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An American National Standard

Standard Guide for Measuring Horizontal Positioning During Measurements of Surface Water Depths [1]

This standard is issued under the fixed designation D 5906; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers the selection of procedures commonly used to establish a measurement of horizontal position during investigations of surface water bodies that are as follows:

	Sections
Procedure A—Manual Measurement	7 to 12
Procedure B—Optical Measurement	13 to 17
Procedure C—Electronic Measurement	18 to 27

1.1.1 The narrative specifies horizontal positioning terminology and describes manual, optical, and electronic measuring equipment and techniques.

1.2 The references cited contain information that may help in the design of a high quality measurement program.

1.3 The information provided on horizontal positioning is descriptive in nature and not intended to endorse any particular item of manufactured equipment or procedure.

1.4 This guide pertains to determining horizontal position of a depth measurement in quiescent or low velocity flow.

1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1129 Terminology Relating to Water [2]

D 3858 Test Method for Open-Channel Flow Measurement of Water by Velocity Area Method [2]

D 4410 Terminology for Fluvial Sediment [2]

D 4581 Guide for Measurement of Morphologic Characteristics of Surface Water Bodies [2]

D 5073 Practice for Depth Measurement of Surface Water [3]

3. Terminology

3.1 *Definitions:* For definitions of terms used in this guide, refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *accuracy*—refers to how close a measurement is to the true or actual value. (See Terminology D 1129.)

3.2.2 *baseline*—the primary reference line for use in measuring azimuth angles and positioning distances.

3.2.3 *continuous wave system*—an electronic positioning system in which the signal transmitted between the transmitter and responder stations travels as a wave having constant frequency and amplitude.

3.2.4 *electronic distance measurement (EDM)*—measurement of distance using pulsing or phase comparison systems.

3.2.5 *electronic positioning system (EPS)*—a system that receives two or more EDM to obtain a position.

3.2.6 *global positioning system (GPS)*—a global positioning system (GPS) is a satellite-based EDM system used in determining Cartesian coordinates (x, y, z) of a position by means of radio signals from NAVSTAR satellites.

3.2.7 *horizontal control*—a series of connected lines whose azimuths and lengths have been determined by triangulation, trilateration, and traversing.

3.2.8 *line of position (LOP)*—locus of points established along a rangeline.

3.2.9 *precision*—refers to how close a set of measurements can be repeated. (See Terminology D 1129.)

3.2.10 *pulsed wave system*—an electronic positioning system in which the signal from the transmitting station to the reflecting station travels in an electromagnetic wave pulse.

3.2.11 *range*—distance to a point measured by physical, optical, or electronic means.

3.2.12 *range line*—an imaginary, straight line extending across a body of water between fixed shore markings.

3.2.13 *range line markers*—site poles or other identifiable objects used for positioning alignment on a range line.

[1] This guide is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

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[2] *Annual Book of ASTM Standards*, Vol 11.01.

[3] *Annual Book of ASTM Standards*, Vol 11.02.

3.2.14 *shore markings*—any object, natural or artificial, that can be used as a reference for maintaining boat alignment or establishing the boats position as it moves along it course. Examples include range line markers, sight poles, trees, power poles, land surface features, structures, and etc.

3.2.15 *site poles*—metal or wood poles used as a sighting rod.

3.2.16 *stadia*—telescopic instrument equipment with horizontal hairs and used for measuring the vertical intercept on a graduated vertical rod held vertically and at some distance to and in front of the instrument.

3.2.17 *total station*—an electronic surveying instrument which digitally measures and displays horizontal distances and vertical angles to a distant object.

4. Summary of Guide

4.1 This guide includes three general procedures for determining the location or horizontal position in surveying of surface water bodies. The first determines position by a manual procedure. The equipment to perform this procedure may be most readily available and most practical under certain conditions.

4.2 The second determines position by a optical procedure.

4.3 The third determines position by a electronic procedure.

4.4 Horizontal control stations shall be in accordance with Third Order, Class I, Federal Geodetic Control Committee Classification (FGCC) Standards,[4] with traverses for such controls beginning and ending at existing first- or second-order stations **(1)**.[5]

5. Significance and Use

5.1 This guide is intended to provide instructions for the selection of horizontal positioning equipment under a wide range of conditions encountered in measurement of water depth in surface water bodies. These conditions, that include physical conditions at the measuring site, the quality of data required, the availability of appropriate measuring equipment, and the distances over which the measurements are to be made (including cost considerations), that govern the selection process. A step-by-step procedure for obtaining horizontal position is not discussed. This guide is to be used in conjunction with standard guide on measurement of surface water depth (such as standard Practice D 5173.)

