuth equation is then written as shown with the error of closure of the angles as the constant or "n" term.

The projected length and perpendicular of each line in the loop are computed in the same manner as described on page 84, using the measured length of each line and the azimuth as computed above. The discrepency between the sum of the plus and minus perpendiculars, divided by sin 1″, becomes the constant term of the equation for the perpendiculars. The coefficient of the v for each angle in the "perpendicular" equation is the sum of the projected lengths of all the lines between it and the terminal point ahead. For example, the coefficient of v_1 is the sum of all the projected lengths between the terminal points, the coefficient of v_2 is this sum diminished by the projected length of the first line, the coefficient of v_3 is the coefficient

of v_2 diminished by the projected length of the second line, etc. The solution of the azimuth and "perpendicular" equations gives the corrections to the angles which will eliminate the angle and perpendicular discrepancies. The correlate equations, normal equations, forward solution, back solution, and values of the v's are computed as described in Special Publication No. 138.

The adopted v's are then applied to the angles to obtain the adjusted azimuths. With these adjusted azimuths the projected lengths and perpendiculars are recomputed. The sum of the plus and minus perpendiculars should now be very nearly equal, if not exactly, and

FIG. 53.—Adjustment of traverse loop

the sum of the projected lengths gives the desired length, which in the example given is the length of the line White Lake to Peter.

The following are the field data on which the loop adjustment is based.

Observed data for loop

Station	Angle			Distance from preceding station	Station	Angle			Distance from preceding station
	°	′	″	*Meters*		°	′	″	*Meters*
White Lake	1	15	14.6	----------	E	167	59	41.9	1031.104
A	198	43	09.4	2645.946	F	180	00	30.2	1899.881
B	179	57	29.6	849.929	G	179	56	52.2	2349.800
C	171	00	05.0	429.987	Peter	3	37	59.3	7730.853
D	179	59	30.9	1899.738					

Formation of azimuth equation

Stations	Azimuths and angles	Adopted v	Corrected azimuths and angles
	° ′ ″	″	″
White Lake to Peter	0 00 00.0		00.0
Angle 1	358 44 45.4	+1.8	47.2
White Lake to A	358 44 45.4		47.2
	180		
Angle 2	198 43 09.4	+0.9	10.3
A to B	17 27 54.8		57.5
	180		
Angle 3	179 57 29.6	+0.7	30.3
B to C	17 25 24.4		27.8
	180		
Angle 4	171 00 05.0	+0.5	05.5
C to D	8 25 29.4		33.3
	180		
Angle 5	179 59 30.9	−0.1	30.8
D to E	8 25 00.3		04.1
	180		
Angle 6	167 59 41.9	−0.4	41.5
E to F	356 24 42.2		45.6
	180		
Angle 7	180 00 30.2	−1.1	29.1
F to G	356 25 12.4		14.7
	180		
Angle 8	179 56 52.2	−1.8	50.4
G to Peter	356 22 04.6		05.1
	180		
Angle 9	3 37 59.3	−4.4	54.9
Peter to White Lake (computed)	180 00 03.9		00.0
Peter to White Lake (fixed)	180 00 00.0		
Azimuth discrepancy	+3.9		

The azimuth equation is as follows: 0=+3.9+(1)+(2)+(3)+(4)+(5)+(6)+(7)+(8)+(9).

Formation of perpendicular equation

[For convenience of computation some of the lines in the table below are arranged in reverse order. The logarithms in line 2 are obtained by adding the logarithms in line 3 to those in line 4, and the numbers in line 1 are obtained from the logarithms in line 2]

	White Lake to A	A to B	B to C	C to D	D to E	E to F	F to G	G to Peter
Perpendicular	−57.908	+255.087	+123.752	+278.341	+150.925	−118.907	−146.722	−489.741
Log perpendicular	1.7627404	2.4066876	2.1097525	2.4445778	2.1787612	2.0752059	2.1664952	2.6899663
Log sin azimuth	8.3401595	9.4773049	9.4762971	9.1658726	9.1654587	8.7964795	8.7954643	8.8017389
Log measured length	3.4225809	2.9293827	2.6334554	3.2787053	3.0133025	3.2787264	3.3710309	3.8882274
Log cos azimuth	9.9998959	9.9795025	9.9796020	9.9952880	9.9952971	9.9991477	9.9991517	9.9991268
Log projected length	3.4224768	2.9088852	2.6130574	3.2739932	3.0085996	3.2778741	3.3701826	3.8873542
Projected length	+2,645	+811	+410	+1,879	+1,020	+1,896	+2,345	+7,715
Sum of projected lengths to terminal point ahead	18,721	16,076	15,265	14,855	12,976	11,956	10,060	7,715

Algebraic sum of perpendiculars=−0.173.

Constant term of equation$=\frac{-0.173}{\sin 1''}=\frac{-0.173}{0.000004848137}=-35684.$

The "perpendicular" equation after dividing by 10,000 is as follows:

0=−3.568+1.872 (1) +1.608 (2) +1.526 (3) +1.486 (4) +1.298 (5) +1.196 (6) +1.006 (7) +0.772 (8)

Correlate equations

	1	2
1	+1	+1.872
2	+1	+1.608
3	+1	+1.526
4	+1	+1.486
5	+1	+1.298
6	+1	+1.196
7	+1	+1.006
8	+1	+0.772
9	+1	

Normal equations

1	2	n
+9.000	+10.764 +15.350	+3.900 −3.567

Solution of normal equations

1	2	n
+9.000 C_1	+10.764 −1.1960	+3.900 −0.4333
	+15.350 −12.874	−3.568 −4.664
	+2.486 C_2	−8.232 +3.3113

Back solution

1	2
−0.4333	+3.3113
−3.9603	+3.3113
−4.3936	

Computation of v's

	1	2	v	Adopted v
1	−4.394	+6.199	+1.805	+1.8
2	−4.394	+5.325	+0.931	+0.9
3	−4.394	+5.053	+0.659	+0.7
4	−4.394	+4.921	+0.537	+0.5
5	−4.394	+4.298	−0.096	−0.1
6	−4.394	+3.960	−0.434	−0.4
7	−4.394	+3.331	−1.063	−1.1
8	−4.394	+2.556	−1.838	−1.8
9	−4.394	----------	−4.394	−4.4

Results of final projection computation

[Adjusted azimuths are used in computing the projected lengths and perpendiculars in this table]

Stations	Projected length	Perpendicular distance
White Lake to A	2,645.312	−57.885
A to B	810.744	+255.097
B to C	410.256	+128.758
C to D	1,879.282	+278.377
D to E	1,019.996	+150.944
E to F	1,896.159	−118.875
F to G	2,345.216	−146.696
G to Peter	7,715.327	−489.722
	18,722.292	− .002

COMPUTATION OF FINAL GEOGRAPHIC POSITIONS

After the azimuth, latitude, and longitude discrepancies have all been eliminated by any one of the above methods (except the one making use of plane coordinates) and the resulting corrections to the angles and lengths have been obtained it is necessary to compute again the geographic positions of the stations. The corrected angles and lengths should be used for this computation, and the resulting azimuths should agree with the fixed azimuths, and the computed latitude and longitude of the final point should agree with the fixed position of that point. This is the final check on the accuracy of the adjustment. A list of geographic positions should now be prepared on Form 28B, a sample of which is shown in Special Publication No. 138. This is the final operation in the computation of traverse as the list of geographic positions, together with the descriptions of the stations, contain all the essential data for the stations.

Part III.—MISCELLANEOUS TABLES

Differences of elevation and inclination corrections for varying angles of inclination

[Length=50 meters. Argument is inclination angle]

Angle of inclination	Difference of elevation	Inclination correction	Angle of inclination	Difference of elevation	Inclination correction	Angle of inclination	Difference of elevation	Inclination correction	Angle of inclination	Difference of elevation	Inclination correction	Angle of inclination	Difference of elevation	Inclination correction	Angle of inclination	Difference of elevation	Inclination correction
° ′	*M.*	*Mm.*	° ′	*M.*	*Mm.*	° ′	*M.*	*Mm.*	° ′	*M.*	*Mm.*	° ′	*M.*	*Mm.*	° ′	*M.*	*Mm.*
0 00	0.00	0.0	0 30	0.44	1.9	1 00	0.87	7.6	1 30	1.31	17.1	2 00	1.74	30.5	2 30	2.18	47.6
01	.01	.0	31	.45	2.0	01	.89	7.9	31	.32	17.5	01	.76	31.0	31	.20	48.2
02	.03	.0	32	.47	2.2	02	.90	8.1	32	.34	17.9	02	.77	31.5	32	.21	48.9
03	.04	.0	33	.48	2.3	03	.92	8.4	33	.35	18.3	03	.79	32.0	33	.22	49.5
04	.06	.0	34	.49	2.4	04	.93	8.7	34	.37	18.7	04	.80	32.5	34	.24	50.2
0 05	0.07	0.1	0 35	0.51	2.6	1 05	0.95	8.9	1 35	1.38	19.1	2 05	1.82	33.0	2 35	2.25	50.8
06	.09	.1	36	.52	2.7	06	.96	9.2	36	.40	19.5	06	.83	33.6	36	.27	51.5
07	.10	.1	37	.54	2.9	07	.97	9.5	37	.41	19.9	07	.85	34.1	37	.28	52.1
08	.12	.1	38	.55	3.1	08	.99	9.8	38	.42	20.3	08	.86	34.7	38	.30	52.8
09	.13	.2	39	.57	3.2	09	1.00	10.1	39	.44	20.7	09	.88	35.2	39	.31	53.5
0 10	0.15	0.2	0 40	0.58	3.4	1 10	1.02	10.4	1 40	1.45	21.2	2 10	1.89	35.7	2 40	2.33	54.1
11	.16	.3	41	.60	3.6	11	.03	10.7	41	.47	21.6	11	.90	36.3	41	.34	54.8
12	.17	.3	42	.61	3.7	12	.05	11.0	42	.48	22.0	12	.92	36.9	42	.36	55.5
13	.19	.4	43	.63	3.9	13	.06	11.3	43	.50	22.4	13	.93	37.4	43	.37	56.2
14	.20	.4	44	.64	4.1	14	.08	11.6	44	.51	22.9	14	.95	38.0	44	.38	56.9
0 15	0.22	0.5	0 45	0.65	4.3	1 15	1.09	11.9	1 45	1.53	23.3	2 15	1.96	38.6	2 45	2.40	57.6
16	.23	.5	46	.67	4.5	16	.10	12.2	46	.54	23.8	16	.98	39.1	46	.41	58.3
17	.25	.6	47	.68	4.7	17	.12	12.5	47	.56	24.2	17	.99	39.7	47	.43	59.0
18	.26	.7	48	.70	4.9	18	.13	12.9	48	.57	24.7	18	2.01	40.3	48	.44	59.7
19	.28	.8	49	.71	5.1	19	.15	13.2	49	.59	25.1	19	.02	40.9	49	.46	60.4
0 20	0.29	0.8	0 50	0.73	5.3	1 20	1.16	13.5	1 50	1.60	25.6	2 20	2.04	41.5	2 50	2.47	61.1
21	.31	.9	51	.74	5.5	21	.18	13.9	51	.61	26.1	21	.05	42.1	51	.49	61.8
22	.32	1.0	52	.76	5.7	22	.19	14.2	52	.63	26.5	22	.06	42.7	52	.50	62.6
23	.33	1.1	53	.77	5.9	23	.21	14.6	53	.64	27.0	23	.08	43.3	53	.52	63.3
24	.35	1.2	54	.79	6.2	24	.22	14.9	54	.66	27.5	24	.09	43.9	54	.53	64.0
0 25	0.36	1.3	0 55	0.80	6.4	1 25	1.24	15.3	1 55	1.67	28.0	2 25	2.11	44.5	2 55	2.54	64.8
26	.38	1.4	56	.81	6.6	26	.25	15.6	56	.69	28.5	26	.12	45.1	56	.56	65.5
27	.39	1.5	57	.83	6.9	27	.27	16.0	57	.70	29.0	27	.14	45.7	57	.57	66.3
28	.41	1.7	58	.84	7.1	28	.28	16.4	58	.72	29.5	28	.15	46.3	58	.59	67.0
29	.42	1.8	59	.86	7.4	29	.29	16.8	59	.73	30.0	29	.17	47.0	59	.60	67.8
0 30	0.44	1.9	1 00	0.87	7.6	1 30	1.31	17.1	2 00	1.74	30.5	2 30	2.18	47.6	3 00	2.62	68.5

Inclination corrections for 50-meter tape lengths

[Cor. $=-0.01h^2-0.000001h^4$ (h in meters)]

Difference of elevation		Correction	Difference of elevation		Correction	Difference of elevation		Correction	Difference of elevation		Correction
Meters	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*
0.00	0.000	0.0	.65	2.133	4.2	1.30	4.265	16.9	1.95	6.398	38.0
.01	.033	.0	.66	2.165	4.4	1.31	4.298	17.2	1.96	6.430	38.4
.02	.066	.0	.67	2.198	4.5	1.32	4.331	17.4	1.97	6.463	38.8
.03	.098	.0	.68	2.231	4.6	1.33	4.364	17.7	1.98	6.496	39.2
.04	.131	.0	.69	2.264	4.8	1.34	4.396	18.0	1.99	6.529	39.6
.05	.164	.0	.70	2.297	4.9	1.35	4.429	18.2	2.00	6.562	40.0
.06	.197	.0	.71	2.329	5.0	1.36	4.462	18.5	2.01	6.594	40.4
.07	.230	.0	.72	2.362	5.2	1.37	4.495	18.8	2.02	6.627	40.8
.08	.262	.1	.73	2.395	5.3	1.38	4.528	19.0	2.03	6.660	41.2
.09	.295	.1	.74	2.428	5.5	1.39	4.560	19.3	2.04	6.693	41.6
.10	.328	.1	.75	2.461	5.6	1.40	4.593	19.6	2.05	6.726	42.0
.11	.361	.1	.76	2.493	5.8	1.41	4.626	19.9	2.06	6.759	42.5
.12	.394	.1	.77	2.526	5.9	1.42	4.659	20.2	2.07	6.791	42.9
.13	.427	.2	.78	2.559	6.1	1.43	4.692	20.4	2.08	6.824	43.3
.14	.459	.2	.79	2.592	6.2	1.44	4.724	20.7	2.09	6.857	43.7
.15	.492	.2	.80	2.625	6.4	1.45	4.757	21.0	2.10	6.890	44.1
.16	.525	.3	.81	2.657	6.6	1.46	4.790	21.3	2.11	6.923	44.5
.17	.558	.3	.82	2.690	6.7	1.47	4.823	21.6	2.12	6.955	45.0
.18	.591	.3	.83	2.723	6.9	1.48	4.856	21.9	2.13	6.988	45.4
.19	.623	.4	.84	2.756	7.1	1.49	4.888	22.2	2.14	7.021	45.8
.20	.656	.4	.85	2.789	7.2	1.50	4.921	22.5	2.15	7.054	46.2
.21	.689	.4	.86	2.822	7.4	1.51	4.954	22.8	2.16	7.087	46.7
.22	.722	.5	.87	2.854	7.6	1.52	4.987	23.1	2.17	7.119	47.1
.23	.755	.5	.88	2.887	7.7	1.53	5.020	23.4	2.18	7.152	47.5
.24	.787	.6	.89	2.920	7.9	1.54	5.052	23.7	2.19	7.185	48.0
.25	.820	.6	.90	2.953	8.1	1.55	5.085	24.0	2.20	7.218	48.4
.26	.853	.7	.91	2.986	8.3	1.56	5.118	24.3	2.21	7.251	48.9
.27	.886	.7	.92	3.018	8.5	1.57	5.151	24.6	2.22	7.283	49.3
.28	.919	.8	.93	3.051	8.6	1.58	5.184	25.0	2.23	7.316	49.8
.29	.951	.8	.94	3.084	8.8	1.59	5.217	25.3	2.24	7.349	50.2
.30	.984	.9	.95	3.117	9.0	1.60	5.249	25.6	2.25	7.382	50.7
.31	1.017	1.0	.96	3.150	9.2	1.61	5.282	25.9	2.26	7.415	51.1
.32	1.050	1.0	.97	3.182	9.4	1.62	5.315	26.2	2.27	7.447	51.6
.33	1.083	1.1	.98	3.215	9.6	1.63	5.348	26.6	2.28	7.480	52.0
.34	1.115	1.2	.99	3.248	9.8	1.64	5.381	26.9	2.29	7.513	52.5
.35	1.148	1.2	1.00	3.281	10.0	1.65	5.413	27.2	2.30	7.546	52.9
.36	1.181	1.3	1.01	3.314	10.2	1.66	5.446	27.6	2.31	7.579	53.4
.37	1.214	1.4	1.02	3.346	10.4	1.67	5.479	27.9	2.32	7.612	53.9
.38	1.247	1.4	1.03	3.379	10.6	1.68	5.512	28.2	2.33	7.644	54.3
.39	1.280	1.5	1.04	3.412	10.8	1.69	5.545	28.6	2.34	7.677	54.8
.40	1.312	1.6	1.05	3.445	11.0	1.70	5.577	28.9	2.35	7.710	55.3
.41	1.345	1.7	1.06	3.478	11.2	1.71	5.610	29.2	2.36	7.743	55.7
.42	1.378	1.8	1.07	3.510	11.4	1.72	5.643	29.6	2.37	7.776	56.2
.43	1.411	1.8	1.08	3.543	11.7	1.73	5.676	29.9	2.38	7.808	56.7
.44	1.444	1.9	1.09	3.576	11.9	1.74	5.709	30.3	2.39	7.841	57.2
.45	1.476	2.0	1.10	3.609	12.1	1.75	5.741	30.6	2.40	7.874	57.6
.46	1.509	2.1	1.11	3.642	12.3	1.76	5.774	31.0	2.41	7.907	58.1
.47	1.542	2.2	1.12	3.675	12.5	1.77	5.807	31.3	2.42	7.940	58.6
.48	1.575	2.3	1.13	3.707	12.8	1.78	5.840	31.7	2.43	7.972	59.1
.49	1.608	2.4	1.14	3.740	13.0	1.79	5.873	32.0	2.44	8.005	59.6
.50	1.640	2.5	1.15	3.773	13.2	1.80	5.906	32.4	2.45	8.038	60.1
.51	1.673	2.6	1.16	3.806	13.5	1.81	5.938	32.8	2.46	8.071	60.6
.52	1.706	2.7	1.17	3.839	13.7	1.82	5.971	33.1	2.47	8.104	61.0
.53	1.739	2.8	1.18	3.871	13.9	1.83	6.004	33.5	2.48	8.136	61.5
.54	1.772	2.9	1.19	3.904	14.2	1.84	6.037	33.9	2.49	8.169	62.0
.55	1.804	3.0	1.20	3.937	14.4	1.85	6.070	34.2	2.50	8.202	62.5
.56	1.837	3.1	1.21	3.970	14.6	1.86	6.102	34.6	2.51	8.235	63.0
.57	1.370	3.2	1.22	4.003	14.9	1.87	6.135	35.0	2.52	8.268	63.5
.58	1.903	3.4	1.23	4.035	15.1	1.88	6.168	35.3	2.53	8.301	64.0
.59	1.936	3.5	1.24	4.068	15.4	1.89	6.201	35.7	2.54	8.333	64.6
.60	1.968	3.6	1.25	4.101	15.6	1.90	6.234	36.1	2.55	8.366	65.1
.61	2.001	3.7	1.26	4.134	15.9	1.91	6.266	36.5	2.56	8.399	65.6
.62	2.034	3.8	1.27	4.167	16.1	1.92	6.299	36.9	2.57	8.432	66.1
.63	2.067	4.0	1.28	4.199	16.4	1.93	6.332	37.2	2.58	8.465	66.6
.64	2.100	4.1	1.29	4.232	16.6	1.94	6.365	37.6	2.59	8.497	67.1

Inclination corrections for 50-meter tape lengths—Continued

Difference of elevation		Correction	Difference of elevation		Correction	Difference of elevation		Correction	Difference of elevation		Correction
Meters	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*
2.60	8.530	67.6	3.25	10.663	105.7	3.90	12.795	152.3	4.55	14.928	207.5
2.61	8.563	68.2	3.26	10.696	106.4	3.91	12.828	153.1	4.56	14.961	208.4
2.62	8.596	68.7	3.27	10.728	107.0	3.92	12.861	153.9	4.57	14.993	209.3
2.63	8.629	69.2	3.28	10.761	107.7	3.93	12.894	154.7	4.58	15.026	210.2
2.64	8.661	69.7	3.29	10.794	108.4	3.94	12.926	155.5	4.59	15.059	211.1
2.65	8.694	70.3	3.30	10.827	109.0	3.95	12.959	156.3	4.60	15.092	212.0
2.66	8.727	70.8	3.31	10.860	109.7	3.96	12.992	157.1	4.61	15.125	213.0
2.67	8.760	71.3	3.32	10.892	110.3	3.97	13.025	157.9	4.62	15.157	213.9
2.68	8.793	71.9	3.33	10.925	111.0	3.98	13.058	158.7	4.63	15.190	214.8
2.69	8.825	72.4	3.34	10.958	111.7	3.99	13.091	159.5	4.64	15.223	215.8
2.70	8.858	73.0	3.35	10.991	112.4	4.00	13.123	160.3	4.65	15.256	216.7
2.71	8.891	73.5	3.36	11.024	113.0	4.01	13.156	161.1	4.66	15.289	217.6
2.72	8.924	74.0	3.37	11.056	113.7	4.02	13.189	161.9	4.67	15.321	218.6
2.73	8.957	74.6	3.38	11.089	114.4	4.03	13.222	162.7	4.68	15.354	219.5
2.74	8.989	75.1	3.39	11.122	115.1	4.04	13.255	163.5	4.69	15.387	220.4
2.75	9.022	75.7	3.40	11.155	115.7	4.05	13.287	164.3	4.70	15.420	221.4
2.76	9.055	76.2	3.41	11.188	116.4	4.06	13.320	165.1	4.71	15.453	222.3
2.77	9.088	76.8	3.42	11.220	117.1	4.07	13.353	165.9	4.72	15.486	223.3
2.78	9.121	77.3	3.43	11.253	117.8	4.08	13.386	166.7	4.73	15.518	224.2
2.79	9.154	77.9	3.44	11.286	118.5	4.09	13.419	167.6	4.74	15.551	225.2
2.80	9.186	78.5	3.45	11.319	119.2	4.10	13.451	168.4	4.75	15.584	226.1
2.81	9.219	79.0	3.46	11.352	119.9	4.11	13.484	169.2	4.76	15.617	227.1
2.82	9.252	79.6	3.47	11.384	120.6	4.12	13.517	170.0	4.77	15.650	228.0
2.83	9.285	80.2	3.48	11.417	121.3	4.13	13.550	170.9	4.78	15.682	229.0
2.84	9.318	80.7	3.49	11.450	122.0	4.14	13.583	171.7	4.79	15.715	230.0
2.85	9.350	81.3	3.50	11.483	122.7	4.15	13.615	172.5	4.80	15.748	230.9
2.86	9.383	81.9	3.51	11.516	123.4	4.16	13.648	173.4	4.81	15.781	231.9
2.87	9.416	82.4	3.52	11.549	124.1	4.17	13.681	174.2	4.82	15.814	232.9
2.88	9.449	83.0	3.53	11.581	124.8	4.18	13.714	175.0	4.83	15.846	233.8
2.89	9.482	83.6	3.54	11.614	125.5	4.19	13.747	175.9	4.84	15.879	234.8
2.90	9.514	84.2	3.55	11.647	126.2	4.20	13.780	176.7	4.85	15.912	235.8
2.91	9.547	84.8	3.56	11.680	126.9	4.21	13.812	177.6	4.86	15.945	236.8
2.92	9.580	85.3	3.57	11.713	127.6	4.22	13.845	178.4	4.87	15.978	237.7
2.93	9.613	85.9	3.58	11.745	128.3	4.23	13.878	179.2	4.88	16.010	238.7
2.94	9.646	86.5	3.59	11.778	129.0	4.24	13.911	180.1	4.89	16.043	239.7
2.95	9.678	87.1	3.60	11.811	129.8	4.25	13.944	181.0	4.90	16.076	240.7
2.96	9.711	87.7	3.61	11.844	130.5	4.26	13.976	181.8	4.91	16.109	241.7
2.97	9.744	88.3	3.62	11.877	131.2	4.27	14.009	182.7	4.92	16.142	242.7
2.98	9.777	88.9	3.63	11.909	131.9	4.28	14.042	183.5	4.93	16.175	243.6
2.99	9.810	89.5	3.64	11.942	132.7	4.29	14.075	134.4	4.94	16.207	244.6
3.00	9.842	90.1	3.65	11.975	133.4	4.30	14.108	185.2	4.95	16.240	245.6
3.01	9.875	90.7	3.66	12.008	134.1	4.31	14.140	186.1	4.96	16.273	246.6
3.02	9.908	91.3	3.67	12.041	134.9	4.32	14.173	187.0	4.97	16.306	247.6
3.03	9.941	91.9	3.68	12.073	135.6	4.33	14.206	187.8	4.98	16.339	248.6
3.04	9.974	92.5	3.69	12.106	136.3	4.34	14.239	188.7	4.99	16.371	249.6
3.05	10.007	93.1	3.70	12.139	137.1	4.35	14.272	189.6	5.00	16.404	250.6
3.06	10.039	93.7	3.71	12.172	137.8	4.36	14.304	190.5	5.01	16.437	251.6
3.07	10.072	94.3	3.72	12.205	138.6	4.37	14.337	191.3	5.02	16.470	252.6
3.08	10.105	95.0	3.73	12.238	139.3	4.38	14.370	192.2	5.03	16.503	253.6
3.09	10.138	95.6	3.74	12.270	140.1	4.39	14.403	193.1	5.04	16.535	254.7
3.10	10.171	96.2	3.75	12.303	140.8	4.40	14.436	194.0	5.05	16.568	255.7
3.11	10.203	96.8	3.76	12.336	141.6	4.41	14.468	194.9	5.06	16.601	256.7
3.12	10.236	97.4	3.77	12.369	142.3	4.42	14.501	195.7	5.07	16.634	257.7
3.13	10.269	98.1	3.78	12.402	143.1	4.43	14.534	196.6	5.08	16.667	258.7
3.14	10.302	98.7	3.79	12.434	143.8	4.44	14.567	197.5	5.09	16.699	259.8
3.15	10.335	99.3	3.80	12.467	144.6	4.45	14.600	198.4	5.10	16.732	260.8
3.16	10.367	100.0	3.81	12.500	145.4	4.46	14.633	199.3	5.11	16.765	261.8
3.17	10.400	100.6	3.82	12.533	146.1	4.47	14.665	200.2	5.12	16.798	262.8
3.18	10.433	101.2	3.83	12.566	146.9	4.48	14.698	201.1	5.13	16.831	263.9
3.19	10.466	101.9	3.84	12.598	147.7	4.49	14.731	202.0	5.14	16.863	264.9
3.20	10.499	102.5	3.85	12.631	148.4	4.50	14.764	202.9	5.15	16.896	265.9
3.21	10.531	103.1	3.86	12.664	149.2	4.51	14.797	203.8	6.16	16.929	267.0
3.22	10.564	103.8	3.87	12.697	150.0	4.52	14.829	204.7	5.17	16.962	268.0
3.23	10.597	104.4	3.88	12.730	150.8	4.53	14.862	205.6	5.18	16.995	269.0
3.24	10.630	105.1	3.89	12.762	151.6	4.54	14.895	206.5	5.19	17.028	270.1

Inclination corrections for 50-meter tape lengths—Continued

Difference of elevation		Correction	Difference of elevation		Correction	Difference of elevation		Correction	Difference of elevation		Correction
Meters	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*	*Meters*	*Feet*	*Mm.*
5.20	17.060	271.1	5.80	19.029	337.5	6.40	20.997	411.3	7.00	22.966	492.4
5.21	17.093	272.2	5.81	19.062	338.7	6.41	21.030	412.6	7.01	22.999	493.8
5.22	17.126	273.2	5.82	19.094	339.9	6.42	21.063	413.9	7.02	23.031	495.2
5.23	17.159	274.3	5.83	19.127	341.0	6.43	21.096	415.2	7.03	23.064	496.6
5.24	17.192	275.3	5.84	19.160	342.2	6.44	21.129	416.5	7.04	23.097	498.1
5.25	17.224	276.4	5.85	19.193	343.4	6.45	21.161	417.8	7.05	23.130	499.5
5.26	17.257	277.4	5.86	19.226	344.6	6.46	21.194	419.1	7.06	23.163	500.9
5.27	17.290	278.5	5.87	19.258	345.8	6.47	21.227	420.4	7.07	23.195	502.3
5.28	17.323	279.6	5.88	19.291	346.9	6.48	21.260	421.7	7.08	23.228	503.8
5.29	17.356	280.6	5.89	19.324	348.1	6.49	21.293	423.0	7.09	23.261	505.2
5.30	17.388	281.7	5.90	19.357	349.3	6.50	21.325	424.3	7.10	23.294	506.6
5.31	17.421	282.8	5.91	19.390	350.5	6.51	21.358	425.6	7.11	23.327	508.1
5.32	17.454	283.8	5.92	19.423	351.7	6.52	21.391	426.9	7.12	23.360	509.5
5.33	17.487	284.9	5.93	19.455	352.9	6.53	21.424	428.2	7.13	23.392	511.0
5.34	17.520	286.0	5.94	19.488	354.1	6.54	21.457	429.5	7.14	23.425	512.4
5.35	17.552	287.0	5.95	19.521	355.3	6.55	21.489	430.9	7.15	23.458	513.8
5.36	17.585	288.1	5.96	19.554	356.5	6.56	21.522	432.2	7.16	23.491	515.3
5.37	17.618	289.2	5.97	19.587	357.7	6.57	21.555	433.5	7.17	23.524	516.7
5.38	17.651	290.3	5.98	19.619	358.9	6.58	21.588	434.8	7.18	23.556	518.2
5.39	17.684	291.4	5.99	19.652	360.1	6.59	21.621	436.2	7.19	23.589	519.6
5.40	17.716	292.5	6.00	19.685	361.3	6.60	21.654	437.5	7.20	23.622	521.1
5.41	17.749	293.5	6.01	19.718	362.5	6.61	21.686	438.8	7.21	23.655	522.5
5.42	17.782	294.6	6.02	19.751	363.7	6.62	21.719	440.2	7.22	23.688	524.0
5.43	17.815	295.7	6.03	19.783	364.9	6.63	21.752	441.5	7.23	23.720	525.5
5.44	17.848	296.8	6.04	19.816	366.1	6.64	21.785	442.8	7.24	23.753	526.9
5.45	17.881	297.9	6.05	19.849	367.4	6.65	21.818	444.2	7.25	23.786	528.4
5.46	17.913	299.0	6.06	19.882	368.6	6.66	21.850	445.5	7.26	23.819	529.9
5.47	17.946	300.1	6.07	19.915	369.8	6.67	21.883	446.9	7.27	23.852	531.3
5.48	17.979	301.2	6.08	19.947	371.0	6.68	21.916	448.2	7.28	23.884	532.8
5.49	18.012	302.3	6.09	19.980	372.3	6.69	21.949	449.6	7.29	23.917	534.3
5.50	18.045	303.4	6.10	20.013	373.5	6.70	21.982	450.9	7.30	23.950	535.7
5.51	18.077	304.5	6.11	20.046	374.7	6.71	22.014	452.3	7.31	23.983	537.2
5.52	18.110	305.6	6.12	20.079	375.9	6.72	22.047	453.6	7.32	24.016	538.7
5.53	18.143	306.7	6.13	20.112	377.2	6.73	22.080	455.0	7.33	24.049	540.2
5.54	18.176	307.9	6.14	20.144	378.4	6.74	22.113	456.3	7.34	24.081	541.7
5.55	18.209	309.0	6.15	20.177	379.7	6.75	22.146	457.7	7.35	24.114	543.1
5.56	18.241	310.1	6.16	20.210	380.9	6.76	22.178	459.1	7.36	24.147	544.6
5.57	18.274	311.2	6.17	20.243	382.1	6.77	22.211	460.4	7.37	24.180	546.1
5.58	18.307	312.3	6.18	20.276	383.4	6.78	22.244	461.8	7.38	24.213	547.6
5.59	18.340	313.5	6.19	20.308	384.6	6.79	22.277	463.2	7.39	24.245	549.1
5.60	18.373	314.6	6.20	20.341	385.9	6.80	22.310	464.5	7.40	24.278	550.6
5.61	18.405	315.7	6.21	20.374	387.1	6.81	22.342	465.9	7.41	24.311	552.1
5.62	18.438	316.8	6.22	20.407	388.4	6.82	22.375	467.3	7.42	24.344	553.6
5.63	18.471	318.0	6.23	20.440	389.6	6.83	22.408	468.7	7.43	24.377	555.1
5.64	18.504	319.1	6.24	20.472	390.9	6.84	22.441	470.0	7.44	24.409	556.6
5.65	18.537	320.2	6.25	20.505	392.2	6.85	22.474	471.4	7.45	24.442	558.1
5.66	18.570	321.4	6.26	20.538	393.4	6.86	22.507	472.8	7.46	24.475	559.6
5.67	18.602	322.5	6.27	20.571	394.7	6.87	22.539	474.2	7.47	24.508	561.1
5.68	18.635	323.7	6.28	20.604	395.9	6.88	22.572	475.6	7.48	24.541	562.6
5.69	18.668	324.8	6.29	20.636	397.2	6.89	22.605	477.0	7.49	24.573	564.1
5.70	18.701	326.0	6.30	20.669	398.5	6.90	22.638	478.4	7.50	24.606	565.7
5.71	18.734	327.1	6.31	20.702	399.7	6.91	22.671	479.8			
5.72	18.766	328.3	6.32	20.735	401.0	6.92	22.703	481.2			
5.73	18.799	329.4	6.33	20.768	402.3	6.93	22.736	482.6			
5.74	18.832	330.6	6.34	20.800	403.6	6.94	22.769	484.0			
5.75	18.865	331.7	6.35	20.833	404.9	6.95	22.802	485.4			
5.76	18.898	332.9	6.36	20.866	406.1	6.96	22.835	486.8			
5.77	18.930	334.0	6.37	20.899	407.4	6.97	22.867	488.2			
5.78	18.963	335.2	6.38	20.932	408.7	6.98	22.900	489.6			
5.79	18.996	336.4	6.39	20.965	410.0	6.99	22.933	491.0			

Inclination corrections for 25-meter lengths

[Cor. $=-0.00186\,h^2-0.000000069\,h^4$ (h in feet)]

Difference in elevation		Correction	Difference in elevation		Correction	Difference in elevation		Correction	Difference in elevation		Correction
Foot	*Meter*	*Mm.*	*Feet*	*Meter*	*Mm.*	*Feet*	*Meter*	*Mm.*	*Feet*	*Meter*	*Mm.*
0.00	0.0000	0.0	0.70	0.2134	0.9	1.40	0.4267	3.6	2.10	0.6401	8.2
.01	.0030	.0	.71	.2164	.9	.41	.4298	3.7	.11	.6431	8.3
.02	.0061	.0	.72	.2195	1.0	.42	.4328	3.7	.12	.6462	8.4
.03	.0091	.0	.73	.2225	1.0	.43	.4359	3.8	.13	.6492	8.4
.04	.0122	.0	.74	.2256	1.0	.44	.4389	3.8	.14	.6523	8.5
.05	.0152	.0	.75	.2286	1.0	.45	.4420	3.9	.15	.6553	8.6
.06	.0183	.0	.76	.2316	1.1	.46	.4450	4.0	.16	.6584	8.7
.07	.0213	.0	.77	.2347	1.1	.47	.4481	4.0	.17	.6614	8.8
.08	.0244	.0	.78	.2377	1.1	.48	.4511	4.1	.18	.6645	8.8
.09	.0274	.0	.79	.2408	1.2	.49	.4542	4.1	.19	.6675	8.9
0.10	0.0305	0.0	0.80	0.2438	1.2	1.50	0.4572	4.2	2.20	0.6706	9.0
.11	.0335	.0	.81	.2469	1.2	.51	.4602	4.3	.21	.6736	9.1
.12	.0366	.0	.82	.2499	1.2	.52	.4633	4.3	.22	.6767	9.2
.13	.0396	.0	.83	.2530	1.3	.53	.4663	4.4	.23	.6797	9.2
.14	.0427	.0	.84	.2560	1.3	.54	.4694	4.4	.24	.6828	9.3
.15	.0457	.0	.85	.2591	1.3	.55	.4724	4.5	.25	.6858	9.4
.16	.0488	.0	.86	.2621	1.4	.56	.4755	4.6	.26	.6888	9.5
.17	.0513	.1	.87	.2652	1.4	.57	.4785	4.6	.27	.6919	9.6
.18	.0549	.1	.88	.2682	1.4	.58	.4816	4.7	.28	.6949	9.6
.19	.0579	.1	.89	.2713	1.5	.59	.4846	4.7	.29	.6980	9.7
0.20	0.0610	0.1	0.90	0.2743	1.5	1.60	0.4877	4.8	2.30	0.7010	9.8
.21	.0640	.1	.91	.2774	1.5	.61	.4907	4.8	.31	.7041	9.9
.22	.0671	.1	.92	.2804	1.6	.62	.4938	4.9	.32	.7071	10.0
.23	.0701	.1	.93	.2835	1.6	.63	.4968	5.0	.33	.7102	10.1
.24	.0732	.1	.94	.2865	1.6	.64	.4999	5.0	.34	.7132	10.2
.25	.0762	.1	.95	.2896	1.7	.65	.5029	5.1	.35	.7163	10.3
.26	.0792	.1	.96	.2926	1.7	.66	.5060	5.2	.36	.7193	10.3
.27	.0823	.1	.97	.2957	1.8	.67	.5090	5.2	.37	.7224	10.4
.28	.0853	.1	.98	.2987	1.8	.68	.5121	5.3	.38	.7254	10.5
.29	.0884	.2	.99	.3018	1.8	.69	.5151	5.3	.39	.7285	10.6
0.30	0.0914	0.2	1.00	0.3048	1.9	1.70	0.5182	5.4	2.40	0.7315	10.7
.31	.0945	.2	.01	.3078	1.9	.71	.5212	5.5	.41	.7346	10.8
.32	.0975	.2	.02	.3109	1.9	.72	.5243	5.5	.42	.7376	10.9
.33	.1006	.2	.03	.3139	2.0	.73	.5273	5.6	.43	.7407	11.0
.34	.1036	.2	.04	.3170	2.0	.74	.5304	5.6	.44	.7437	11.1
.35	.1067	.2	.05	.3200	2.0	.75	.5334	5.7	.45	.7468	11.2
.36	.1097	.2	.06	.3231	2.1	.76	.5364	5.8	.46	.7498	11.2
.37	.1128	.3	.07	.3261	2.1	.77	.5395	5.8	.47	.7529	11.3
.38	.1158	.3	.08	.3292	2.2	.78	.5425	5.9	.48	.7559	11.4
.39	.1189	.3	.09	.3322	2.2	.79	.5456	5.9	.49	.7590	11.5
0.40	0.1219	0.3	1.10	0.3353	2.2	1.80	0.5486	6.0	2.50	0.7620	11.6
.41	.1250	.3	.11	.3383	2.3	.81	.5517	6.1	.51	.7650	11.7
.42	.1280	.3	.12	.3414	2.3	.82	.5547	6.1	.52	.7681	11.8
.43	.1311	.3	.13	.3444	2.4	.83	.5578	6.2	.53	.7711	11.9
.44	.1341	.4	.14	.3475	2.4	.84	.5608	6.3	.54	.7742	12.0
.45	.1372	.4	.15	.3505	2.5	.85	.5639	6.4	.55	.7772	12.1
.46	.1402	.4	.16	.3536	2.5	.86	.5669	6.4	.56	.7803	12.2
.47	.1433	.4	.17	.3566	2.5	.87	.5700	6.5	.57	.7833	12.3
.48	.1463	.4	.18	.3597	2.6	.88	.5730	6.6	.58	.7864	12.4
.49	.1494	.4	.19	.3627	2.6	.89	.5761	6.6	.59	.7894	12.5
0.50	0.1524	0.5	1.20	0.3658	2.7	1.90	0.5791	6.7	2.60	0.7925	12.6
.51	.1554	.5	.21	.3688	2.7	.91	.5822	6.8	.61	.7955	12.7
.52	.1585	.5	.22	.3719	2.8	.92	.5852	6.8	.62	.7986	12.8
.53	.1615	.5	.23	.3749	2.8	.93	.5883	6.9	.63	.8016	12.9
.54	.1646	.5	.24	.3780	2.9	.94	.5913	7.0	.64	.8047	13.0
.55	.1676	.6	.25	.3810	2.9	.95	.5944	7.1	.65	.8077	13.1
.56	.1707	.6	.26	.3840	2.9	.96	.5974	7.1	.66	.8108	13.1
.57	.1737	.6	.27	.3871	3.0	.97	.6005	7.2	.67	.8138	13.2
.58	.1768	.6	.28	.3901	3.1	.98	.6035	7.3	.68	.8169	13.3
.59	.1798	.6	.29	.3932	3.1	.99	.6066	7.3	.69	.8199	13.4
0.60	0.1829	0.7	1.30	0.3962	3.1	2.00	0.6096	7.4	2.70	0.8230	13.5
.61	.1859	.7	.31	.3993	3.2	.01	.6126	7.5	.71	.8260	13.6
.62	.1890	.7	.32	.4023	3.2	.02	.6157	7.6	.72	.8291	13.7
.63	.1920	.7	.33	.4054	3.3	.03	.6187	7.6	.73	.8321	13.8
.64	.1951	.8	.34	.4084	3.3	.04	.6218	7.7	.74	.8352	13.9
.65	.1981	.8	.35	.4115	3.4	.05	.6248	7.8	.75	.8382	14.1
.66	.2012	.8	.36	.4145	3.4	.06	.6279	7.9	.76	.8412	14.2
.67	.2042	.8	.37	.4176	3.5	.07	.6309	8.0	.77	.8443	14.3
.68	.2073	.9	.38	.4206	3.5	.08	.6340	8.0	.78	.8473	14.4
.69	.2103	.9	.39	.4237	3.6	.09	.6370	8.1	.79	.8504	14.5