6. Horizontal Positioning Criteria

6.1 The level of accuracy required in horizontal positioning can be defined in three general classes:

6.1.1 Class One pertains to precise positioning demanding a high degree of repeatability.

6.1.2 Class Two is for medium accuracy requirements typical of project condition studies or offshore/river hydraulic investigations, or both.

6.1.3 Class Three is for general reconnaissance investigations requiring only approximate measurements of positions.

6.1.4 Table 1 provides an estimate of the suitability by Class for the different horizontal positioning discussed within this guide **(2)**.

PROCEDURE A—MANUAL MEASUREMENT

7. Scope

7.1 This procedure explains the measurement of horizontal position using manual techniques and equipment. These include use of tagline positioning techniques and application of shore marks.

7.2 Description of techniques and equipment are general in nature and may need to be modified for use in specific field conditions.

8. Significance and Use

8.1 Prior to the development of optical and electronic positioning equipment, manual equipment and techniques were the only means of measuring horizontal position. These techniques and equipment are still widely used where precise controlled measurements may be required (for example, taut cable method), or where limitations in equipment availability, site conditions and cost considerations prohibit use of more modern equipment.

9. Tagline Positioning Techniques

9.1 Tagline positioning techniques makes use of a measuring line having markings at fixed intervals along its length to indicate distance. These can be either a taut cable in which the line is anchored firmly at opposite banks and stretched taut, or a boat mounted cable in which one end of the line is firmly anchored at the bank and the other is attached to a boat with the line fed out as the boat proceeds along its course. Both methods are frequently used low cost positioning techniques. The taut cable is most commonly used for obtaining streamflow measurements and sediment sampling data at non-bridge locations on rivers and streams, but is equally applicable for controlled boat positioning when obtaining river or lake bed profiles for other purposes. In this regard it has proven especially useful for positioning on small lakes or reservoirs, usually where distances involved are less than 1000 ft (305 m), and where sheer walls exist at both ends of the range, or where the presence of dense vegetation along the shoreline precludes use of optical or

TABLE 1 Allowable Horizontal Positioning System Error (7)

System	Estimated Positional Accuracy ±1 ft RMS	(±1 m) (RMS)	Suitable for Survey Class 1	2	3
Visual range intersection	10 to 66	(3 to 20)	No	No	Yes
Sextant angle resection	7 to 30	(2 to 10)	No	Yes	Yes
Transit/theodolite angle intersection	3 to 16	(1 to 5)	Yes	Yes	Yes
Range-azimuth intersection	1.6 to 10	(0.5 to 3)	Yes	Yes	Yes
Tagline high frequency EPS	3 to 13	(1 to 4)	Yes	Yes	Yes

[4] Available from NOAA, National Geodetic Survey, 1315 East West Highway, Room 8657, Silver Spring, MD 20910-3282.

[5] The boldface numbers given in parentheses refer to a list of references at the end of this standard.

electronic positioning methods. The boat mounted tagline, in contrast, is much easier to set up and use since only one end of the line is anchored at the shore, but this method can be considerably less accurate due to the increased possibility of misalignment errors.

9.1.1 *Taut Cable Method (Manual Procedure)*:

9.1.1.1 For the taut cable method (see Fig. 1), firmly anchor the ends of the cable on both banks (see 9.1.1.2 for installation) and the line then pulled as taut as possible without pulling the anchors out of the bank. This method of positioning is recognized as accurate for use on streams where the flow velocity does not exceed more than a few feet per second so that the drag induced by the flow, on any boat or other attachment, does not substantially deflect the line. The taut cable method is time consuming when compared to other more modern optical and electronic positioning equipment and techniques; take this into consideration when deciding on which equipment and techniques best apply **(3)**.

9.1.1.2 Installation of the taut cable should be done either in one of two ways: either securely anchor the cable to one bank and the line fed from a boat mounted reel as the boat proceeds across the body of water; or securely anchor the reel to one bank near the water's edge with the loose end towed across. Shore markings can be used for visual alignment, but the normal procedure is to place a transit or theodolite on line for this purpose. The transmit person, equipped with a two-way radio, relays alignment directions to the boat operator (also equipped with a two-way radio), as the line is transported to the opposite bank. A power or hand winch or hand cranked reel, skid mounted on locally fabricated support assemblies, can be attached to a tree or other firm support on shore and used to take slack out of the line and to minimize sag associated errors in distance. For safety, the reel should come equipped with a spring-loaded pin lock brake assembly. Buoys may be placed at optimum locations along the line to help reduce sag as well as provide an indicator of boat alinement.