Inclination corrections for 25-meter lengths—Continued

Difference in elevation		Correction	Difference in elevation		Correction	Difference in elevation		Correction	Difference in elevation		Correction
Feet	*Meters*	*Mm.*	*Feet*	*Meters*	*Mm.*	*Feet*	*Meters*	*Mm.*	*Feet*	*Meters*	*Mm.*
2.80	0.8534	14.6	3.50	1.0668	22.8	4.20	1.2802	32.8	4.90	1.4935	44.7
.81	.8565	14.7	.51	.0699	22.9	.21	.2832	33.0	.91	.4966	44.9
.82	.8595	14.8	.52	.0729	23.1	.22	.2863	33.1	.92	.4996	45.1
.83	.8626	14.9	.53	.0759	23.2	.23	.2893	33.3	.93	.5027	45.2
.84	.8656	15.0	.54	.0790	23.3	.24	.2924	33.4	.94	.5057	45.4
.85	.8687	15.1	.55	.0820	23.5	.25	.2954	33.6	.95	.5088	45.6
.86	.8717	15.2	.56	.0851	23.6	.26	.2985	33.8	.96	.5118	45.8
.87	.8748	15.3	.57	.0881	23.7	.27	.3015	33.9	.97	.5149	46.0
.88	.8778	15.4	.58	.0912	23.8	.28	.3045	34.1	.98	.5179	46.1
.89	.8809	15.5	.59	.0942	24.0	.29	.3076	34.2	.99	.5210	46.3
2.90	0.8839	15.6	3.60	1.0973	24.1	4.30	1.3106	34.4	5.00	1.5240	46.5
.91	.8870	15.7	.61	.1003	24.2	.31	.3137	34.6	.01	.5271	46.7
.92	.8900	15.8	.62	.1034	24.4	.32	.3167	34.7	.02	.5301	46.9
.93	.8931	15.9	.63	.1064	24.5	.33	.3198	34.9	.03	.5331	47.1
.94	.8961	16.0	.64	.1095	24.6	.34	.3228	35.0	.04	.5362	47.3
.95	.8992	16.2	.65	.1125	24.8	.35	.3259	35.2	.05	.5392	47.5
.96	.9022	16.3	.66	.1156	24.9	.36	.3289	35.4	.06	.5423	47.6
.97	.9053	16.4	.67	.1186	25.0	.37	.3320	35.5	.07	.5453	47.8
.98	.9083	16.5	.68	.1217	25.1	.38	.3350	35.7	.08	.5484	48.0
.99	.9114	16.6	.69	.1247	25.3	.39	.3381	35.8	.09	.5514	48.2
3.00	0.9144	16.7	3.70	1.1278	25.4	4.40	1.3411	36.0	5.10	1.5545	48.4
.01	.9174	16.8	.71	.1308	25.5	.41	.3442	36.2	.11	.5575	48.6
.02	.9205	16.9	.72	.1339	25.7	.42	.3472	36.3	.12	.5606	48.8
.03	.9235	17.1	.73	.1369	25.8	.43	.3503	36.5	.13	.5636	49.0
.04	.9266	17.2	.74	.1400	26.0	.44	.3533	36.7	.14	.5667	49.2
.05	.9296	17.3	.75	.1430	26.1	.45	.3564	36.9	.15	.5697	49.4
.06	.9327	17.4	.76	.1461	26.2	.46	.3594	37.0	.16	.5728	49.5
.07	.9357	17.5	.77	.1491	26.4	.47	.3625	37.2	.17	.5758	49.7
.08	.9388	17.7	.78	.1521	26.5	.48	.3655	37.4	.18	.5789	49.9
.09	.9418	17.8	.79	.1552	26.7	.49	.3686	37.5	.19	.5819	50.1
3.10	0.9449	17.9	3.80	1.1582	26.8	4.50	1.3716	37.7	5.20	1.5850	50.3
.11	.9479	18.0	.81	.1613	27.0	.51	.3747	37.9	.21	.5880	50.5
.12	.9510	18.1	.82	.1643	27.1	.52	.3777	38.0	.22	.5911	50.7
.13	.9540	18.2	.83	.1674	27.3	.53	.3807	38.2	.23	.5941	50.9
.14	.9571	18.3	.84	.1704	27.4	.54	.3838	38.4	.24	.5972	51.1
.15	.9601	18.5	.85	.1735	27.6	.55	.3868	38.6	.25	.6002	51.3
.16	.9632	18.6	.86	.1765	27.7	.56	.3899	38.7	.26	.6033	51.5
.17	.9662	18.7	.87	.1796	27.9	.57	.3929	38.9	.27	.6063	51.7
.18	.9693	18.8	.88	.1826	28.0	.58	.3960	39.1	.28	.6093	51.9
.19	.9723	18.9	.89	.1857	28.2	.59	.3990	39.2	.29	.6124	52.1
3.20	0.9754	19.0	3.90	1.1887	28.3	4.60	1.4021	39.4	5.30	1.6154	52.3
.21	.9784	19.1	.91	.1918	28.4	.61	.4051	39.6	.31	.6185	52.5
.22	.9815	19.2	.92	.1948	28.6	.62	.4082	39.7	.32	.6215	52.7
.23	.9845	19.4	.93	.1979	28.7	.63	.4112	39.9	.33	.6246	52.9
.24	.9876	19.5	.94	.2009	28.9	.64	.4143	40.1	.34	.6276	53.1
.25	.9906	19.6	.95	.2040	29.0	.65	.4173	40.3	.35	.6307	53.3
.26	.9936	19.7	.96	.2070	29.1	.66	.4204	40.4	.36	.6337	53.5
.27	.9967	19.8	.97	.2101	29.3	.67	.4234	40.6	.37	.6368	53.7
.28	.9997	20.0	.98	.2131	29.4	.68	.4265	40.8	.38	.6398	53.9
.29	1.0028	20.1	.99	.2162	29.6	.69	.4295	40.9	.39	.6429	54.1
3.30	1.0058	20.2	4.00	1.2192	29.7	4.70	1.4326	41.1	5.40	1.6459	54.3
.31	.0089	20.3	.01	.2223	29.9	.71	.4356	41.3	.41	.6490	54.5
.32	.0119	20.5	.02	.2253	30.0	.72	.4387	41.5	.42	.6520	54.7
.33	.0150	20.6	.03	.2283	30.2	.73	.4417	41.6	.43	.6551	54.9
.34	.0180	20.7	.04	.2314	30.3	.74	.4448	41.8	.44	.6581	55.1
.35	.0211	20.9	.05	.2344	30.5	.75	.4478	42.0	.45	.6612	55.3
.36	.0241	21.0	.06	.2375	30.6	.76	.4509	42.2	.46	.6642	55.5
.37	.0272	21.1	.07	.2405	30.8	.77	.4539	42.4	.47	.6673	55.7
.38	.0302	21.2	.08	.2436	30.9	.78	.4569	42.5	.48	.6703	55.9
.39	.0333	21.4	.09	.2466	31.1	.79	.4600	42.7	.49	.6734	56.1
3.40	1.0363	21.5	4.10	1.2497	31.2	4.80	1.4630	42.9	5.50	1.6764	56.3
.41	.0394	21.6	.11	.2527	31.4	.81	.4661	43.1	.51	.6795	56.5
.42	.0424	21.8	.12	.2558	31.5	.82	.4691	43.3	.52	.6825	56.7
.43	.0455	21.9	.13	.2588	31.7	.83	.4722	43.4	.53	.6855	56.9
.44	.0485	22.0	.14	.2619	31.8	.84	.4752	43.6	.54	.6886	57.1
.45	.0516	22.2	.15	.2649	32.0	.85	.4783	43.8	.55	.6916	57.3
.46	.0546	22.3	.16	.2680	32.2	.86	.4813	44.0	.56	.6947	57.5
.47	.0577	22.4	.17	.2710	32.3	.87	.4844	44.2	.57	.6977	57.7
.48	.0607	22.5	.18	.2741	32.5	.88	.4874	44.3	.58	.7008	57.9
.49	.0638	22.7	.19	.2771	32.6	.89	.4905	44.5	.59	.7038	58.1

Inclination corrections for 25-meter lengths—Continued

Difference in elevation		Correction	Difference in elevation		Correction	Difference in elevation		Correction	Difference in elevation		Correction
Feet	*Meters*	*Mm.*	*Feet*	*Meters*	*Mm.*	*Feet*	*Meters*	*Mm.*	*Feet*	*Meters*	*Mm.*
5.60	1.7069	58.3	6.30	1.9202	73.9	7.00	2.1336	91.2	7.70	2.3470	110.4
.61	.7099	58.5	.31	.9233	74.1	.01	.1367	91.5	.71	.3500	110.7
.62	.7130	58.7	.32	.9263	74.4	.02	.1397	91.7	.72	.3531	111.0
.63	.7160	58.9	.33	.9294	74.6	.03	.1427	92.0	.73	.3561	111.3
.64	.7191	59.1	.34	.9324	74.8	.04	.1458	92.2	.74	.3592	111.6
.65	.7221	59.4	.35	.9355	75.1	.05	.1488	92.5	.75	.3622	111.9
.66	.7252	59.6	.36	.9385	75.3	.06	.1519	92.8	.76	.3653	112.1
.67	.7282	59.8	.37	.9416	75.5	.07	.1549	93.0	.77	.3683	112.4
.68	.7313	60.0	.38	.9446	75.7	.08	.1580	93.3	.78	.3713	112.7
.69	.7343	60.2	.39	.9477	76.0	.09	.1610	93.5	.79	.3744	113.0
5.70	1.7374	60.4	6.40	1.9507	76.2	7.10	2.1641	93.8	7.80	2.3774	113.3
.71	.7404	60.6	.41	.9538	76.4	.11	.1671	94.1	.81	.3805	113.6
.72	.7435	60.8	.42	.9568	76.7	.12	.1702	94.3	.82	.3835	113.9
.73	.7465	61.1	.43	.9599	76.9	.13	.1732	94.6	.83	.3866	114.2
.74	.7496	61.3	.44	.9629	77.2	.14	.1763	94.9	.84	.3896	114.5
.75	.7526	61.5	.45	.9660	77.4	.15	.1793	95.2	.85	.3927	114.8
.76	.7557	61.7	.46	.9690	77.6	.16	.1824	95.4	.86	.3957	115.0
.77	.7587	61.9	.47	.9721	77.9	.17	.1854	95.7	.87	.3988	115.3
.78	.7617	62.2	.48	.9751	78.1	.18	.1885	96.0	.88	.4018	115.6
.79	.7648	62.4	.49	.9782	78.4	.19	.1915	96.2	.89	.4049	115.9
5.80	1.7678	62.6	6.50	1.9812	78.6	7.20	2.1946	96.5	7.90	2.4079	116.2
.81	.7709	62.8	.51	.9843	78.9	.21	.1976	96.8	.91	.4110	116.5
.82	.7739	63.0	.52	.9873	79.1	.22	.2007	97.0	.92	.4140	116.8
.83	.7770	63.3	.53	.9903	79.4	.23	.2037	97.3	.93	.4171	117.1
.84	.7800	63.5	.54	.9934	79.6	.24	.2068	97.6	.94	.4201	117.4
.85	.7831	63.7	.55	.9964	79.9	.25	.2098	97.9	.95	.4232	117.7
.86	.7861	63.9	.56	.9995	80.1	.26	.2129	98.1	.96	.4262	118.0
.87	.7892	64.1	.57	2.0025	80.4	.27	.2159	98.4	.97	.4293	118.3
.88	.7922	84.4	.58	.0056	80.6	.28	.2189	98.7	.98	.4323	118.6
.89	.7953	64.6	.59	.0086	80.9	.29	.2220	98.9	.99	.4354	118.9
5.90	1.7983	64.8	6.60	2.0117	81.1	7.30	2.2250	99.2	8.00	2.4384	119.2
.91	.8014	65.0	.61	.0147	81.4	.31	.2281	99.5	.01	.4415	119.5
.92	.8044	65.2	.62	.0178	81.6	.32	.2311	99.8	.02	.4445	119.8
.93	.8075	65.5	.63	.0208	81.9	.33	.2342	100.0	.03	.4475	120.1
.94	.8105	65.7	.64	.0239	82.1	.34	.2372	100.3	.04	.4506	120.4
.95	.8136	65.9	.65	.0269	82.4	.35	.2403	100.6	.05	.4536	120.7
.96	.8166	66.1	.66	.0300	82.6	.36	.2433	100.9	.06	.4567	121.0
.97	.8197	66.3	.67	.0330	82.9	.37	.2464	101.2	.07	.4597	121.3
.98	.8227	66.6	.68	.0361	83.1	.38	.2494	101.4	.08	.4628	121.6
.99	.8258	66.8	.69	.0391	83.4	.39	.2525	101.7	.09	.4658	121.9
6.00	1.8288	67.0	6.70	2.0422	83.6	7.40	2.2555	102.0	8.10	2.4689	122.2
.01	.8319	67.2	.71	.0452	83.9	.41	.2586	102.3	.11	.4719	122.5
.02	.8349	67.4	.72	.0483	84.1	.42	.2616	102.6	.12	.4750	122.8
.03	.8379	67.7	.73	.0513	84.4	.43	.2647	102.8	.13	.4780	123.1
.04	.8410	67.9	.74	.0544	84.6	.44	.2677	103.1	.14	.4811	123.4
.05	.8440	68.1	.75	.0574	84.9	.45	.2708	103.4	.15	.4841	123.7
.06	.8471	68.3	.76	.0605	85.1	.46	.2738	103.7	.16	.4872	124.0
.07	.8501	68.5	.77	.0635	85.4	.47	.2769	104.0	.17	.4902	124.3
.08	.8532	63.8	.78	.0665	85.6	.48	.2799	104.2	.18	.4933	124.6
.09	.8562	69.0	.79	.0696	85.9	.49	.2830	104.5	.19	.4963	124.9
6.10	1.8593	69.2	6.80	2.0726	86.1	7.50	2.2860	104.8	8.20	2.4994	125.2
.11	.8623	69.4	.81	.0757	86.4	.51	.2891	105.1	.21	.5024	125.5
.12	.8654	69.7	.82	.0787	86.6	.52	.2921	105.4	.22	.5055	125.8
.13	.8684	69.9	.83	.0818	86.9	.53	.2951	105.6	.23	.5085	126.1
.14	.8715	70.1	.84	.0848	87.1	.54	.2982	105.9	.24	.5116	126.4
.15	.8745	70.4	.85	.0879	87.4	.55	.3012	106.2	.25	.5146	126.8
.16	.8776	70.6	.86	.0909	87.6	.56	.3043	106.5	.26	.5177	127.1
.17	.8806	70.8	.87	.0940	87.9	.57	.3073	106.8	.27	.5207	127.4
.18	.8837	71.0	.88	.0970	88.1	.58	.3104	107.0	.28	.5237	127.7
.19	.8867	71.3	.89	.1001	88.4	.59	.3134	107.3	.29	.5268	128.0
6.20	1.8898	71.5	6.90	2.1031	88.6	7.60	2.3165	107.6	8.30	2.5298	128.3
.21	.8928	71.7	.91	.1062	88.9	.61	.3195	107.8	.31	.5329	128.6
.22	.8959	72.0	.92	.1092	89.1	.62	.3226	108.2	.32	.5359	128.9
.23	.8989	72.2	.93	.1123	89.4	.63	.3256	108.4	.33	.5390	129.2
.24	.9020	72.5	.94	.1153	89.6	.64	.3287	108.7	.34	.5420	129.5
.25	.9050	72.7	.95	.1184	89.9	.65	.3317	109.0	.35	.5451	129.9
.26	.9081	72.9	.96	.1214	90.2	.66	.3348	109.3	.36	.5481	130.2
.27	.9111	73.2	.97	.1245	90.4	.67	.3378	109.6	.37	.5512	130.5
.28	.9141	73.4	.98	.1275	90.7	.68	.3409	109.8	.38	.5542	130.8
.29	.9172	73.7	.99	.1306	90.9	.69	.3439	110.1	.39	.5573	131.1
									8.40	2.5603	131.4