9.1.1.3 Taglines for the taut cable method are commonly stainless steel or galvanized 7 by 7 cable, although a fiber line is increasingly being used. The stainless steel lines generally come pre-beaded at 2 ft intervals for the first 50 ft, at 5 ft for the next 100 ft (30 m), and at 10-ft intervals for to the end of the line. Sizes vary in diameter with the length of the cable used. For a length less than 400 ft (122 m), a $\frac{1}{32}$ in. (0.79 mm) diameter line is recommended; for lengths up to 800 ft (244 m), a $\frac{1}{16}$ in. (1.59 mm) diameter is recommended; for greater lengths, the diameter should be at least $\frac{1}{8}$ in. (3.18 mm). The fiber line is normally $\frac{3}{16}$ in. (4.76 mm) diameter, is normally yellow with black markings and generally comes available in any length up to 1000 ft (305 m). It is usually pre-marked with one mark every 10 ft (3 m) and two marks every 100 ft (30 m). To prevent damage when attaching the tagline to a tree, connect the free end of the tagline (the end not connected to a reel), to a 30 ft length of $\frac{3}{32}$-in. (2.37 mm) diameter cable. One end of this cable should have a harness snap and the other should have a pelican hook. The free end of the tagline should be equipped with a sleeve and thimble, of size matching the tagline diameter **(4)**.

9.1.1.4 Attachments for holding the boat in position at a fixed location along the tag line will vary depending on the specific needs of the data collection effort. Normally the attachment is some form of clamp arrangement. If velocity measurements or sediment sampling is being done along with the water depth measurements, the standard procedure is to equip the boat with a crosspiece (I-beam), normally a little longer than the width of the boat, and set perpendicular to the boat's centerline. The crosspiece is either clamped or bolted in place and has guide sheaves at each end and a clamp arrangement somewhere along the length of the crosspiece. With the tagline fed through the sheaves, the boat can be held in place or moved along the tagline from station to station. The mid-point clamp permits the boat to be fixed to a one location and not move laterally along the line as measurements are being taken. For safety, fasten a small rope to the clamp to permit quick release in the event of an emergency **(4)**.

9.1.1.5 Position a standby person near the quick-release end of the cable, to release the cable, if there is a possibility of a boat, barge, or other large obstruction colliding with the cable. In addition, a chase boat should also be present in traffic locations, to warn boaters of the cable's presence. For locations where flow velocities are high and boats and obstructions are present upstream, it is recommended that all work boats be kept downstream of the cable.

9.1.1.6 Positions along the line are determined either through the use of a calibrated measuring wheel, or by keeping track of markings attached to the line. Weight, sag, and strength of the line limit its range to less than 1000 ft (305 m). Markings

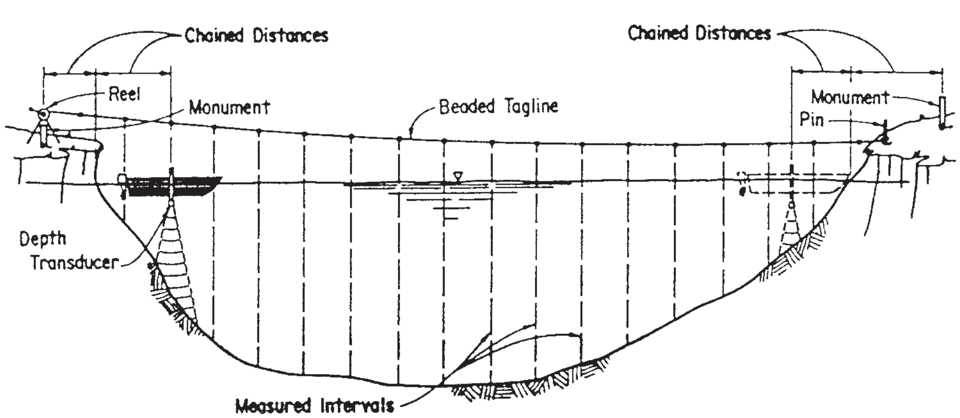

FIG. 1 Taut Cable Method

must be clearly visible and easy to understand. The markings are normally crimped brass beads set at 20 ft (6 m) intervals, but this can vary significantly depending on the field application and specific measurement requirements. Attach fluorescent flagging in 4 to 5 ft (1.2 to 1.5 m) lengths at 50 ft (15.2 m) intervals along the length of the cable to assist in ease of distance measurements. Fluorescent flagging provides the best visibility for all types of lighting and is recommended for use in visually marking the cable for safety purposes.

9.1.1.7 Begin measurements by positioning the boat near the bank at a fixed mark on the cable. This initial or starting mark should be determined by chain measurements from a surveyed control point near the water's edge. The boat proceeds from this initial mark along the cable to the opposite shore with a person on board calling out "fix" marks as each marking on the line is reached **(5)**.

9.1.1.8 Maintain alignment of a taut cable within at least 1 to 2 ft (0.3 to 0.6 m) of accuracy.

9.1.2 *Boat Mounted Tagline (Manual Procedure)*:

9.1.2.1 This method (see Fig. 2, Fig. 3, and Fig. 4), also referred to as tethered piano-wire method, is similar in principle to the taut cable with the distinction that only one end of the line is anchored at the bank. The opposite end is attached to a reel mounted on the boat and the line is fed out as the boat proceeds along its path. Boat mounted taglines can be used over substantial distances but are not suitable for Class 1 survey use unless the length of the cable is less than 1500 ft (457 m) when stationary measurements are made or less than 1000 ft (305 m) if the boat is moving. Table 2 provides an estimate of positional accuracies for different cable lengths **(2)**. The cable should be constructed of 0.059 in. (0.15 cm) diameter, steel piano wire or steel cable, and have markings attached that permit distance to be read by the length of line released from the reel. The standard guide is to use a reel with a calibrated measuring wheel and mechanical counter that activates as the wheel rotates. Locate the reel in the rear of the boat for safety and position as near as possible to the desired point of measurement (that is, sounding device). If the reel and the point of measurement do not coincide, record the distances between the two and add to the tagline measurements. Boat draft should be less than 1 ft (0.3 m) for accurate measurements in shallow water areas.

9.1.2.2 Establish positions along the boat's path by setting the boat on line and as near to the shore as practical. Then set

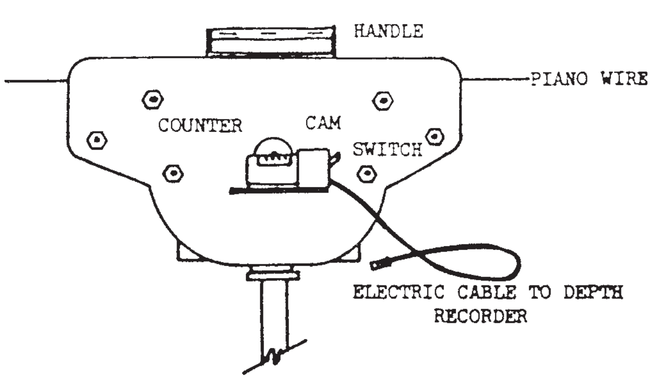

FIG. 2 Calibrated Wheel—Front Cover

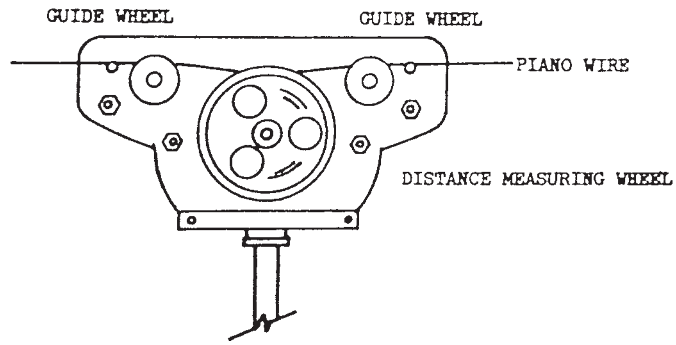

FIG. 3 Calibrated Wheel (Cover Removed)

the counter to zero and pull the loose end of the wire out and fasten it to a pin or other anchoring device driven on-line near the shore. Record distance from the pin to the water's edge on a chart or notebook kept in the boat. With this done, the boat begins to proceed along its designated path. Attach styrofoam floats to the line and dropped overboard at 100 to 300 ft (30 to 91 m) intervals that reduces sag by holding the wire near the surface. Release the line from its starting point as the boat reaches the opposite shore and retrieve it using the motor driven winch aboard the boat **(6)**.

9.1.2.3 Special care should be made to certify that the lateral alignment of the boat is held as the boat proceeds along its path and that the line is held taut. The tagline method maintains alignment through use of visual shore marks. But accuracy can be improved appreciably with a transit or theolodite person relaying alignment directions by a two-way radio.

9.1.2.4 If tagline markings are used in lieu of a measuring wheel, they should be easy to see and understand to avoid errors in determining the readings.

9.2 *Calibrated Wheel (Manual Procedure)*:

9.2.1 A 2 ft (0.6 m) diameter calibrated measuring wheel (see Fig. 5) can be used with the taut cable as a replacement for line markings. A counter attached to the wheel registers the revolutions of the wheel as the boat moves along its prescribed path. Anchor the piano wire on both banks and hold taut with enough sag to permit the piano wire to encircle the wheel, but provide enough friction to prevent slippage. Repair breaks that might occur in the line through the use of a compressed-sleeve type wire splicer.

9.2.2 The procedure for the calibrated wheel method is the same as that described for the taut cable, except that the calibrated wheel is used in lieu of markings permanently attached to the line. The positioning begins with the boat stationed at a fixed measured point on the line (established by distance measurement from a control station on shore), the counter on the wheel set to zero, and the boat's position relative to this starting position measured as the boat moves along its path.