Inclination corrections for 5, 10, 15, 20, 25, 30, 35, 40, and 45 meter lengths

Difference in elevation		Length in meters								
		5	10	15	20	25	30	35	40	45
Meters	*Feet*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
0.01	0.033	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.02	0.066	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.03	0.098	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.04	0.131	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.05	0.164	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
0.06	0.197	0.4	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0
0.07	0.230	0.5	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
0.08	0.262	0.6	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1
0.09	0.295	0.8	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1
0.10	0.328	1.0	0.5	0.3	0.2	0.2	0.2	0.1	0.1	0.1
0.11	0.361	1.2	0.6	0.4	0.3	0.2	0.2	0.2	0.2	0.1
0.12	0.394	1.4	0.7	0.5	0.4	0.3	0.2	0.2	0.2	0.2
0.13	0.427	1.7	0.8	0.6	0.4	0.3	0.3	0.2	0.2	0.2
0.14	0.459	2.0	1.0	0.7	0.5	0.4	0.3	0.3	0.2	0.2
0.15	0.492	2.3	1.1	0.8	0.6	0.4	0.3	0.3	0.3	0.2
0.16	0.525	2.6	1.3	0.9	0.6	0.5	0.4	0.4	0.3	0.3
0.17	0.558	2.9	1.4	1.0	0.7	0.6	0.5	0.4	0.4	0.3
0.18	0.591	3.2	1.6	1.1	0.8	0.6	0.5	0.5	0.4	0.4
0.19	0.623	3.6	1.8	1.2	0.9	0.7	0.6	0.5	0.5	0.4
0.20	0.656	4.0	2.0	1.3	1.0	0.8	0.7	0.6	0.5	0.4
0.21	0.689	4.4	2.2	1.5	1.1	0.9	0.7	0.6	0.6	0.5
0.22	0.722	4.8	2.4	1.6	1.2	1.0	0.8	0.7	0.6	0.5
0.23	0.755	5.3	2.6	1.8	1.3	1.0	0.9	0.8	0.7	0.6
0.24	0.787	5.8	2.9	1.9	1.4	1.1	1.0	0.8	0.7	0.6
0.25	0.820	6.3	3.1	2.1	1.6	1.2	1.0	0.9	0.8	0.7
0.26	0.853	6.8	3.4	2.3	1.7	1.3	1.1	1.0	0.8	0.8
0.27	0.886	7.3	3.6	2.4	1.8	1.5	1.2	1.0	0.9	0.8
0.28	0.919	7.8	3.9	2.6	2.0	1.6	1.3	1.1	1.0	0.9
0.29	0.951	8.4	4.2	2.8	2.1	1.7	1.4	1.2	1.1	0.9
0.30	0.984	9.0	4.5	3.0	2.2	1.8	1.5	1.3	1.1	1.0
0.31	1.017	9.6	4.8	3.2	2.4	1.9	1.6	1.4	1.2	1.1
0.32	1.050	10.2	5.1	3.4	2.6	2.0	1.7	1.5	1.3	1.1
0.33	1.083	10.9	5.4	3.6	2.7	2.2	1.8	1.6	1.4	1.2
0.34	1.115	11.6	5.8	3.9	2.9	2.3	1.9	1.7	1.4	1.3
0.35	1.148	12.3	6.1	4.1	3.1	2.5	2.0	1.8	1.5	1.4
0.36	1.181	13.0	6.5	4.3	3.2	2.6	2.2	1.9	1.6	1.4
0.37	1.214	13.7	6.8	4.6	3.4	2.7	2.3	2.0	1.7	1.5
0.38	1.247	14.4	7.2	4.8	3.6	2.9	2.4	2.1	1.8	1.6
0.39	1.280	15.2	7.6	5.1	3.8	3.1	2.5	2.2	1.9	1.7
0.40	1.312	16.0	8.0	5.3	4.0	3.2	2.7	2.3	2.0	1.8
0.41	1.345	16.8	8.4	5.6	4.2	3.4	2.8	2.4	2.1	1.9
0.42	1.378	17.7	8.8	5.9	4.4	3.5	2.9	2.5	2.2	2.0
0.43	1.411	18.5	9.3	6.2	4.6	3.7	3.1	2.6	2.3	2.1
0.44	1.444	19.4	9.7	6.5	4.8	3.9	3.2	2.8	2.4	2.2
0.45	1.476	20.3	10.1	6.8	5.1	4.1	3.4	2.9	2.5	2.3
0.46	1.509	21.2	10.6	7.1	5.3	4.2	3.5	3.0	2.6	2.4
0.47	1.542	22.1	11.1	7.4	5.5	4.4	3.7	3.2	2.8	2.5
0.48	1.575	23.1	11.5	7.7	5.8	4.6	3.8	3.3	2.9	2.6
0.49	1.608	24.1	12.0	8.0	6.0	4.8	4.0	3.4	3.0	2.7
0.50	1.640	25.1	12.5	8.3	6.3	5.0	4.2	3.6	3.1	2.8
0.51	1.673	26.1	13.0	8.7	6.5	5.2	4.3	3.7	3.3	2.9
0.52	1.706	27.1	13.5	9.0	6.8	5.4	4.5	3.9	3.4	3.0
0.53	1.739	28.2	14.1	9.4	7.0	5.6	4.7	4.0	3.5	3.1
0.54	1.772	29.2	14.6	9.7	7.3	5.8	4.9	4.2	3.6	3.2
0.55	1.804	30.3	15.1	10.1	7.6	6.0	5.0	4.3	3.8	3.4
0.56	1.837	31.5	15.7	10.5	7.8	6.3	5.2	4.5	3.9	3.5
0.57	1.870	32.6	16.2	10.8	8.1	6.5	5.4	4.6	4.1	3.6
0.58	1.903	33.8	16.8	11.2	8.4	6.7	5.6	4.8	4.2	3.7
0.59	1.936	34.9	17.4	11.6	8.7	7.0	5.8	5.0	4.4	3.9
0.60	1.968	36.1	18.0	12.0	9.0	7.2	6.0	5.1	4.5	4.0
0.61	2.001	37.3	18.6	12.4	9.3	7.4	6.2	5.3	4.7	4.1
0.62	2.034	38.6	19.2	12.8	9.6	7.6	6.4	5.5	4.8	4.3
0.63	2.067	39.8	19.8	13.2	9.9	8.0	6.6	5.7	5.0	4.4
0.64	2.100	41.1	20.5	13.7	10.2	8.2	6.8	5.9	5.1	4.3
0.65	2.133	42.4	21.1	14.1	10.6	8.4	7.0	6.0	5.3	4.7

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Inclination corrections for 5, 10, 15, 20, 25, 30, 35, 40, and 45 meter lengths—Continued.

Difference in elevation		Length in meters								
		5	10	15	20	25	30	35	40	45
Meters	*Feet*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
0.66	2.165	43.8	21.8	14.5	10.9	8.7	7.3	6.2	5.4	4.8
0.67	2.198	45.1	22.5	15.0	11.2	9.0	7.5	6.4	5.6	5.0
0.68	2.231	46.5	23.2	15.4	11.6	9.2	7.7	6.6	5.8	5.2
0.69	2.264	47.8	23.8	15.9	11.9	9.5	7.9	6.8	6.0	5.3
0.70	2.297	49.2	24.5	16.3	12.3	9.8	8.2	7.0	6.1	5.4
0.71	2.329	50.7	25.2	16.8	12.6	10.1	8.4	7.2	6.3	5.6
0.72	2.362	52.1	25.9	17.3	13.0	10.4	8.6	7.4	6.5	5.8
0.73	2.395	53.6	26.6	17.8	13.3	10.7	8.9	7.6	6.7	5.9
0.74	2.428	55.1	27.4	18.3	13.7	11.0	9.1	7.8	6.8	6.1
0.75	2.461	56.6	28.1	18.8	14.1	11.3	9.4	8.0	7.0	6.3
0.76	2.493	58.1	28.9	19.3	14.4	11.6	9.6	8.3	7.2	6.4
0.77	2.526	59.6	29.7	19.8	14.8	11.9	9.9	8.5	7.4	6.6
0.78	2.559	61.2	30.5	20.3	15.2	12.2	10.1	8.7	7.6	6.8
0.79	2.592	62.8	31.3	20.8	15.6	12.5	10.4	8.9	7.8	6.9
0.80	2.625	64.4	32.1	21.4	16.0	12.8	10.7	9.1	8.0	7.1
0.81	2.657	66.0	32.9	21.9	16.4	13.1	10.9	9.4	8.2	7.3
0.82	2.690	67.7	33.7	22.4	16.8	13.4	11.2	9.6	8.4	7.5
0.83	2.723	69.4	34.5	23.0	17.2	13.7	11.5	9.8	8.6	7.7
0.84	2.756	71.1	35.3	23.5	17.6	14.1	11.8	10.1	8.8	7.8
0.85	2.789	72.8	36.2	24.1	18.1	14.5	12.0	10.3	9.0	8.0
0.86	2.822	74.5	37.0	24.7	18.5	14.8	12.3	10.6	9.2	8.2
0.87	2.854	76.3	37.9	25.2	18.9	15.1	12.6	10.8	9.5	8.4
0.88	2.887	78.0	38.8	25.8	19.4	15.5	12.9	11.1	9.7	8.6
0.89	2.920	79.8	39.7	26.4	19.8	15.8	13.2	11.3	9.9	8.8
0.90	2.953	81.7	40.6	27.0	20.3	16.2	13.5	11.6	10.1	9.0
0.91	2.986	83.5	41.5	27.6	20.7	16.6	13.8	11.8	10.4	9.2
0.92	3.018	85.4	42.4	28.2	21.2	16.9	14.1	12.1	10.6	9.4
0.93	3.051	87.3	43.3	28.8	21.6	17.3	14.4	12.4	10.8	9.6
0.94	3.084	89.2	44.3	29.5	22.1	17.7	14.7	12.6	11.0	9.8
0.95	3.117	91.1	45.2	30.1	22.6	18.1	15.0	12.9	11.3	10.0
0.96	3.150	93.0	46.2	30.8	23.1	18.5	15.4	13.2	11.5	10.2
0.97	3.182	95.0	47.2	31.4	23.5	18.8	15.7	13.4	11.8	10.5
0.98	3.215	97.0	48.1	32.0	24.0	19.2	16.0	13.7	12.0	10.7
0.99	3.248	99.0	49.1	32.7	24.5	19.6	16.3	14.0	12.3	10.9
1.00	3.281	101.0	50.1	33.3	25.0	20.0	16.7	14.3	12.5	11.1
1.01	3.314	103.1	51.1	34.0	25.5	20.4	17.0	14.6	12.8	11.3
1.02	3.346	105.1	52.2	34.7	26.0	20.8	17.3	14.9	13.0	11.6
1.03	3.379	107.2	53.2	35.4	26.5	21.2	17.7	15.2	13.3	11.8
1.04	3.412	109.4	54.2	36.1	27.0	21.6	18.0	15.5	13.5	12.0
1.05	3.445	111.5	55.3	36.8	27.6	22.1	18.4	15.8	13.8	12.2
1.06	3.478	113.6	56.3	37.5	28.1	22.5	18.7	16.1	14.0	12.5
1.07	3.510	115.8	57.4	38.2	28.6	22.9	19.1	16.4	14.3	12.7
1.08	3.543	118.0	58.5	38.9	29.2	23.4	19.4	16.7	14.6	13.0
1.09	3.576	120.2	59.6	39.6	29.7	23.8	19.8	17.0	14.9	13.2
1.10	3.609	122.5	60.7	40.4	30.3	24.2	20.2	17.3	15.1	13.4
1.11	3.642	124.8	61.8	41.1	30.8	24.6	20.5	17.6	15.4	13.7
1.12	3.675	127.1	62.9	41.9	31.4	25.0	20.9	17.9	15.7	13.9
1.13	3.707	129.4	64.1	42.6	31.9	25.5	21.3	18.2	16.0	14.2
1.14	3.740	131.7	65.2	43.3	32.5	26.0	21.7	18.6	16.2	14.4
1.15	3.773	134.0	66.3	44.1	33.1	26.4	22.0	18.9	16.5	14.7
1.16	3.806	136.4	67.5	44.9	33.7	26.9	22.4	19.2	16.8	14.9
1.17	3.839	138.8	68.7	45.7	34.3	27.4	22.8	19.6	17.1	15.2
1.18	3.871	141.2	69.9	46.5	34.8	27.9	23.2	19.9	17.4	15.5
1.19	3.904	143.7	71.1	47.3	35.4	28.3	23.6	20.2	17.7	15.7
1.20	3.937	146.1	72.3	48.1	36.0	28.8	24.0	20.6	18.0	16.0
1.21	3.970	148.6	73.5	48.9	36.6	29.3	24.4	20.9	18.3	16.3
1.22	4.003	151.1	74.7	49.7	37.2	29.8	24.8	21.3	18.6	16.5
1.23	4.035	153.7	75.9	50.5	37.9	30.3	25.2	21.6	18.9	16.8
1.24	4.068	156.2	77.1	51.3	38.5	30.8	25.6	22.0	19.2	17.1
1.25	4.101	158.8	78.4	52.2	39.1	31.2	26.0	22.3	19.5	17.4
1.26	4.134	161.4	79.7	53.0	39.7	31.7	26.5	22.7	19.8	17.6
1.27	4.167	164.0	81.0	53.8	40.4	32.3	26.9	23.0	20.2	17.9
1.28	4.199	166.6	82.3	54.7	41.0	32.8	27.3	23.4	20.5	18.2
1.29	4.232	169.3	83.6	55.6	41.6	33.3	27.7	23.8	20.8	18.5
1.30	4.265	172.0	84.9	56.4	42.3	33.8	28.2	24.1	21.1	18.8
1.31	4.298	174.7	86.2	57.3	42.9	34.4	28.6	24.5	21.5	19.1
1.32	4.331	177.4	87.5	58.2	43.6	34.9	29.0	24.9	21.8	19.4
1.33	4.364	180.1	88.8	59.1	44.3	35.4	29.5	25.3	22.1	19.7
1.34	4.396	182.9	90.2	60.0	44.9	35.9	29.9	25.6	22.4	19.9
1.35	4.429	185.7	91.5	60.9	45.6	36.5	30.4	26.0	22.8	20.2

Inclination corrections for 5, 10, 15, 20, 25, 30, 35, 40, and 45 meter lengths—Continued

Difference in elevation		Length in meters								
		5	10	15	20	25	30	35	40	45
Meters	*Feet*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
1.36	4.462	188.5	92.9	61.8	46.3	37.0	30.8	26.4	23.1	20.5
1.37	4.495	191.4	94.3	62.7	47.0	37.6	31.3	26.8	23.5	20.8
1.38	4.528	194.2	95.7	63.6	47.7	38.2	31.7	27.2	23.8	21.2
1.39	4.560	197.1	97.1	64.5	48.4	38.7	32.2	27.6	24.2	21.5
1.40	4.593	200.0	98.5	65.5	49.1	39.3	32.7	28.0	24.5	21.8
1.41	4.626	202.9	99.9	66.4	49.8	39.8	33.1	28.4	24.9	22.1
1.42	4.659	205.9	101.3	67.3	50.5	40.4	33.6	28.8	25.2	22.4
1.43	4.692	208.9	102.8	68.3	51.2	40.9	34.1	29.2	25.6	22.7
1.44	4.724	211.8	104.2	69.3	51.9	41.5	34.6	29.6	25.9	23.0
1.45	4.757	214.9	105.7	70.2	52.6	42.1	35.0	30.0	26.3	23.4
1.46	4.790	217.9	107.2	71.2	53.4	42.7	35.5	30.5	26.6	23.7
1.47	4.823	221.0	108.6	72.2	54.1	43.3	36.0	30.9	27.0	24.0
1.48	4.856	224.1	110.1	73.2	54.8	43.9	36.5	31.3	27.4	24.3
1.49	4.888	227.2	111.6	74.2	55.6	44.5	37.0	31.7	27.8	24.7
1.50	4.921	230.3	113.1	75.2	56.3	45.1	37.5	32.1	28.1	25.0
1.51	4.954	233.5	114.7	76.2	57.1	45.7	38.0	32.6	28.5	25.3
1.52	4.987	236.6	116.2	77.2	57.8	46.3	38.5	33.0	28.9	25.7
1.53	5.020	239.8	117.7	78.2	58.6	46.9	39.0	33.4	29.3	26.0
1.54	5.052	243.1	119.3	79.3	59.4	47.5	39.5	33.9	29.6	26.3
1.55	5.085	246.3	120.8	80.3	60.2	48.1	40.0	34.3	30.0	26.7
1.56	5.118	249.6	122.4	81.3	60.9	48.8	40.6	34.8	30.4	27.0
1.57	5.151	252.9	124.0	82.4	61.7	49.4	41.1	35.2	30.8	27.4
1.58	5.184	256.2	125.6	83.4	62.5	50.0	41.6	35.7	31.2	27.7
1.59	5.217	259.5	127.2	84.5	63.3	50.6	42.1	36.1	31.6	28.1
1.60	5.249	262.9	128.8	85.6	64.1	51.3	42.7	36.6	32.0	28.4
1.61	5.282	266.3	130.4	86.6	64.9	52.0	43.2	37.0	32.4	28.8
1.62	5.315	269.7	132.1	87.7	65.7	52.6	43.7	37.5	32.8	29.2
1.63	5.348	273.2	133.7	88.8	66.5	53.3	44.3	38.0	33.2	29.5
1.64	5.381	276.6	135.4	89.9	67.4	53.9	44.8	38.4	33.6	29.9
1.65	5.413	280.1	137.0	91.0	68.2	54.6	45.4	38.9	34.0	30.3
1.66	5.446	283.6	138.7	92.1	69.0	55.2	45.9	39.4	34.4	30.6
1.67	5.479	287.1	140.4	93.2	69.8	55.9	46.5	39.8	34.9	31.0
1.68	5.512	290.7	142.1	94.4	70.7	56.5	47.0	40.3	35.3	31.4
1.69	5.545	294.3	143.8	95.5	71.5	57.2	47.6	40.8	35.7	31.7
1.70	5.577	297.9	145.5	96.6	72.4	57.9	48.2	41.3	36.1	32.1
1.71	5.610	301.5	147.3	97.8	73.2	58.6	48.7	41.8	36.6	32.5
1.72	5.643	305.2	149.0	98.9	74.1	59.3	49.3	42.3	37.0	32.9
1.73	5.676	308.8	150.8	100.1	75.0	59.9	49.9	42.8	37.4	33.2
1.74	5.709	312.5	152.5	101.2	75.8	60.6	50.5	43.3	37.8	33.6
1.75	5.741	316.2	154.3	102.4	76.7	61.3	51.0	43.8	38.3	34.0
1.76	5.774	320.0	156.1	103.6	77.6	62.0	51.6	44.3	38.7	34.4
1.77	5.807	323.8	157.9	104.8	78.5	62.7	52.2	44.8	39.2	34.8
1.78	5.840	327.6	159.7	106.0	79.4	63.5	52.8	45.3	39.6	35.2
1.79	5.873	331.4	161.5	107.2	80.3	64.2	53.4	45.8	40.1	35.6
1.80	5.906	335.2	163.3	108.4	81.2	64.9	54.0	46.3	40.5	36.0
1.81	5.938	339.1	165.1	109.6	82.1	65.6	54.6	46.8	41.0	36.4
1.82	5.971	343.0	167.0	110.8	83.0	66.3	55.2	47.3	41.4	36.8
1.83	6.004	346.9	168.8	112.0	83.9	67.1	55.8	47.8	41.9	37.2
1.84	6.037	350.9	170.7	113.3	84.8	67.8	56.4	48.4	42.3	37.6
1.85	6.070	354.8	172.6	114.5	85.7	68.5	57.0	48.9	42.8	38.0
1.86	6.102	358.8	174.5	115.8	86.7	69.2	57.7	49.4	43.2	38.4
1.87	6.135	362.9	176.4	117.0	87.6	70.0	58.3	50.0	43.7	38.9
1.88	6.168	366.9	178.3	118.3	88.6	70.8	59.0	50.5	44.2	39.3
1.89	6.201	371.0	180.2	119.6	89.5	71.5	59.6	51.0	44.7	39.7
1.90	6.234	375.1	182.2	120.8	90.5	72.3	60.2	51.6	45.1	40.1
1.91	6.266	379.2	184.1	122.1	91.4	73.1	60.8	52.1	45.6	40.5
1.92	6.299	383.3	186.1	123.4	92.4	73.9	61.4	52.7	46.1	41.0
1.93	6.332	387.5	188.0	124.7	93.3	74.6	62.1	53.2	46.6	41.4
1.94	6.365	391.7	190.0	126.0	94.3	75.4	62.7	53.8	47.0	41.8
1.95	6.398	395.9	192.0	127.3	95.3	76.2	63.4	54.3	47.5	42.2
1.96	6.430	400.2	194.0	128.6	96.3	76.9	64.0	54.9	48.0	42.7
1.97	6.463	404.4	196.0	129.9	97.3	77.7	64.7	55.4	48.5	43.1
1.98	6.496	408.7	198.0	131.2	98.3	78.5	65.3	56.0	49.0	43.6
1.99	6.529	413.1	200.0	132.6	99.3	79.3	66.0	56.6	49.5	44.0
2.00	6.562	417.4	202.0	133.9	100.3	80.1	66.7	57.2	50.0	44.4

Factors for computing catenary correction

[Combined side and top arguments=weight of tape in grams per meter. Tabular values $=\frac{1}{24}\left(\frac{w}{t}\right)^2\times10^w$ when t=15,000 grams. To obtain catenary correction between supports multiply by cube of length between supports and point off 10 decimal places]

	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
20	741	748	756	763	771	778	786	794	801	809
21	817	824	832	840	848	856	864	872	880	888
22	896	904	913	921	929	938	946	954	963	971
23	980	988	997	1,005	1,014	1,023	1,031	1,040	1,049	1,058
24	1,067	1,076	1,085	1,094	1,103	1,112	1,121	1,130	1,139	1,148
25	1,157	1,167	1,176	1,185	1,195	1,204	1,214	1,223	1,233	1,242
26	1,252	1,262	1,271	1,281	1,291	1,300	1,310	1,320	1,330	1,340
27	1,350	1,360	1,370	1,380	1,390	1,400	1,411	1,421	1,431	1,442
28	1,452	1,462	1,473	1,483	1,494	1,504	1,515	1,525	1,536	1,547
29	1,557	1,568	1,579	1,590	1,601	1,612	1,623	1,634	1,645	1,656
30	1,667									

Catenary corrections for various lengths and weights of tape

Length of tape (meters)	Weight of tape in grams per meter									
	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8	20.9
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
15	0.25	0.25	0.26	0.26	0.26	0.26	0.27	0.27	0.27	0.27
20	0.59	0.60	0.60	0.61	0.62	0.62	0.63	0.63	0.64	0.65
25	1.16	1.17	1.18	1.19	1.20	1.22	1.23	1.24	1.25	1.26
30	2.00	2.02	2.04	2.06	2.08	2.10	2.12	2.14	2.16	2.18
35	3.18	3.21	3.24	3.27	3.30	3.34	3.37	3.40	3.44	3.47
40	4.74	4.79	4.84	4.88	4.93	4.98	5.03	5.08	5.13	5.18
45	6.75	6.82	6.89	6.95	7.02	7.09	7.16	7.23	7.30	7.37
50	9.26	9.35	9.45	9.54	9.63	9.73	9.82	9.92	10.01	10.11
	21.0	21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8	21.9
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09
15	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.29	0.30	0.30
20	0.65	0.66	0.67	0.67	0.68	0.68	0.69	0.70	0.70	0.71
25	1.28	1.29	1.30	1.31	1.33	1.34	1.35	1.36	1.38	1.39
30	2.21	2.23	2.25	2.27	2.29	2.31	2.33	2.35	2.38	2.40
35	3.50	3.53	3.57	3.60	3.64	3.67	3.70	3.74	3.77	3.81
40	5.23	5.28	5.33	5.38	5.43	5.48	5.53	5.58	5.63	5.68
45	7.44	7.51	7.58	7.66	7.73	7.80	7.87	7.95	8.02	8.09
50	10.21	10.31	10.40	10.50	10.60	10.70	10.80	10.90	11.00	11.10
	22.0	22.1	22.2	22.3	22.4	22.5	22.6	22.7	22.8	22.9
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10
15	0.30	0.31	0.31	0.31	0.31	0.32	0.32	0.32	0.32	0.33
20	0.72	0.72	0.73	0.74	0.74	0.75	0.76	0.76	0.77	0.78
25	1.40	1.41	1.43	1.44	1.45	1.46	1.48	1.49	1.50	1.52
30	2.42	2.44	2.46	2.49	2.51	2.53	2.55	2.58	2.60	2.62
35	3.84	3.88	3.91	3.95	3.98	4.02	4.06	4.09	4.13	4.16
40	5.74	5.79	5.84	5.89	5.95	6.00	6.05	6.11	6.16	6.22
45	8.17	8.24	8.32	8.39	8.47	8.54	8.62	8.70	8.77	8.85
50	11.20	11.31	11.41	11.51	11.61	11.72	11.82	11.93	12.03	12.14
	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7	23.8	23.9
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11
15	0.33	0.33	0.34	0.34	0.34	0.35	0.35	0.35	0.35	0.36
20	0.78	0.79	0.80	0.80	0.81	0.82	0.83	0.83	0.84	0.85
25	1.53	1.54	1.56	1.57	1.58	1.60	1.61	1.63	1.64	1.65
30	2.65	2.67	2.69	2.71	2.74	2.76	2.78	2.81	2.83	2.86
35	4.20	4.24	4.27	4.31	4.35	4.38	4.42	4.46	4.50	4.54
40	6.27	6.32	6.38	6.43	6.49	6.55	6.60	6.66	6.71	6.77
45	8.93	9.00	9.08	9.16	9.24	9.32	9.40	9.48	9.56	9.64
50	12.25	12.35	12.46	12.57	12.68	12.78	12.89	13.00	13.11	13.22

Catenary corrections for various lengths and weights of tape—Continued

Length of tape (meters)	Weight of tape in grams per meter									
	24.0	24.1	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.9
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
15	0.36	0.36	0.37	0.37	0.37	0.38	0.38	0.38	0.38	0.39
20	0.85	0.86	0.87	0.87	0.88	0.89	0.90	0.90	0.91	0.92
25	1.67	1.68	1.69	1.71	1.72	1.74	1.75	1.77	1.78	1.79
30	2.88	2.90	2.93	2.95	2.98	3.00	3.03	3.05	3.08	3.10
35	4.57	4.61	4.65	4.69	4.73	4.77	4.80	4.84	4.88	4.92
40	6.83	6.88	6.94	7.00	7.06	7.11	7.17	7.23	7.29	7.35
45	9.72	9.80	9.88	9.96	10.05	10.13	10.21	10.30	10.38	10.46
50	13.33	13.44	13.56	13.67	13.78	13.89	14.01	14.12	14.24	14.35
	25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25.8	25.9
5	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
10	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
15	0.39	0.39	0.40	0.40	0.40	0.41	0.41	0.41	0.42	0.42
20	0.93	0.93	0.94	0.95	0.96	0.96	0.97	0.98	0.99	0.99
25	1.81	1.82	1.84	1.85	1.87	1.88	1.90	1.91	1.93	1.94
30	3.13	3.15	3.18	3.20	3.23	3.25	3.28	3.30	3.33	3.35
35	4.96	5.00	5.04	5.08	5.12	5.16	5.20	5.24	5.29	5.33
40	7.41	7.47	7.53	7.59	7.65	7.71	7.77	7.83	7.89	7.95
45	10.55	10.63	10.72	10.80	10.89	10.97	11.06	11.15	11.23	11.32
50	14.47	14.58	14.70	14.82	14.93	15.05	15.17	15.29	15.41	15.53
	26.0	26.1	26.2	26.3	26.4	26.5	26.6	26.7	26.8	26.9
5	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
15	0.42	0.43	0.43	0.43	0.44	0.44	0.44	0.45	0.45	0.45
20	1.00	1.01	1.02	1.02	1.03	1.04	1.05	1.06	1.06	1.07
25	1.96	1.97	1.99	2.00	2.02	2.03	2.05	2.06	2.08	2.09
30	3.38	3.41	3.43	3.46	3.48	3.51	3.54	3.56	3.59	3.62
35	5.37	5.41	5.45	5.49	5.53	5.58	5.62	5.66	5.70	5.75
40	8.01	8.07	8.14	8.20	8.26	8.32	8.39	8.45	8.51	8.58
45	11.41	11.50	11.58	11.67	11.76	11.85	11.94	12.03	12.12	12.21
50	15.65	15.77	15.89	16.01	16.13	16.26	16.38	16.50	16.63	16.75
	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9
5	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
15	0.46	0.46	0.46	0.47	0.47	0.47	0.48	0.48	0.48	0.49
30	1.08	1.09	1.10	1.10	1.11	1.12	1.13	1.14	1.14	1.15
25	2.11	2.13	2.14	2.16	2.17	2.19	2.20	2.22	2.24	2.25
30	3.64	3.67	3.70	3.73	3.75	3.78	3.81	3.84	3.86	3.89
35	5.79	5.83	5.87	5.92	5.96	6.00	6.05	6.09	6.14	6.18
40	8.64	8.70	8.77	8.83	8.90	8.96	9.03	9.09	9.16	9.23
45	12.30	12.39	12.48	12.58	12.67	12.76	12.85	12.95	13.04	13.14
50	16.88	17.00	17.13	17.25	17.38	17.51	17.63	17.76	17.89	18.02
	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9
5	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
15	0.49	0.49	0.50	0.50	0.50	0.51	0.51	0.51	0.52	0.52
20	1.16	1.17	1.18	1.19	1.19	1.20	1.21	1.22	1.23	1.24
25	2.27	2.28	2.30	2.32	2.33	2.35	2.37	2.38	2.40	2.42
30	3.92	3.95	3.98	4.00	4.03	4.06	4.09	4.12	4.15	4.18
35	6.22	6.27	6.31	6.36	6.40	6.45	6.49	6.54	6.59	6.63
40	9.29	9.36	9.43	9.49	9.56	9.63	9.69	9.76	9.83	9.90
45	13.23	13.32	13.42	13.52	13.61	13.71	13.80	13.90	14.00	14.09
50	18.15	18.28	18.41	18.54	18.67	18.80	18.93	19.07	19.20	19.33
	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9
5	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17
15	0.53	0.53	0.53	0.54	0.54	0.54	0.55	0.55	0.56	0.56
20	1.25	1.25	1.26	1.27	1.28	1.29	1.30	1.31	1.32	1.32
25	2.43	2.45	2.47	2.48	2.50	2.52	2.54	2.55	2.57	2.59
30	4.21	4.23	4.26	4.29	4.32	4.35	4.38	4.41	4.44	4.47
35	6.68	6.72	6.77	6.82	6.86	6.91	6.96	7.00	7.05	7.10
40	9.97	10.04	10.11	10.17	10.24	10.31	10.38	10.45	10.52	10.60
45	14.19	14.29	14.39	14.49	14.59	14.69	14.79	14.89	14.99	15.09
50	19.47	19.60	19.74	19.87	20.01	20.14	20.28	20.42	20.56	20.69

Temperature corrections for steel tapes

Coefficient of expansion = 0.0000116 per degree centigrade. Standard temperature of tape = 20 degrees centigrade. For temperatures above 20 the corrections are plus, for temperatures below 20 the corrections are minus.

Length of tape (meters)	Temperature of tape in degrees centigrade																								
	19 21	18 22	17 23	16 24	15 25	14 26	13 27	12 28	11 29	10 30	9 31	8 32	7 33	6 34	5 35	4 36	3 37	2 38	1 39	0 40	−1 41	−2 42	−3 43	−4 44	−5 45
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
2	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6
3	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9
4	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2
5	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.3	1.4	1.4
6	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7
7	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2.0	2.0
8	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.2	2.3
9	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6
10	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9
11	0.1	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.1	3.2
12	0.1	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.3	1.4	1.5	1.7	1.8	1.9	2.1	2.2	2.4	2.5	2.6	2.8	2.9	3.1	3.2	3.3	3.5
13	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1	2.3	2.4	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.8
14	0.2	0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.5	1.6	1.8	1.9	2.1	2.3	2.4	2.6	2.8	2.9	3.1	3.2	3.4	3.6	3.7	3.9	4.1
15	0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3.0	3.1	3.3	3.5	3.7	3.8	4.0	4.2	4.4
16	0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.6
17	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9
18	0.2	0.4	0.6	0.8	1.0	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2
19	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.2	2.4	2.6	2.9	3.1	3.3	3.5	3.7	4.0	4.2	4.4	4.6	4.8	5.1	5.3	5.5
20	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	2.3	2.6	2.8	3.0	3.2	3.5	3.7	3.9	4.2	4.4	4.6	4.9	5.1	5.3	5.6	5.8
21	0.2	0.5	0.7	1.0	1.2	1.5	1.7	1.9	2.2	2.4	2.7	2.9	3.2	3.4	3.7	3.9	4.1	4.4	4.6	4.9	5.1	5.4	5.6	5.8	6.1
22	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.6	2.8	3.1	3.3	3.6	3.8	4.1	4.3	4.6	4.8	5.1	5.4	5.6	5.9	6.1	6.4
23	0.3	0.5	0.8	1.1	1.3	1.6	1.9	2.1	2.4	2.7	2.9	3.2	3.5	3.7	4.0	4.3	4.5	4.8	5.1	5.3	5.6	5.9	6.1	6.4	6.7
24	0.3	0.6	0.8	1.1	1.4	1.7	1.9	2.2	2.5	2.8	3.1	3.3	3.6	3.9	4.2	4.5	4.7	5.0	5.3	5.6	5.8	6.1	6.4	6.7	7.0
25	0.3	0.6	0.9	1.2	1.4	1.7	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.2
26	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6.0	6.3	6.6	6.9	7.2	7.5
27	0.3	0.6	0.9	1.3	1.6	1.9	2.2	2.5	2.8	3.1	3.4	3.8	4.1	4.4	4.7	5.0	5.3	5.6	6.0	6.3	6.6	6.9	7.2	7.5	7.8
28	0.3	0.6	1.0	1.3	1.6	1.9	2.3	2.6	2.9	3.2	3.6	3.9	4.2	4.5	4.9	5.2	5.5	5.8	6.2	6.5	6.8	7.1	7.5	7.8	8.1
29	0.3	0.7	1.0	1.3	1.7	2.0	2.4	2.7	3.0	3.4	3.7	4.0	4.4	4.7	5.0	5.4	5.7	6.1	6.4	6.7	7.1	7.4	7.7	8.1	8.4
30	0.3	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1	3.5	3.8	4.2	4.5	4.9	5.2	5.6	5.9	6.3	6.6	7.0	7.3	7.7	8.0	8.4	8.7

Proportional change in a number corresponding to a change in its logarithm

[Computed from the formula $\frac{\Delta N}{N}=\frac{\Delta \log N}{\mu}$, where μ=modulus of common logarithms=0.4343]

$\Delta \log N$ units of seventh decimal place	$\frac{\Delta N}{N}$ one part in—	$\Delta \log N$ units of seventh decimal place	$\frac{\Delta N}{N}$ one part in—	$\Delta \log N$ units of seventh decimal place	$\frac{\Delta N}{N}$ one part in—	$\Delta \log N$ units of seventh decimal place	$\frac{\Delta N}{N}$ one part in—
1	4,343,000	26	167,000	51	85,000	76	57,100
2	2,171,000	27	161,000	52	84,000	77	56,400
3	1,448,000	28	155,000	53	82,000	78	55,700
4	1,086,000	29	150,000	54	80,000	79	55,000
5	869,000	30	145,000	55	79,000	80	54,300
6	724,000	31	140,000	56	78,000	81	53,600
7	620,000	32	136,000	57	76,000	82	53,000
8	543,000	33	132,000	58	75,000	83	52,300
9	483,000	34	128,000	59	74,000	84	51,700
10	434,000	35	124,000	60	72,000	85	51,100
11	395,000	36	121,000	61	71,000	86	50,500
12	362,000	37	117,000	62	70,000	87	49,900
13	334,000	38	114,000	63	69,000	88	49,400
14	310,000	39	111,000	64	68,000	89	48,800
15	290,000	40	109,000	65	67,000	90	48,300
16	271,000	41	106,000	66	66,000	91	47,700
17	255,000	42	103,000	67	65,000	92	47,200
18	241,000	43	101,000	68	64,000	93	46,700
19	229,000	44	99,000	69	63,000	94	46,200
20	217,000	45	97,000	70	62,000	95	45,700
21	207,000	46	94,000	71	61,000	96	45,200
22	197,000	47	92,000	72	60,000	97	44,800
23	189,000	48	90,000	73	59,000	98	44,300
24	181,000	49	89,000	74	58,700	99	43,900
25	174,000	50	87,000	75	57,900	100	43,400

Computation of seconds, directions observed with two-micrometer theodolite

[Combined side and top arguments=sum of seconds obtained as described on p. 70]

	0	1	2	3	4	5	6	7	8	9
0	.0	0.1	0.2	0.4	0.5	0.6	0.8	0.9	1.0	1.1
10	1.2	1.4	1.5	1.6	1.8	1.9	2.0	2.1	2.2	2.4
20	2.5	2.6	2.8	2.9	3.0	3.1	3.2	3.4	3.5	3.6
30	3.8	3.9	4.0	4.1	4.2	4.4	4.5	4.6	4.8	4.9
40	5.0	5.1	5.2	5.4	5.5	5.6	5.8	5.9	6.0	6.1
50	6.2	6.4	6.5	6.6	6.8	6.9	7.0	7.1	7.2	7.4
60	7.5	7.6	7.8	7.9	8.0	8.1	8.2	8.4	8.5	8.6
70	8.8	8.9	9.0	9.1	9.2	9.4	9.5	9.6	9.8	9.9
80	10.0	10.1	10.2	10.4	10.5	10.6	10.8	10.9	11.0	11.1
90	11.2	11.4	11.5	11.6	11.8	11.9	12.0	12.1	12.2	12.4
100	12.5	12.6	12.8	12.9	13.0	13.1	13.2	13.4	13.5	13.6
110	13.8	13.9	14.0	14.1	14.2	14.4	14.5	14.6	14.8	14.9
120	15.0	15.1	15.2	15.4	15.5	15.6	15.8	15.9	16.0	16.1
130	16.2	16.4	16.5	16.6	16.8	16.9	17.0	17.1	17.2	17.4
140	17.5	17.6	17.8	17.9	18.0	18.1	18.2	18.4	18.5	18.6
150	18.8	18.9	19.0	19.1	19.2	19.4	19.5	19.6	19.8	19.9
160	20.0	20.1	20.2	20.4	20.5	20.6	20.8	20.9	21.0	21.1
170	21.2	21.4	21.5	21.6	21.8	21.9	22.0	22.1	22.2	22.4
180	22.5	22.6	22.8	22.9	23.0	23.1	23.2	23.4	23.5	23.6
190	23.8	23.9	24.0	24.1	24.2	24.4	24.5	24.6	24.8	24.9
200	25.0	25.1	25.2	25.4	25.5	25.6	25.8	25.9	26.0	26.1
210	26.2	26.4	26.5	26.6	26.8	26.9	27.0	27.1	27.2	27.4
220	27.5	27.6	27.8	27.9	28.0	28.1	28.2	28.4	28.5	28.6
230	28.8	28.9	29.0	29.1	29.2	29.4	29.5	29.6	29.8	29.9
240	30.0	30.1	30.2	30.4	30.5	30.6	30.8	30.9	31.0	31.1
250	31.2	31.4	31.5	31.6	31.8	31.9	32.0	32.1	32.2	32.4
260	32.5	32.6	32.8	32.9	33.0	33.1	33.2	33.4	33.5	33.6
270	33.8	33.9	34.0	34.1	34.2	34.4	34.5	34.6	34.8	34.9
280	35.0	35.1	35.2	35.4	35.5	35.6	35.8	35.9	36.0	36.1
290	36.2	36.4	36.5	36.6	36.8	36.9	37.0	37.1	37.2	37.4