10. Cable Reels (Manual Procedure)

10.1 Cable reels must be constructed of sturdy material and be equipped with a manual, electrical, or gasoline powered winch, including a clutching and braking assembly. The brake is used both for controlling rotation of the reel as the cable is let out and to serve as a safety feature. For hand operated reels,

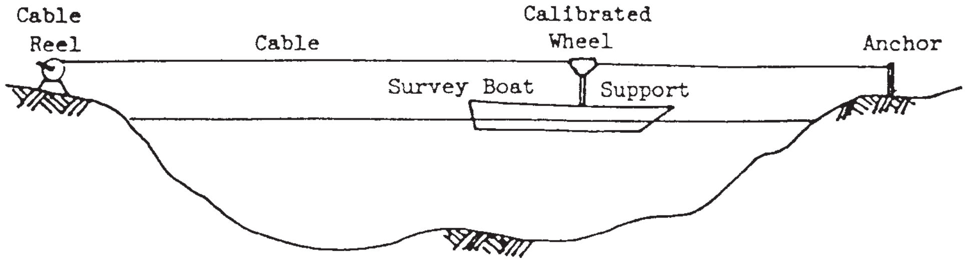

FIG. 4 Calibrated Wheel Method

TABLE 2 Allowable Tagline Positioning Procedures/Systems Criteria (7)

NOTE 1—Tagline distance range limits shown for Class 1 and Class 2 surveys are contingent on the tagline being pulled clear of the water and held taut during measurement. Distances for Class 1 surveys shall be adjusted downward depending on the capabilities of the boat and equipment used.

	Estimated Positional Accuracy				
System	±1 ft RMS	±1 m RMS	Suitable for Survey Class		
			1	2	3
Tagline (Boat Stationary)					
<1500 ft from baseline	1 to 3	(0.3 to 1)	Yes	Yes	Yes
>1500 to <3000 ft	3 to 16	(1 to 5)	No	Yes	Yes
>3000 ft from baseline	16 to 164	(5 to 50 +)	No	No	Yes
Tagline (Boat Moving)					
<1000 ft from baseline	3 to 9	(1 to 3)	Yes	Yes	Yes
>1000 to <2000 ft	8 to 20	(3 to 6)	No	Yes	Yes
>2000 from baseline	20 to 164 +	(6 to 50 +)	No	No	Yes
Tagline Calibration Frequency (in months)			1	6	12
Accuracy of Independent Calibration (feet)			0.1	1	5
Accuracy of Independent Calibration (meters)			0.03	0.01	1.52

the crank should be hinged to allow the crank to be disengaged from the shaft while the wire is let out and engaged for reeling in. Various devices are employed to drive a counter to register the amount of cable released from the reel **(5)**.

10.2 The cable for the boat mounted tagline should be made of galvanized, commercially available aircraft cable with 3⁄32 in. (2.38 mm) outside diameter (O.D.) and seven by seven construction. Some cables may also come with a nylon coating to reduce fraying typical of uncoated steel cables. The coating, however, increases the outside diameter to 1⁄8 in. (3.18 mm) and reduces the length of cable that can be wound on a reel by about 50 %. Plastic water-ski tow cable of 1⁄4 in. (6.35 mm) diameter, 1 lb/100 ft weight (0.45 kg/30.5 m), is available from sporting goods stores and may also be used occasionally with good success but is not recommended for use during windy conditions because of the tendency to be deflected. The plastic cable has the advantage of being easily repaired in the field by telescoping one end into the other.

11. Current Meters (Manual Procedure)

11.1 A standard "Price current meter" suspended from a boat, in which the propeller blade rotates because of movement of the boat, can be used to measure the distance the boat has traveled by keeping track of the accumulative revolutions of the meter times a calibration constant for the mounted meter. When coupled with the sonic-sound" fix" switch, the current meter can be used in a semi-automatic operation for recording and documenting positions along the range line.

12. Shore Marks (Manual Procedure)

12.1 Shore marks may be used with taglines, alone in pairs, or with optical and electronic procedures. Their function is to help maintain boat alignment as the boat moves along its prescribed course. The boat operator can visually align the boat's movement on target with the two or more shore marks, or an instrument man on shore can convey instructions by two-way radio as the boat proceeds between shore marks on the opposite bank. A transit works well for stadia positioning since the transit can be used both for alignment and stadia measurements. Shore marks, placed in a perpendicular alignment to the boats path, can serve as an indicator of position and, as such, provide a good, rough measurement of position for reconnaissance surveys.

12.2 Accuracy in use of shore marks depends on ease of visibility and how sharp the delineation is between the two or more objects being used for line of sight. Place the shore marks far enough apart to enable alignment to be clearly distinguishable.