Computation of seconds, directions observed with two-micrometer theodolite—Continued

	0	1	2	3	4	5	6	7	8	9
300	37.5	37.6	37.8	37.9	38.0	38.1	38.2	38.4	38.5	38.6
310	38.8	38.9	39.0	39.1	39.2	39.4	39.5	39.6	39.8	39.9
320	40.0	40.1	40.2	40.4	40.5	40.6	40.8	40.9	41.0	41.1
330	41.2	41.4	41.5	41.6	41.8	41.9	42.0	42.1	42.2	42.4
340	42.5	42.6	42.8	42.9	43.0	43.1	43.2	43.4	43.5	43.6
350	43.8	43.9	44.0	44.1	44.2	44.4	44.5	44.6	44.8	44.9
360	45.0	45.1	45.2	45.4	45.5	45.6	45.8	45.9	46.0	46.1
370	46.2	46.4	46.5	46.6	46.8	46.9	47.0	47.1	47.2	47.4
380	47.5	47.6	47.8	47.9	48.0	48.1	48.2	48.4	48.5	48.6
390	48.8	48.9	49.0	49.1	49.2	49.4	49.5	49.6	49.8	49.9
400	50.0	50.1	50.2	50.4	50.5	50.6	50.8	50.9	51.0	51.1
410	51.2	51.4	51.5	51.6	51.8	51.9	52.0	52.1	52.2	52.4
420	52.5	52.6	52.8	52.9	53.0	53.1	53.2	53.4	53.5	53.6
430	53.8	53.9	54.0	54.1	54.2	54.4	54.5	54.6	54.8	54.9
440	55.0	55.1	55.2	55.4	55.5	55.6	55.8	55.9	56.0	56.1
450	56.2	56.4	56.5	56.6	56.8	56.9	57.0	57.1	57.2	57.4
460	57.5	57.6	57.8	57.9	58.0	58.1	58.2	58.4	58.5	58.6
470	58.8	58.9	59.0	59.1	59.2	59.4	59.5	59.6	59.8	59.9
480	60.0									

Computation of seconds, directions observed with three-micrometer theodolite

[Combined side and top arguments=sum of seconds obtained as described on p. 70. For sums greater than 360, use right-hand argument and add 30 to the tabular values]

	0	1	2	3	4	5	6	7	8	9	
0	0.0	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	360
10	0.8	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	370
20	1.7	1.8	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.4	380
30	2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.2	3.2	390
40	3.3	3.4	3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	400
50	4.2	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.8	4.9	410
60	5.0	5.1	5.2	5.2	5.3	5.4	5.5	5.6	5.7	5.8	420
70	5.8	5.9	6.0	6.1	6.2	6.2	6.3	6.4	6.5	6.6	430
80	6.7	6.8	6.8	6.9	7.0	7.1	7.2	7.2	7.3	7.4	440
90	7.5	7.6	7.7	7.8	7.8	7.9	8.0	8.1	8.2	8.2	450
100	8.3	8.4	8.5	8.6	8.7	8.8	8.8	8.9	9.0	9.1	460
110	9.2	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.8	9.9	470
120	10.0	10.1	10.2	10.2	10.3	10.4	10.5	10.6	10.7	10.8	480
130	10.8	10.9	11.0	11.1	11.2	11.2	11.3	11.4	11.5	11.6	490
140	11.7	11.8	11.8	11.9	12.0	12.1	12.2	12.2	12.3	12.4	500
150	12.5	12.6	12.7	12.8	12.8	12.9	13.0	13.1	13.2	13.2	510
160	13.3	13.4	13.5	13.6	13.7	13.8	13.8	13.9	14.0	14.1	520
170	14.2	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.8	14.9	530
180	15.0	15.1	15.2	15.2	15.3	15.4	15.5	15.6	15.7	15.8	540
190	15.8	15.9	16.0	16.1	16.2	16.2	16.3	16.4	16.5	16.6	550
200	16.7	16.8	16.8	16.9	17.0	17.1	17.2	17.2	17.3	17.4	560
210	17.5	17.6	17.7	17.8	17.8	17.9	18.0	18.1	18.2	18.2	570
220	18.3	18.4	18.5	18.6	18.7	18.8	18.8	18.9	19.0	19.1	580
230	19.2	19.2	19.3	19.4	19.5	19.6	19.7	19.8	19.8	19.9	590
240	20.0	20.1	20.2	20.2	20.3	20.4	20.5	20.6	20.7	20.8	600
250	20.8	20.9	21.0	21.1	21.2	21.2	21.3	21.4	21.5	21.6	610
260	21.7	21.8	21.8	21.9	22.0	22.1	22.2	22.2	22.3	22.4	620
270	22.5	22.6	22.7	22.8	22.8	22.9	23.0	23.1	23.2	23.2	630
280	23.3	23.4	23.5	23.6	23.7	23.8	23.8	23.9	24.0	24.1	640
290	24.2	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.8	24.9	650
300	25.0	25.1	25.2	25.2	25.3	25.4	25.5	25.6	25.7	25.8	660
310	25.8	25.9	26.0	26.1	26.2	26.2	26.3	26.4	26.5	26.6	670
320	26.7	26.8	26.8	26.9	27.0	27.1	27.2	27.2	27.3	27.4	680
330	27.5	27.6	27.7	27.8	27.8	27.9	28.0	28.1	28.2	28.2	690
340	28.3	28.4	28.5	28.6	28.7	28.8	28.8	28.9	29.0	29.1	700
350	29.2	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.8	29.9	710
360	30.0										720

Logarithms of radii of curvature of the earth's surface (in meters)

[Based upon Clarke's spheroid of 1866 as expressed in meters]

Azimuth (degrees)	Latitude								
	0°	1°	2°	3°	4°	5°	6°	7°	8°
0	6.80175	6.80175	6.80175	6.80176	6.80177	6.80178	6.80180	6.80181	6.80183
5	177	177	178	178	179	180	182	184	186
10	184	184	184	185	186	187	188	190	192
15	195	195	195	196	197	198	199	201	203
20	209	209	210	210	211	212	214	215	217
25	227	228	228	228	229	230	232	233	235
30	248	249	249	250	250	251	252	254	256
35	272	272	272	273	273	274	276	277	278
40	296	297	297	297	298	299	300	301	303
45	322	322	322	323	324	324	325	326	328
50	348	348	348	348	349	350	351	352	353
55	373	373	373	373	374	374	375	376	377
60	396	396	396	396	397	398	398	399	400
65	417	417	417	418	418	418	419	420	421
70	435	435	436	436	436	437	437	438	439
75	450	450	450	450	451	451	452	452	453
80	461	461	461	461	462	462	463	463	464
85	468	468	468	468	468	469	469	470	470
90	470	470	470	470	471	471	472	472	473

Azimuth (degrees)	Latitude								
	8°	9°	10°	11°	12°	13°	14°	15°	16°
0	6.80183	6.80186	6.80188	6.80191	6.80194	6.80197	6.80201	6.80204	6.80208
5	186	188	190	193	196	199	203	206	210
10	192	194	197	200	202	206	209	213	217
15	203	205	207	210	213	216	219	223	227
20	217	219	222	224	227	230	233	236	240
25	235	237	239	242	244	247	250	254	257
30	256	257	260	262	264	267	270	273	276
35	278	280	282	284	287	289	292	295	298
40	303	304	306	308	310	313	315	318	321
45	328	329	331	333	335	337	339	342	344
50	353	354	356	358	359	361	364	366	368
55	377	379	380	382	383	385	387	389	391
60	400	401	403	404	406	407	409	411	413
65	421	422	423	424	426	427	429	430	432
70	439	440	441	442	443	444	446	447	449
75	453	454	455	456	457	458	460	461	463
80	464	465	466	467	468	469	470	471	473
85	470	471	472	473	474	475	476	478	479
90	473	474	474	475	476	477	478	480	481

Azimuth (degrees)	Latitude								
	16°	17°	18°	19°	20°	21°	22°	23°	24°
0	6.80208	6.80213	6.80217	6.80222	6.80226	6.80232	6.80237	6.80242	6.80248
5	210	215	219	224	228	234	239	244	250
10	217	221	225	230	234	239	244	250	255
15	227	231	235	239	244	249	254	259	264
20	240	244	248	252	257	262	266	271	277
25	257	261	265	269	273	277	282	287	292
30	276	280	284	287	292	296	300	305	309
35	298	301	305	308	312	316	320	324	329
40	321	324	327	330	334	338	341	345	350
45	344	347	350	353	357	360	364	367	371
50	368	371	373	376	379	382	386	389	392
55	391	394	396	398	401	404	407	410	413
60	413	415	417	419	422	424	427	430	432
65	432	434	436	438	440	443	445	448	450
70	449	451	453	454	456	459	461	463	465
75	463	464	466	468	470	472	473	476	478
80	473	474	476	478	479	481	483	485	487
85	479	480	482	483	485	487	489	490	492
90	481	482	484	485	487	489	490	492	494

Logarithms of radii of curvature of the earth's surface (in meters)—Continued

Azimuth (degrees)	Latitude								
	24°	25°	26°	27°	28°	29°	30°	31°	32°
0	6.80248	6.80254	6.80260	6.80266	6.80272	6.80279	6.80285	6.80292	6.80299
5	250	256	262	268	274	280	287	294	300
10	255	261	267	273	279	285	292	298	305
15	264	270	276	282	288	294	300	306	313
20	277	282	288	293	299	305	311	317	324
25	292	297	302	308	313	319	325	331	337
30	309	314	319	324	330	335	340	346	352
35	329	333	338	343	348	353	358	363	369
40	350	354	358	362	367	372	377	382	386
45	371	375	379	383	387	391	396	400	405
50	392	396	399	403	407	411	415	419	423
55	413	416	420	423	426	430	434	437	441
60	432	435	438	442	445	448	451	455	458
65	450	453	455	458	461	464	467	470	473
70	465	468	470	473	475	478	481	484	486
75	478	480	482	484	487	489	492	494	497
80	487	489	491	493	495	498	500	502	505
85	492	494	496	498	501	503	505	507	510
90	494	496	498	500	502	504	507	509	511

Azimuth (degrees)	Latitude								
	32°	33°	34°	35°	36°	37°	38°	39°	40°
0	6.80299	6.80306	6.80313	6.80320	6.80327	6.80335	6.80342	6.80350	6.80357
5	300	307	314	322	329	336	344	351	359
10	305	312	319	326	333	340	348	355	363
15	313	320	326	333	340	348	355	362	369
20	324	330	337	343	350	357	364	371	378
25	337	343	349	355	362	368	375	382	388
30	352	358	364	370	376	382	388	394	401
35	369	374	380	385	391	397	402	408	414
40	386	392	397	402	407	412	418	423	429
45	405	410	414	419	424	429	434	439	444
50	423	428	432	436	441	445	450	454	459
55	441	445	449	453	457	461	465	469	474
60	458	462	465	469	472	476	480	484	487
65	473	476	480	483	486	489	493	496	500
70	486	489	492	495	498	501	504	507	510
75	497	500	502	505	508	510	513	516	519
80	505	507	510	512	515	517	520	523	525
85	510	512	514	517	519	522	524	527	529
90	511	514	516	518	521	523	526	528	531

Azimuth (degrees)	Latitude								
	40°	41°	42°	43°	44°	45°	46°	47°	48°
0	6.80357	6.80365	6.80373	6.80380	6.80388	6.80396	6.80404	6.80411	6.80419
5	359	366	374	382	389	397	404	412	420
10	363	370	378	385	393	400	408	415	423
15	369	376	384	391	398	406	413	420	428
20	378	385	392	399	406	413	420	427	434
25	388	395	402	408	415	422	429	436	442
30	401	407	413	420	426	433	439	446	452
35	414	420	426	432	438	444	450	456	462
40	429	434	440	446	451	457	462	468	474
45	444	449	454	459	464	470	475	480	485
50	459	464	468	473	478	482	487	492	496
55	474	478	482	486	490	495	499	503	508
60	487	491	495	499	502	506	510	514	518
65	500	503	507	510	514	517	520	524	528
70	510	514	517	520	523	526	529	532	536
75	519	522	525	528	531	534	536	539	542
80	525	528	531	534	536	539	542	544	547
85	529	532	534	537	540	542	545	548	550
90	531	533	536	538	541	544	546	549	551

Logarithms of radii of curvature of the earth's surface (in meters)—Continued

Azimuth (degrees)	Latitude								
	48°	49°	50°	51°	52°	53°	54°	55°	56°
0	6.80419	6.80426	6.80434	6.80442	6.80449	6.80457	6.80464	6.80471	6.80479
5	420	423	435	443	450	458	465	472	479
10	423	430	438	445	453	460	467	474	481
15	428	435	442	450	457	464	471	478	435
20	434	441	448	455	462	469	476	483	489
25	442	449	456	463	469	476	482	489	495
30	452	458	465	471	477	484	490	496	502
35	462	468	474	480	486	492	498	503	509
40	474	479	485	490	496	501	506	512	517
45	485	490	495	500	505	510	515	520	525
50	496	501	506	510	515	520	524	528	533
55	508	512	516	520	524	528	533	537	541
60	518	522	526	530	533	537	541	544	548
65	528	531	534	538	541	545	548	551	555
70	536	539	542	545	548	551	554	557	560
75	542	545	548	551	554	557	559	562	565
80	547	550	553	555	558	561	563	566	568
85	550	553	555	558	560	563	566	568	570
90	551	554	556	559	561	564	566	569	571

Azimuth (degrees)	Latitude								
	56°	57°	58°	59°	60°	61°	62°	63°	64°
0	6.80479	6.80486	6.80493	6.80500	6.80506	6.80513	6.80520	6.80526	6.80532
5	479	486	493	500	507	514	520	526	532
10	481	488	495	502	509	515	522	528	534
15	485	492	498	505	511	518	524	530	536
20	489	496	502	509	515	521	527	533	539
25	495	501	508	514	520	526	531	537	542
30	502	508	514	519	525	530	536	541	546
35	509	515	520	525	531	536	541	546	551
40	517	522	527	532	537	542	546	551	556
45	525	530	534	539	543	548	552	556	560
50	533	537	542	546	550	554	558	562	565
55	541	545	548	552	556	560	563	567	570
60	548	552	555	558	562	565	568	572	575
65	555	558	561	564	567	570	573	576	579
70	560	563	566	569	572	574	577	580	582
75	565	568	570	573	575	578	580	583	585
80	568	571	573	576	578	580	583	585	587
85	570	573	575	578	580	582	584	586	588
90	571	574	576	578	580	583	585	587	589

Azimuth (degrees)	Latitude								
	64°	65°	66°	67°	68°	69°	70°	71°	72°
0	6.80532	6.80538	6.80544	6.80550	6.80555	6.80560	6.80565	6.80570	6.80575
5	532	538	544	550	555	561	566	570	575
10	534	540	545	551	556	562	566	571	576
15	536	542	547	553	558	563	568	572	577
20	539	544	550	555	560	565	570	574	578
25	542	548	553	558	562	567	572	576	580
30	546	551	556	561	565	570	574	578	582
35	551	556	560	564	569	573	577	581	584
40	556	560	564	568	572	576	580	583	587
45	560	564	568	572	576	579	583	586	589
50	565	569	573	576	579	583	586	589	592
55	570	574	577	580	583	586	589	591	594
60	575	578	581	584	586	589	591	594	596
65	579	582	584	587	589	592	594	596	598
70	582	585	587	590	592	594	596	598	600
75	585	587	590	592	594	596	598	600	601
80	587	589	591	593	595	597	599	601	602
85	588	590	592	594	596	598	600	601	603
90	589	591	593	595	597	598	600	602	603

CONVERSION TABLES

Lengths—Feet to meters (from 1 to 1,000 units)

[Reduction factor: 1 foot=0.3048006096 meter]

Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
0	0.0	50	15.24003	100	30.48006	150	45.72009	200	60.96012
1	0.30480	1	15.54483	1	30.78486	1	46.02489	1	61.26492
2	0.60960	2	15.84963	2	31.08966	2	46.32969	2	61.56972
3	0.91440	3	16.15443	3	31.39446	3	46.63449	3	61.87452
4	1.21920	4	16.45923	4	31.69926	4	46.93929	4	62.17932
5	1.52400	5	16.76403	5	32.00406	5	47.24409	5	62.48412
6	1.82880	6	17.06883	6	32.30886	6	47.54890	6	62.78893
7	2.13360	7	17.37363	7	32.61367	7	47.85370	7	63.09373
8	2.43840	8	17.67844	8	32.91847	8	48.15850	8	63.39853
9	2.74321	9	17.98324	9	33.22327	9	48.46330	9	63.70333
10	3.04801	60	18.28804	110	33.52807	160	48.76810	210	64.00813
1	3.35281	1	18.59284	1	33.83287	1	49.07290	1	64.31293
2	3.65761	2	18.89764	2	34.13767	2	49.37770	2	64.61773
3	3.96241	3	19.20244	3	34.44247	3	49.68250	3	64.92253
4	4.26721	4	19.50724	4	34.74727	4	49.98730	4	65.22733
5	4.57201	5	19.81204	5	35.05207	5	50.29210	5	65.53213
6	4.87681	6	20.11684	6	35.35687	6	50.59690	6	65.83693
7	5.18161	7	20.42164	7	35.66167	7	50.90170	7	66.14173
8	5.48641	8	20.72644	8	35.96647	8	51.20650	8	66.44653
9	5.79121	9	21.03124	9	36.27127	9	51.51130	9	66.75133
20	6.09601	70	21.33604	120	36.57607	170	51.81610	220	67.05613
1	6.40081	1	21.64084	1	36.88087	1	52.12090	1	67.36093
2	6.70561	2	21.94564	2	37.18567	2	52.42570	2	67.66574
3	7.01041	3	22.25044	3	37.49047	3	52.73051	3	67.97054
4	7.31521	4	22.55525	4	37.79528	4	53.03531	4	68.27534
5	7.62002	5	22.86005	5	38.10008	5	53.34011	5	68.58014
6	7.92482	6	23.16485	6	38.40488	6	53.64491	6	68.88494
7	8.22962	7	23.46965	7	38.70968	7	53.94971	7	69.18974
8	8.53442	8	23.77445	8	39.01448	8	54.25451	8	69.49454
9	8.83922	9	24.07925	9	39.31928	9	54.55931	9	69.79934
30	9.14402	80	24.38405	130	39.62408	180	54.86411	230	70.10414
1	9.44882	1	24.68885	1	39.92888	1	55.16891	1	70.40894
2	9.75362	2	24.99365	2	40.23368	2	55.47371	2	70.71374
3	10.05842	3	25.29845	3	40.53848	3	55.77851	3	71.01854
4	10.36322	4	25.60325	4	40.84328	4	56.08331	4	71.32334
5	10.66802	5	25.90805	5	41.14808	5	56.38811	5	71.62814
6	10.97282	6	26.21285	6	41.45288	6	56.69291	6	71.93294
7	11.27762	7	26.51765	7	41.75768	7	56.99771	7	72.23774
8	11.58242	8	26.82245	8	42.06248	8	57.30251	8	72.54255
9	11.88722	9	27.12725	9	42.36728	9	57.60732	9	72.84735
40	12.19202	90	27.43205	140	42.67209	190	57.91212	240	73.15215
1	12.49682	1	27.73686	1	42.97689	1	58.21692	1	73.45695
2	12.80163	2	28.04166	2	43.28169	2	58.52172	2	73.76175
3	13.10643	3	28.34646	3	43.58649	3	58.82652	3	74.06655
4	13.41123	4	28.65126	4	43.89129	4	59.13132	4	74.37135
5	13.71603	5	28.95606	5	44.19609	5	59.43612	5	74.67615
6	14.02083	6	29.26086	6	44.50089	6	59.74092	6	74.98095
7	14.32563	7	29.56566	7	44.80569	7	60.04572	7	75.28575
8	14.63043	8	29.87046	8	45.11049	8	60.35052	8	75.59055
9	14.93523	9	30.17526	9	45.41529	9	60.65532	9	75.89535