PROCEDURE B—OPTICAL MEASUREMENT AND ALIGNMENT

13. Scope

13.1 This procedure explains the use of optical equipment in horizontal positioning.

13.2 Equipment includes transits, theodolites, and alidades, along with sextants, or range poles. The techniques applied include stadia positioning, transit intersection, transit-stadia positioning, and sextant positioning.

14. Stadia Measurements (Optical Procedure)

14.1 The stadia method (see Fig. 6) uses transit or alidade standard guides similar to that applied in standard land surveying applications. For boat positioning, however, the stadia board is much larger in size and often has coded markings in lieu of numbers. Fig. 7 illustrates a section of a typical board used by some field offices of the U.S. Army Corps of Engineers. The board must be securely mounted in the sounding boat and positioned as near to the required point of measurement as possible. Distances are normally read at 100 ft (30.5 m) intervals, unless field needs warrant otherwise. The transit operator is stationed on shore at a surveyed control point and conveys alignment and distance instructions to the boat operator through use of two-way radios. Each distance measurement is usually preceded by a "stand-by" message (including an indication of the distance), followed in a few seconds by the signal "fix" as the actual distance is read. The spacing of fix

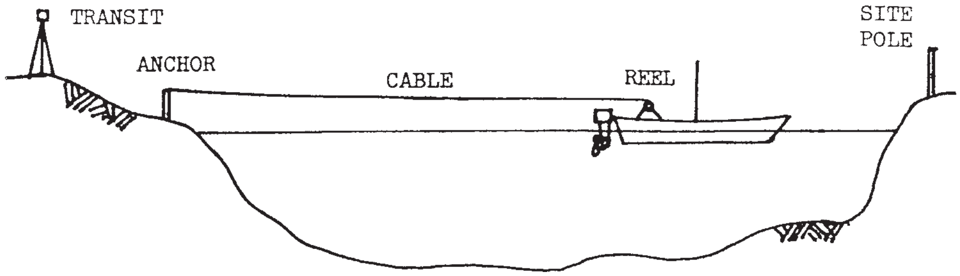

FIG. 5 Tag Line

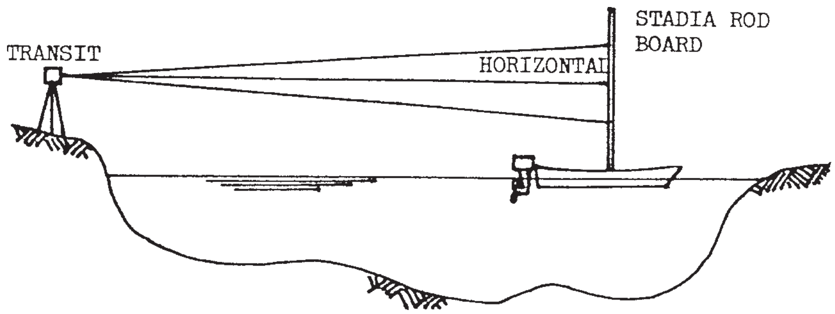

FIG. 6 Stadia Method

marks can be made either by the transit or sounder operator. If made by the transit operator, the spacing is more uniform and the chance for erroneous readings is reduced. If made by the sounding operator, the operator of the water depth measurement instrument, the spacing can be determined by the change in boat speed and the need for distance reading is indicated when abrupt changes in depth are detected.

14.2 The limit for distance measurements using stadia depends on the length of the stadia board and the telescopic power of the transit. This limit should not normally exceed 1000 to 1500 ft (305 to 457 m). Longer distances are possible by stationing an instrument person at each end of the range and overlapping and averaging several stadia readings.

14.3 A stadia board should be at least 15 ft (4.6 m) in length, hinged into two 7½ ft (2.3 m) sections for easy transport, have a triangular cross section with 6 in. (1.5 mm) side widths, and be constructed of aluminum. The markings on the stadia board should be in an alternating pattern of white markings with red points and black markings with yellow points. This enables it to be distinguishable against a variety of backgrounds and more visible at greater distances. In addition the board should be equipped with special marking to signify 250, 500 and 750 ft distances.

14.4 The standard procedure in obtaining stadia measurements is to set the transit on the rangeline alignment, on land, and near the water's edge. The transit should be plumbed over a surveyed control point and be at normal eye level but as near to the water level as possible to avoid the need for excessively long stadia rods. Care must be taken to assure that the stadia rod is firmly mounted in the boat. Stadia readings are best obtained when waves are not present because of the difficulty in obtaining readings in a timely and accurate manner under conditions where the boat is subject to motions of pitch, roll, yaw, and heave. A tape, chain, stadia reading, or other suitable form of measurement will have to be made between the vertical