Lengths—Feet to meters (from 1 to 1,000 units)—Continued

Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
250	76.20015	300	91.44018	350	106.68021	400	121.92024	450	137.16027
1	76.50495	1	91.74498	1	106.98501	1	122.22504	1	137.46507
2	76.80975	2	92.04978	2	107.28981	2	122.52985	2	137.76988
3	77.11455	3	92.35458	3	107.59462	3	122.83465	3	138.07468
4	77.41935	4	92.65939	4	107.89942	4	123.13945	4	138.37948
5	77.72416	5	92.96419	5	108.20422	5	123.44425	5	138.68428
6	78.02896	6	93.26899	6	108.50902	6	123.74905	6	138.98908
7	78.33376	7	93.57379	7	108.81382	7	124.05385	7	139.29388
8	78.63856	8	93.87859	8	109.11862	8	124.35865	8	139.59868
9	78.94336	9	94.18339	9	109.42342	9	124.66345	9	139.90348
260	79.24816	310	94.48819	360	109.72822	410	124.96825	460	140.20828
1	79.55296	1	94.79299	1	110.03302	1	125.27305	1	140.51308
2	79.85776	2	95.09779	2	110.33782	2	125.57785	2	140.81788
3	80.16256	3	95.40259	3	110.64262	3	125.88265	3	141.12268
4	80.46736	4	95.70739	4	110.94742	4	126.18745	4	141.42748
5	80.77216	5	96.01219	5	111.25222	5	126.49225	5	141.73228
6	81.07696	6	96.31699	6	111.55702	6	126.79705	6	142.03708
7	81.38176	7	96.62179	7	111.86182	7	127.10185	7	142.34188
8	81.68656	8	96.92659	8	112.16662	8	127.40665	8	142.64669
9	81.99136	9	97.23139	9	112.47142	9	127.71146	9	142.95149
270	82.29616	320	97.53620	370	112.77623	420	128.01626	470	143.25629
1	82.60097	1	97.84100	1	113.08103	1	128.32106	1	143.56109
2	82.90577	2	98.14580	2	113.38583	2	128.62586	2	143.86589
3	83.21057	3	98.45060	3	113.69063	3	128.93066	3	144.17069
4	83.51537	4	98.75540	4	113.99543	4	129.23546	4	144.47549
5	83.82017	5	99.06020	5	114.30023	5	129.54026	5	144.78029
6	84.12497	6	99.36500	6	114.60503	6	129.84506	6	145.08509
7	84.42977	7	99.66980	7	114.90983	7	130.14986	7	145.38989
8	84.73457	8	99.97460	8	115.21463	8	130.45466	8	145.69469
9	85.03937	9	100.27940	9	115.51943	9	130.75946	9	145.99949
280	85.34417	330	100.58420	380	115.82423	430	131.06426	480	146.30429
1	85.64897	1	100.88900	1	116.12903	1	131.36906	1	146.60909
2	85.95377	2	101.19380	2	116.43383	2	131.67386	2	146.91389
3	86.25857	3	101.49860	3	116.73863	3	131.97866	3	147.21869
4	86.56337	4	101.80340	4	117.04343	4	132.28346	4	147.52350
5	86.86817	5	102.10820	5	117.34823	5	132.58827	5	147.82830
6	87.17297	6	102.41300	6	117.65304	6	132.89307	6	148.13310
7	87.47777	7	102.71781	7	117.95784	7	133.19787	7	148.43790
8	87.78258	8	103.02261	8	118.26264	8	133.50267	8	148.74270
9	88.08738	9	103.32741	9	118.56744	9	133.80747	9	149.04750
290	88.39218	340	103.63221	390	118.87224	440	134.11227	490	149.35230
1	88.69698	1	103.93701	1	119.17704	1	134.41707	1	149.65710
2	89.00178	2	104.24181	2	119.48184	2	134.72187	2	149.96190
3	89.30658	3	104.54661	3	119.78664	3	135.02667	3	150.26670
4	89.61138	4	104.85141	4	120.09144	4	135.33147	4	150.57150
5	89.91618	5	105.15621	5	120.39624	5	135.63627	5	150.87630
6	90.22098	6	105.46101	6	120.70104	6	135.94107	6	151.18110
7	90.52578	7	105.76581	7	121.00584	7	136.24587	7	151.48590
8	90.83058	8	106.07061	8	121.31064	8	136.55067	8	151.79070
9	91.13538	9	106.37541	9	121.61544	9	136.85547	9	152.09550

Lengths—Feet to meters (from 1 to 1,000 units)—Continued

Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
500	152.40030	550	167.64034	600	182.88037	650	198.12040	700	213.36043
1	152.70511	1	167.94514	1	183.18517	1	198.42520	1	213.66523
2	153.00991	2	168.24994	2	183.48997	2	198.73000	2	213.97003
3	153.31471	3	168.55474	3	183.79477	3	199.03480	3	214.27483
4	153.61951	4	168.85954	4	184.09957	4	199.33960	4	214.57963
5	153.92431	5	169.16434	5	184.40437	5	199.64440	5	214.88443
6	154.22911	6	169.46914	6	184.70917	6	199.94920	6	215.18923
7	154.53391	7	169.77394	7	185.01397	7	200.25400	7	215.49403
8	154.83871	8	170.07874	8	185.31877	8	200.55880	8	215.79883
9	155.14351	9	170.38354	9	185.62357	9	200.86360	9	216.10363
510	155.44831	560	170.68834	610	185.92837	660	201.16840	710	216.40843
1	155.75311	1	170.99314	1	186.23317	1	201.47320	1	216.71323
2	156.05791	2	171.29794	2	186.53797	2	201.77800	2	217.01803
3	156.36271	3	171.60274	3	186.84277	3	202.08280	3	217.32283
4	156.66751	4	171.90754	4	187.14757	4	202.38760	4	217.62764
5	156.97231	5	172.21234	5	187.45237	5	202.69241	5	217.93244
6	157.27711	6	172.51715	6	187.75718	6	202.99721	6	218.23724
7	157.58192	7	172.82195	7	188.06198	7	203.30201	7	218.54204
8	157.88672	8	173.12675	8	188.36678	8	203.60681	8	218.84684
9	158.19152	9	173.43155	9	188.67158	9	203.91161	9	219.15164
520	158.49632	570	173.73635	620	188.97638	670	204.21641	720	219.45644
1	158.80112	1	174.04115	1	189.28118	1	204.52121	1	219.76124
2	159.10592	2	174.34595	2	189.58598	2	204.82601	2	220.06604
3	159.41072	3	174.65075	3	189.89078	3	205.13081	3	220.37084
4	159.71552	4	174.95555	4	190.19558	4	205.43561	4	220.67564
5	160.02032	5	175.26035	5	190.50038	5	205.74041	5	220.98044
6	160.32512	6	175.56515	6	190.80518	6	206.04521	6	221.28524
7	160.62992	7	175.86995	7	191.10998	7	206.35001	7	221.59004
8	160.93472	8	176.17475	8	191.41478	8	206.65481	8	221.89484
9	161.23952	9	176.47955	9	191.71958	9	206.95931	9	222.19964
530	161.54432	580	176.78435	630	192.02438	680	207.26441	730	222.50445
1	161.84912	1	177.08915	1	192.32918	1	207.56922	1	222.80925
2	162.15392	2	177.39395	2	192.63399	2	207.87402	2	223.11405
3	162.45872	3	177.69876	3	192.93879	3	208.17882	3	223.41885
4	162.76353	4	178.00356	4	193.24359	4	208.48362	4	223.72365
5	163.06833	5	178.30836	5	193.54839	5	208.78842	5	224.02845
6	163.37313	6	178.61316	6	193.85319	6	209.09322	6	224.33325
7	163.67793	7	178.91796	7	194.15799	7	209.39802	7	224.63805
8	163.98273	8	179.22276	8	194.46279	8	209.70282	8	224.94285
9	164.28753	9	179.52756	9	194.76759	9	210.00762	9	225.24765
540	164.59233	590	179.83236	640	195.07239	690	210.31242	740	225.55245
1	164.89713	1	180.13716	1	195.37719	1	210.61722	1	225.85725
2	165.20193	2	180.44196	2	195.68199	2	210.92202	2	226.16205
3	165.50673	3	180.74676	3	195.98679	3	211.22682	3	226.46685
4	165.81153	4	181.05156	4	196.29159	4	211.53162	4	226.77165
5	166.11633	5	181.35636	5	196.59639	5	211.83642	5	227.07645
6	166.42113	6	181.66116	6	196.90119	6	212.14122	6	227.38125
7	166.72593	7	181.96596	7	197.20599	7	212.44602	7	227.68606
8	167.03073	8	182.27076	8	197.51080	8	212.75083	8	227.99086
9	167.33553	9	182.57557	9	197.81560	9	213.05563	9	228.29566

Lengths—Feet to meters (from 1 to 1,000 units)—Continued

Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
750	228.60046	800	243.84049	850	259.08052	900	274.32055	950	289.56058
1	228.90526	1	244.14529	1	259.38532	1	274.62535	1	289.86538
2	229.21006	2	244.45009	2	259.69012	2	274.93015	2	290.17018
3	229.51486	3	244.75489	3	259.99492	3	275.23495	3	290.47498
4	229.81966	4	245.05969	4	260.29972	4	275.53975	4	290.77978
5	230.12446	5	245.36449	5	260.60452	5	275.84455	5	291.08458
6	230.42926	6	245.66920	6	260.90932	6	276.14935	6	291.38938
7	230.73406	7	235.97400	7	261.21412	7	276.45415	7	291.69418
8	231.03886	8	246.27889	8	261.51892	8	276.75895	8	291.99898
9	231.34366	9	246.58369	9	261.82372	9	277.06375	9	292.30378
760	231.64846	810	246.88849	860	262.12852	910	277.36855	960	292.60859
1	231.95326	1	247.19329	1	262.43332	1	277.67336	1	292.91339
2	232.25806	2	247.49800	2	262.73813	2	277.97816	2	293.21819
3	232.56287	3	247.80290	3	263.04293	3	278.28296	3	293.52299
4	232.86767	4	248.10770	4	263.34773	4	278.58776	4	293.82779
5	233.17247	5	248.41250	5	263.65253	5	278.89256	5	294.13259
6	233.47727	6	248.71730	6	263.95733	6	279.19736	6	294.43739
7	233.78207	7	249.02210	7	264.26213	7	279.50216	7	294.74219
8	234.08687	8	249.32690	8	264.56693	8	279.80696	8	295.04699
9	234.39167	9	249.63170	9	264.87173	9	280.11176	9	295.35179
770	234.69647	820	249.93650	870	265.17653	920	280.41656	970	295.65659
1	235.00127	1	250.24130	1	265.48133	1	280.72136	1	295.96139
2	235.30607	2	250.54610	2	265.78613	2	281.02616	2	296.26619
3	235.61087	3	250.85090	3	266.09093	3	281.33096	3	296.57099
4	235.91567	4	251.15570	4	266.39573	4	281.63576	4	296.87579
5	236.22047	5	251.46050	5	266.70053	5	281.94056	5	297.18059
6	236.52527	6	251.76530	6	267.00533	6	282.24536	6	297.48539
7	236.83007	7	252.07010	7	267.31013	7	282.55017	7	297.79020
8	237.13487	8	252.37490	8	267.61494	8	282.85497	8	298.09500
9	237.43967	9	252.67971	9	267.91974	9	283.15977	9	298.39980
780	237.74448	830	252.98451	880	268.22454	930	283.46457	980	298.70460
1	238.04928	1	253.28931	1	268.52934	1	283.76937	1	299.00940
2	238.35408	2	253.59411	2	268.83414	2	284.07417	2	299.31420
3	238.65888	3	253.89891	3	269.13894	3	284.37897	3	299.61900
4	238.96368	4	254.20371	4	269.44374	4	284.68377	4	299.92380
5	239.26848	5	254.50851	5	269.74854	5	284.98857	5	300.22860
6	239.57328	6	254.81331	6	270.05334	6	285.29337	6	300.53340
7	239.87808	7	255.11811	7	270.35814	7	285.59817	7	300.83820
8	240.18288	8	255.42291	8	270.66294	8	285.90297	8	301.14300
9	240.48768	9	255.72771	9	270.96774	9	286.20777	9	301.44780
790	240.79248	840	256.03251	890	271.27254	940	286.51257	990	301.75260
1	241.09728	1	256.33731	1	271.57734	1	286.81737	1	302.05740
2	241.40208	2	256.64211	2	271.88214	2	287.12217	2	302.36220
3	241.70688	3	256.94691	3	272.18694	3	287.42697	3	302.66701
4	242.01168	4	257.25171	4	272.49174	4	287.73178	4	302.97181
5	242.31648	5	257.55652	5	272.79655	5	288.03658	5	303.27661
6	242.62129	6	257.86132	6	273.10135	6	288.34138	6	303.58141
7	242.92609	7	258.16612	7	273.40615	7	288.64618	7	303.88621
8	243.23089	8	258.47092	8	273.71095	8	288.95098	8	304.19101
9	243.53569	9	258.77572	9	274.01575	9	289.25578	9	304.49581

Lengths—Meters to feet (from 1 to 1,000 units)

[Reduction factor: 1 meter=3.280833333 feet]

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
0		50	164.04167	100	328.08333	150	492.12500	200	656.16667
1	3.28083	1	167.32250	1	331.36417	1	495.40583	1	659.44750
2	6.56167	2	170.60333	2	334.64500	2	498.68667	2	662.72833
3	9.84250	3	173.88417	3	337.92583	3	501.96750	3	666.00917
4	13.12333	4	177.16500	4	341.20667	4	505.24833	4	669.29000
5	16.40417	5	180.44583	5	344.48750	5	508.52917	5	672.57083
6	19.68500	6	183.72667	6	347.76833	6	511.81000	6	675.85167
7	22.96583	7	187.00750	7	351.04917	7	515.09083	7	679.13250
8	26.24667	8	190.28833	8	354.33000	8	518.37167	8	682.41333
9	29.52750	9	193.56917	9	357.61083	9	521.65250	9	685.69417
10	32.80833	60	196.85000	110	360.89167	160	524.93333	210	688.97500
1	36.08917	1	200.13083	1	364.17250	1	528.21417	1	692.25583
2	39.37000	2	203.41167	2	367.45333	2	531.49500	2	695.53667
3	42.65083	3	206.69250	3	370.73417	3	534.77583	3	698.81750
4	45.93167	4	209.97333	4	374.01500	4	538.05667	4	702.09833
5	49.21250	5	213.25417	5	377.29583	5	541.33750	5	705.37917
6	52.49333	6	216.53500	6	380.57667	6	544.61833	6	708.66000
7	55.77417	7	219.81583	7	383.85750	7	547.89917	7	711.94083
8	59.05500	8	223.09667	8	387.13833	8	551.18000	8	715.22167
9	62.33583	9	226.37750	9	390.41917	9	554.46083	9	718.50250
20	65.61667	70	229.65833	120	393.70000	170	557.74167	220	721.78333
1	68.89750	1	232.93917	1	396.98083	1	561.02250	1	725.06417
2	72.17833	2	236.22000	2	400.26167	2	564.30333	2	728.34500
3	75.45917	3	239.50083	3	403.54250	3	567.58417	3	731.62583
4	78.74000	4	242.78167	4	406.82333	4	570.86500	4	734.90667
5	82.02083	5	246.06250	5	410.10417	5	574.14583	5	738.18750
6	85.30167	6	249.34333	6	413.38500	6	577.42667	6	741.46833
7	88.58250	7	252.62417	7	416.66583	7	580.70750	7	744.74917
8	91.86333	8	255.90500	8	419.94667	8	583.98833	8	748.03000
9	95.14417	9	259.18583	9	423.22750	9	587.26917	9	751.31083
30	98.42500	80	262.46667	130	426.50833	180	590.55000	230	754.59167
1	101.70583	1	265.74750	1	429.78917	1	593.83083	1	757.87250
2	104.98667	2	269.02833	2	433.07000	2	597.11167	2	761.15333
3	108.26750	3	272.30917	3	436.35083	3	600.39250	3	764.43417
4	111.54833	4	275.59000	4	439.63167	4	603.67333	4	767.71500
5	114.82917	5	278.87083	5	442.91250	5	606.95417	5	770.99583
6	118.11000	6	282.15167	6	446.19333	6	610.23500	6	774.27667
7	121.39083	7	285.43250	7	449.47417	7	613.51583	7	777.55750
8	124.67167	8	288.71333	8	452.75500	8	616.79667	8	780.83833
9	127.95250	9	291.99417	9	456.03583	9	620.07750	9	784.11917
40	131.23333	90	295.27500	140	459.31667	190	623.35833	240	787.40000
1	134.51417	1	298.55583	1	462.59750	1	626.63917	1	790.68083
2	137.79500	2	301.83667	2	465.87833	2	629.92000	2	793.96167
3	141.07583	3	305.11750	3	469.15917	3	633.20083	3	797.24250
4	144.35667	4	308.39833	4	472.44000	4	636.48167	4	800.52333
5	147.63750	5	311.67917	5	475.72083	5	639.76250	5	803.80417
6	150.91833	6	314.96000	6	479.00167	6	643.04333	6	807.08500
7	154.19917	7	318.24083	7	482.28250	7	646.32417	7	810.36583
8	157.48000	8	321.52167	8	485.56333	8	649.60500	8	813.64667
9	160.76083	9	324.80250	9	488.84417	9	652.88583	9	816.92750

Lengths—Meters to feet (from 1 to 1,000 units)—Continued

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
250	820.20833	300	984.25000	350	1,148.29167	400	1,312.33333	450	1,476.37500
1	823.48917	1	987.53083	1	1,151.57250	1	1,315.61417	1	1,479.65583
2	826.77000	2	990.81167	2	1,154.85333	2	1,318.89500	2	1,482.93667
3	830.05083	3	994.09250	3	1,158.13417	3	1,322.17583	3	1,486.21750
4	833.33167	4	997.37333	4	1,161.41500	4	1,325.45667	4	1,489.49833
5	836.61250	5	1,000.65417	5	1,164.69583	5	1,328.73750	5	1,492.77917
6	839.89333	6	1,003.93500	6	1,167.97667	6	1,332.01833	6	1,496.06000
7	843.17417	7	1,007.21583	7	1,171.25750	7	1,335.29917	7	1,499.34083
8	846.45500	8	1,010.49667	8	1,174.53833	8	1,338.58000	8	1,502.62167
9	849.73583	9	1,013.77750	9	1,177.81917	9	1,341.86083	9	1,505.90250
260	853.01667	310	1,017.05833	360	1,181.10000	410	1,345.14167	460	1,509.18333
1	856.29750	1	1,020.33917	1	1,184.38083	1	1,348.42250	1	1,512.46417
2	859.57833	2	1,023.62000	2	1,187.66167	2	1,351.70333	2	1,515.74500
3	862.85917	3	1,026.90083	3	1,190.94250	3	1,354.98417	3	1,519.02583
4	866.14000	4	1,030.18167	4	1,194.22333	4	1,358.26500	4	1,522.30667
5	869.42083	5	1,033.46250	5	1,197.50417	5	1,361.54583	5	1,525.58750
6	872.70167	6	1,036.74333	6	1,200.78500	6	1,364.82667	6	1,528.86833
7	875.98250	7	1,040.02417	7	1,204.06583	7	1,368.10750	7	1,532.14917
8	879.26333	8	1,043.30500	8	1,207.34667	8	1,371.38833	8	1,535.43000
9	882.54417	9	1,046.58583	9	1,210.62750	9	1,374.66917	9	1,538.71083
270	885.82500	320	1,049.86667	370	1,213.90833	420	1,377.95000	470	1,541.99167
1	889.10583	1	1,053.14750	1	1,217.18917	1	1,381.23083	1	1,545.27250
2	892.38667	2	1,056.42833	2	1,220.47000	2	1,384.51167	2	1,548.55333
3	895.66750	3	1,059.70917	3	1,223.75083	3	1,387.79250	3	1,551.83417
4	898.94833	4	1,062.99000	4	1,227.03167	4	1,391.07333	4	1,555.11500
5	902.22917	5	1,066.27083	5	1,130.31250	5	1,394.35417	5	1,553.39583
6	905.51000	6	1,069.55167	6	1,233.59333	6	1,397.63500	6	1,561.67667
7	908.79083	7	1,072.83250	7	1,236.87417	7	1,400.91583	7	1,564.95750
8	912.07167	8	1,076.11333	8	1,240.15500	8	1,404.19667	8	1,568.23833
9	915.35250	9	1,079.39417	9	1,243.43583	9	1,407.47750	9	1,571.51917
280	918.63333	330	1,082.67500	380	1,246.71667	430	1,410.75833	480	1,574.80000
1	921.91417	1	1,085.95583	1	1,249.99750	1	1,414.03917	1	1,578.08083
2	925.19500	2	1,089.23667	2	1,253.27833	2	1,417.32000	2	1,581.36167
3	928.47583	3	1,092.51750	3	1,256.55917	3	1,420.60083	3	1,584.64250
4	931.75667	4	1,095.79833	4	1,259.84000	4	1,423.88167	4	1,587.92333
5	935.03750	5	1,099.07917	5	1,263.12083	5	1,427.16250	5	1,591.20417
6	938.31833	6	1,102.36000	6	1,266.40167	6	1,430.44333	6	1,594.48500
7	941.59917	7	1,105.64083	7	1,269.68250	7	1,433.72417	7	1,597.76583
8	944.88000	8	1,108.92167	8	1,272.96333	8	1,437.00500	8	1,601.04667
9	948.16083	9	1,112.20250	9	1,276.24417	9	1,440.28583	9	1,604.32750
290	951.44167	340	1,115.48333	390	1,279.52500	440	1,443.56667	490	1,607.60833
1	954.72250	1	1,118.76417	1	1,282.80583	1	1,446.84750	1	1,610.88917
2	958.00333	2	1,122.04500	2	1,286.08667	2	1,450.12833	2	1,614.17000
3	961.28417	3	1,125.32583	3	1,289.36750	3	1,453.40917	3	1,617.45083
4	964.56500	4	1,128.60667	4	1,292.64833	4	1,456.69000	4	1,620.73167
5	967.84583	5	1,131.88750	5	1,295.92917	5	1,459.97083	5	1,624.01250
6	971.12667	6	1,135.16833	6	1,299.21000	6	1,463.25167	6	1,627.29333
7	974.40750	7	1,138.44917	7	1,302.49083	7	1,466.53250	7	1,630.57417
8	977.68833	8	1,141.73000	8	1,305.77167	8	1,469.81333	8	1,633.85500
9	980.96917	9	1,145.01083	9	1,309.05250	9	1,473.09417	9	1,637.13583

Lengths—Meters to feet (from 1 to 1,000 units)—Continued

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
500	1,640.41667	550	1,804.45833	600	1,968.50000	650	2,132.54167	700	2,296.58333
1	1,643.69750	1	1,807.73917	1	1,971.78083	1	2,135.82250	1	2,299.86417
2	1,646.97833	2	1,811.02000	2	1,975.06167	2	2,139.10333	2	2,303.14500
3	1,650.25917	3	1,814.30083	3	1,978.34250	3	2,142.38417	3	2,306.42583
4	1,653.54000	4	1,817.58167	4	1,981.62333	4	2,145.66500	4	2,309.70667
5	1,656.82083	5	1,820.86250	5	1,984.90417	5	2,148.94583	5	2,312.98750
6	1,660.10167	6	1,824.14333	6	1,988.18500	6	2,152.22667	6	2,316.26833
7	1,663.38250	7	1,827.42417	7	1,991.46583	7	2,155.50750	7	2,319.54917
8	1,666.66333	8	1,830.70500	8	1,994.74667	8	2,158.78833	8	2,322.83000
9	1,669.94417	9	1,833.98583	9	1,998.02750	9	2,162.06917	9	2,326.11083
510	1,673.22500	560	1,837.26667	610	2,001.30833	660	2,165.35000	710	2,329.39167
1	1,676.50583	1	1,840.54750	1	2,004.58917	1	2,168.63083	1	2,332.67250
2	1,679.78667	2	1,843.82833	2	2,007.87000	2	2,171.91167	2	2,335.95333
3	1,683.06750	3	1,847.10917	3	2,011.15083	3	2,175.19250	3	2,339.23417
4	1,686.34833	4	1,850.39000	4	2,014.43167	4	2,178.47333	4	2,342.51500
5	1,689.62917	5	1,853.67083	5	2,017.71250	5	2,181.75417	5	2,345.79583
6	1,692.91000	6	1,856.95167	6	2,020.99333	6	2,185.03500	6	2,349.07667
7	1,696.19083	7	1,860.23250	7	2,024.27417	7	2,188.31583	7	2,352.35750
8	1,699.47167	8	1,863.51333	8	2,027.55500	8	2,191.59667	8	2,355.63833
9	1,702.75250	9	1,866.79417	9	2,030.83583	9	2,194.87750	9	2,358.91917
520	1,706.03333	570	1,870.07500	620	2,034.11667	670	2,198.15833	720	2,362.20000
1	1,709.31417	1	1,873.35583	1	2,037.39750	1	2,201.43917	1	2,365.48083
2	1,712.59500	2	1,876.63667	2	2,040.67833	2	2,204.72000	2	2,368.76167
3	1,715.87583	3	1,879.91750	3	2,043.95917	3	2,208.00083	3	2,372.04250
4	1,719.15667	4	1,883.19833	4	2,047.24000	4	2,211.28167	4	2,375.32333
5	1,722.43750	5	1,886.47917	5	2,050.52083	5	2,214.56250	5	2,378.60417
6	1,725.71833	6	1,889.76000	6	2,053.80167	6	2,217.84333	6	2,381.88500
7	1,728.99917	7	1,893.04083	7	2,057.08250	7	2,221.12417	7	2,385.16583
8	1,732.28000	8	1,896.32167	8	2,060.36333	8	2,224.40500	8	2,388.44667
9	1,735.56083	9	1,899.60250	9	2,063.64417	9	2,227.68583	9	2,391.72750
530	1,738.84167	580	1,902.88333	630	2,066.92500	680	2,230.96667	730	2,395.00833
1	1,742.12250	1	1,906.16417	1	2,070.20583	1	2,234.24750	1	2,398.28917
2	1,745.40333	2	1,909.44500	2	2,073.48667	2	2,237.52833	2	2,401.57000
3	1,748.68417	3	1,912.72583	3	2,076.76750	3	2,240.80917	3	2,404.85083
4	1,751.96500	4	1,916.00667	4	2,080.04833	4	2,244.09000	4	2,408.13167
5	1,755.24583	5	1,919.28750	5	2,083.32917	5	2,247.37083	5	2,411.41250
6	1,758.52667	6	1,922.56833	6	2,086.61000	6	2,250.65167	6	2,414.69333
7	1,761.80750	7	1,925.84917	7	2,089.89083	7	2,253.93250	7	2,417.97417
8	1,765.08833	8	1,929.13000	8	2,093.17167	8	2,257.21333	8	2,421.25500
9	1,768.36917	9	1,932.41083	9	2,096.45250	9	2,260.49417	9	2,424.53583
540	1,771.65000	590	1,935.69167	640	2,099.73333	690	2,263.77500	740	2,427.81667
1	1,774.93083	1	1,938.97250	1	2,103.01417	1	2,267.05583	1	2,431.09750
2	1,778.21167	2	1,942.25333	2	2,106.29500	2	2,270.33667	2	2,434.37833
3	1,781.49250	3	1,945.53417	3	2,109.57583	3	2,273.61750	3	2,437.65917
4	1,784.77333	4	1,948.81500	4	2,112.85667	4	2,276.89833	4	2,440.94000
5	1,788.05417	5	1,952.09583	5	2,116.13750	5	2,280.17917	5	2,444.22083
6	1,791.33500	6	1,955.37667	6	2,119.41833	6	2,283.46000	6	2,447.50167
7	1,794.61583	7	1,958.65750	7	2,122.69917	7	2,286.74083	7	2,450.78250
8	1,797.89667	8	1,961.93833	8	2,125.98000	8	2,290.02167	8	2,454.06333
9	1,801.17750	9	1,965.21917	9	2,129.26083	9	2,293.30250	9	2,457.34417

Lengths—Meters to feet (from 1 to 1,000 units)—Continued

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
750	2,460.62500	800	2,624.66667	850	2,788.70833	900	2,952.75000	950	3,116.79167
1	2,463.90583	1	2,627.94750	1	2,791.98917	1	2,956.03083	1	3,120.07250
2	2,467.18667	2	2,631.22833	2	2,795.27000	2	2,959.31167	2	3,123.35333
3	2,470.46750	3	2,634.50917	3	2,798.55083	3	2,962.59250	3	3,126.63417
4	2,473.74833	4	2,637.79000	4	2,801.83167	4	2,965.87333	4	3,129.91500
5	2,477.02917	5	3,641.07083	5	2,805.11250	5	2,969.15417	5	3,133.19583
6	2,480.31000	6	2,644.35167	6	2,808.39333	6	2,972.43500	6	3,136.47667
7	2,483.59083	7	2,647.63250	7	2,811.67417	7	2,975.71583	7	3,139.75750
8	2,486.87167	8	2,650.91333	8	2,814.95500	8	2,978.99667	8	3,143.03833
9	2,490.15250	9	2,654.19417	9	2,818.23583	9	2,982.27750	9	3,146.31917
760	2,493.43333	810	2,657.47500	860	2,821.51667	910	2,985.55833	960	3,149.60000
1	2,496.71417	1	2,660.75583	1	2,824.79750	1	2,988.83917	1	3,152.88083
2	2,499.99500	2	2,664.03667	2	2,828.07833	2	2,992.12000	2	3,156.16167
3	2,503.27583	3	2,667.31750	3	2,831.35917	3	2,995.40083	3	3,159.44250
4	2,506.55667	4	2,670.59833	4	2,834.64000	4	2,998.68167	4	3,162.72333
5	2,509.83750	5	2,673.87917	5	2,837.92083	5	3,001.96250	5	3,166.00417
6	2,513.11833	6	2,677.16000	6	2,841.20167	6	3,005.24333	6	3,169.28500
7	2,516.39917	7	2,680.44083	7	2,844.48250	7	3,008.52417	7	3,172.56583
8	2,519.68000	8	2,683.72167	8	2,847.76333	8	3,011.80500	8	3,175.84667
9	2,522.96083	9	2,687.00250	9	2,851.04417	9	3,015.08583	9	3,179.12750
770	2,526.24167	820	2,690.28333	870	2,854.32500	920	3,018.36667	970	3,182.40833
1	2,529.52250	1	2,693.56417	1	2,857.60583	1	3,021.64750	1	3,185.68917
2	2,532.80333	2	2,696.84500	2	2,860.88667	2	3,024.92833	2	2,188.97000
3	2,536.08417	3	2,700.12583	3	2,864.16750	3	3,028.20917	3	3,192.25083
4	2,539.36500	4	2,703.40667	4	2,867.44833	4	3,031.49000	4	3,195.53167
5	2,542.64583	5	2,706.68750	5	2,870.72917	5	3,034.77083	5	3,198.81250
6	2,545.92667	6	2,709.96833	6	2,874.01000	6	3,038.05167	6	3,202.09333
7	2,549.20750	7	2,713.24917	7	2,877.29083	7	3,041.33250	7	3,205.37417
8	2,552.48833	8	2,716.53000	8	2,880.57167	8	3,044.61333	8	3,208.65500
9	2,555.76917	9	2,719.81083	9	2,883.85250	9	3,047.89417	9	3,211.93583
780	2,559.05000	830	2,723.09167	880	2,887.13333	930	3,051.17500	980	3,215.21667
1	2,562.33083	1	2,726.37250	1	2,890.41417	1	3,054.45583	1	3,218.49750
2	2,565.61167	2	2,729.65333	2	2,893.69500	2	3,057.73667	2	3,221.77833
3	2,568.89250	3	2,732.93417	3	2,896.97583	3	3,061.01750	3	3,225.05917
4	2,572.17333	4	2,736.21500	4	2,900.25667	4	3,064.29833	4	3,228.34000
5	2,575.45417	5	2,739.49583	5	2,903.53750	5	3,067.57917	5	3,231.62083
6	2,578.73500	6	2,742.77667	6	2,906.81833	6	3,070.86000	6	3,234.90167
7	2,582.01583	7	2,746.05750	7	2,910.09917	7	3,074.14083	7	3,238.18250
8	2,585.29667	8	2,749.33833	8	2,913.38000	8	3,077.42167	8	3,241.46333
9	2,588.57750	9	2,752.61917	9	2,916.66083	9	3,080.70250	9	3,244.74417
790	2,591.85833	840	2,755.90000	890	2,919.94167	940	3,083.98333	990	3,248.02500
1	2,595.13917	1	2,759.18083	1	2,923.22250	1	3,087.26417	1	3,251.30583
2	2,598.42000	2	2,762.46167	2	2,926.50333	2	3,090.54500	2	3,254.58667
3	2,601.70083	3	2,765.74250	3	2,929.78417	3	3,093.82583	3	3,257.86750
4	2,604.98167	4	2,769.02333	4	2,933.06500	4	3,097.10667	4	3,261.14833
5	2,608.26250	5	2,772.30417	5	2,936.34583	5	3,100.38750	5	3,264.42917
6	2,611.54333	6	2,775.58500	6	2,939.62667	6	3,103.66833	6	3,267.71000
7	2,614.82417	7	2,778.86583	7	2,942.90750	7	3,106.94917	7	3,270.99083
8	2,618.10500	8	2,782.14667	8	2,946.18833	8	3,110.23000	8	3,274.27167
9	2,621.38583	9	2,785.42750	9	2,949.46917	9	3,113.51083	9	3,277.55250

PUBLICATIONS OF THE COAST AND GEODETIC SURVEY RELATING TO TRAVERSE

Special Publication No. 5.—Tables for a Polyconic Projection of Maps, 20 cents. This publication contains the necessary explanation of the method employed in constructing a polyconic projection, and also gives the values in meters of degrees, minutes, and seconds of latitude and longitude for all latitudes.

Special Publication No. 8.—Formulae and Tables for the Computation of Geodetic Positions, 25 cents. Contains the formulas, instructions, and data for computing the geographical coordinates of triangulation and traverse stations when the distances and angles are known.

Special Publication No. 14.—Determination of Time, Longitude, Latitude, and Azimuth, 35 cents. A manual describing the instruments and methods used by the Coast and Geodetic Survey on its astronomic field and office work.

Special Publication No. 26.—General Instructions for the Field Work of the Coast and Geodetic Survey, 25 cents. Includes condensed instructions for third-order triangulation, topography, hydrography, and tidal and current observations. (It is planned to supersede this publication soon by a number of separate manuals each covering a single class of surveys.)

Special Publication No. 28.—Application of the Theory of Least Squares to the Adjustment of Triangulation, 25 cents. Explains the principles of least-squares adjustments of triangulation, with illustrative examples.

Special Publication No. 65.—Instructions to Light Keepers on First-order Triangulation, 10 cents. A small pamphlet issued to light keepers, containing the signaling code used and instructions for adjusting and sighting the lights.

Special Publication No. 71.—Relation between Plane Rectangular Coordinates and Geographic Positions, 10 cents. Contains formulas and tables for changing from plane to spherical coordinates, and vice versa.

Special Publication No. 79.—Precise Traverse and Triangulation in Indiana, 20 cents. (See below.)

Special Publication No. 86.—Precise Traverse, Racine, Wis., to Vandalia, Ill., 15 cents. In addition to the usual tables of results, this and the publication above contain an account of the methods employed on traverse both in the field work and in the office computation of the field measurements.

Special Publication No. 91.—Use of Geodetic Control for City Surveys, 20 cents. Outlines the reasons why accurate vertical and horizontal control is desirable for city surveys and describes briefly the methods and instruments used on work of that character.

Special Publication No. 93.—Reconnaissance and Signal Building, 30 cents. A manual covering reconnaissance for triangulation and traverse, the marking of stations, and the construction of triangulation and traverse targets and towers.

Special Publication No. 101.—Precise Triangulation, Traverse, and Leveling in North Carolina, 25 cents. Contains an account of the methods employed on traverse both in the field work and in the office computations and contains also the usual tables of results.

Special Publication No. 109.—Wireless Longitude, 15 cents. A description of the apparatus and methods employed in the accurate measurement of differences in longitude when radio time signals are used in place of signals sent over telegraph lines.

Special Publication No. 120.—Manual of First-order Triangulation, 40 cents. Includes detailed instructions for first-order triangulation and base measurement.

Special Publication No. 138.—Manual of Triangulation Computation and Adjustment. (In press.) Contains detailed instructions for computing and adjusting triangulation.

Special Publication No. 140.—Manual of First-order Leveling. (In press.) Contains detailed instructions for both the field work and office computation of first-order leveling.

Any of the publications listed above can be purchased by those outside the bureau from the Superintendent of Documents, Washington, D. C., at the price stated. Numerous publications of this bureau contain the results of geodetic operations in the form of geographic positions of triangulation and traverse stations and elevations of bench marks. An engineer interested in securing those data for any particular locality should address his inquiry to the Director, Coast and Geodetic Survey.

A complete list of the publications of the Coast and Geodetic Survey will be found in the List of Publications of the Department of Commerce, a copy of which may be obtained free of charge upon application to the Department of Commerce.

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