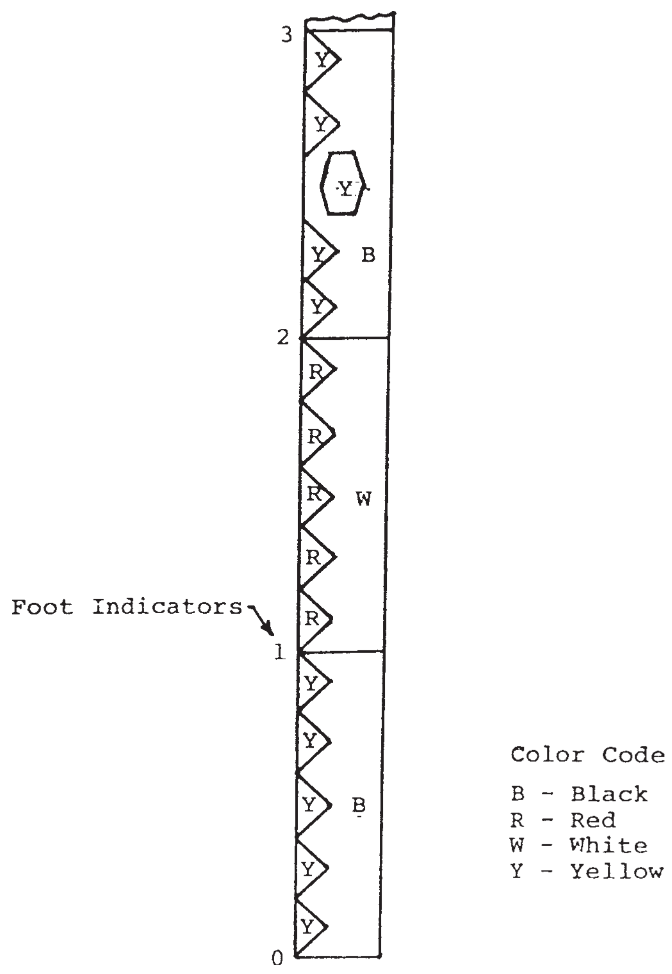

FIG. 7 Stadia Board

centerline of the transit's position and the stadia rod before the boat can begin to proceed along its course. If possible the boat should proceed at a constant speed. A "fix" signal should be given when the boat has to slow down on reaching the shore with a final reading when the boat reaches the opposite bank.

15. Transit Intersection (Optical Procedure)

15.1 This is a two-transit method (see Fig. 8): one transit is placed on line with the boat's prescribed path and used for alignment instructions and the second is located at some known relative position upstream or downstream to permit the determination of an angular position on the boat as it proceeds on its course. The boat's positions along the path is determined by measuring the straight or baseline distance between the two transit stations, A and C, observing the interior angle formed between this baseline and the boat at Station x_i, then solving trigonometrically for the leg of the triangle represented by the distance between the boat and the transit at Station A. Make position readings at 100-ft (30-m) intervals or as essential to permit an accurate profile of the lake bed surface. The angles may be predetermined to intersect fixed positions along the course. Examples would be 100-ft (30 m) or 200-ft (61 m) spacings." Fix" marks are transmitted to the boat by two-way radios as the boat reaches each mark.

15.2 The angle of intersection at the boat should be such that a directional error of 1 min in arc from a transit station will not cause the position of the boat to be in error by more than 1.0 min at the scale of the maps being used. Angles should be maintained between 30 and 150°. Table 3 provides an estimate of positional error due to azimuth misalignments **(7)**.

16. Triangulation/Intersection Positioning (Optical Procedure)

16.1 The intersecting lines of sight (see Fig. 9) from two or more shore based transit or theodolite stations provide an accurate measurement of boat position, suitable for all three classes of horizontal positioning. Each observation point can be determined graphically, by plotting the angular data, or mathematically, by using the known distance between any two shore stations and the inclosed angles formed by the intersecting lines. Read angles to the nearest 0.01° and make at least two backsight checks when the instruments are initially set up. Make frequent rechecks if the instruments are to be used for several sets of measurements.

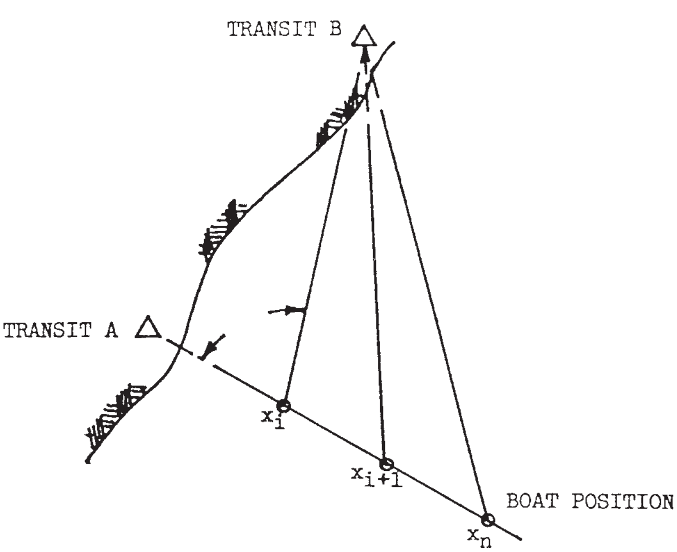

FIG. 8 Transit Intersection

TABLE 3 Positional Error Due to Azimuth Misalignment (7)

Distance, ft (m)		Distance Error per Alignment Procedure			
		Sextant (±20 min), ft (m)		Transit (±2 min), ft (m)	
100	(30)	0.6	(0.2)	0.1	(0.0)
500	(152)	3	(0.9)	0.3	(0.1)
1000	(305)	6	(1.8)	0.6	(0.2)
2000	(610)	12	(3.7)	1.2	(0.4)
5000	(1524)	29	(8.8)	2.9	(0.9)
10 000	(3048)	58	(17.7)	6	(1.8)

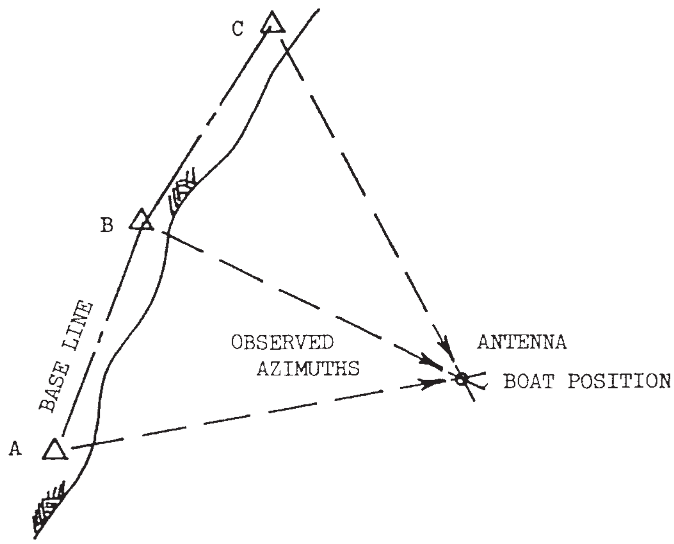

FIG. 9 Triangulation/Intersection

16.2 Accuracy of the triangulation/intersection method is strongly dependent on the precision of the instruments, the experience of the operators, the effectiveness of the coordinated positional "fixes" (made by two way radio), and the accuracy of the control point survey. As in intersection methods, the angle formed by the intersecting lines should be between 30 to 150° **(3)**. Measure azimuths to within 30 s of arc **(1)**.

17. Sextant Measurements (Optical Procedure)

17.1 A sextant is a hand-held instrument used to measure vertical or horizontal angles up to a maximum spread of 140° **(1)**. Although once widely used for boat positioning, a sextant is no longer recommended for positioning of small boats, except under very quiescent stream or lake conditions. This is due to the difficulty in keeping the boat stable long enough to measure the required angles. The sextant angles are observed by holding the sextant in a horizontal plane with the left hand, viewing a specified object through the telescope, and adjusting the mirror reflection of the right hand object until the two objects appear to coincide. At this point, the angle between the two objects is read at the vernier position of a graduated arc attached to the sextant. Sextant positioning should not be made where the angle between the two objects is less than 15° or for short distances of less than 1000 ft (305 m) **(6)**.

17.2 *Sextant Resectioning (Optical Procedure)*:

17.2.1 Sextant resectioning (see Fig. 10) is similar in concept to transit-intersection, except that the observation station is on the boat in lieu of the shore, and baseline distances between shore markings are not normally required. Positions along the boat's path are determined by manually plotting sextant angles between two or more shore marks. Read observations to the nearest 0.1 min of arc. The major drawback to sextant resectioning stems from the fact that it is labor intensive; requiring a boat operator, possibly two sextant observers, a depth recorder operator (if water depths are being measured), and a data logger/plotter **(7)**.

17.2.2 Error sources in sextant resectioning include instability of the observation platform (boat motion), imprecision in the sextant angles, lack of synchronization in observations being made simultaneously, plotting errors, observer fatigue, and target delineation. The potential for error increases noticeably with decreases in boat size because of difficulty in maintaining a stable observation platform with smaller size boats. Precision in the angle measurement depends on the resolution of the instruments, the skills of the observers, how quickly the angles are changing, and the distinction of the shore based targets. The weight of the hand held sextants and the difficulty in holding a stable platform (boat) long enough to obtain an observation adds an additional factor that must be taken into consideration. Such errors make it essential that sextants be calibrated periodically between observations. An estimate of positional error due to sextant azimuth misalignments is given in Table 3 **(7)**.

17.2.3 Angles of observation should ideally be between 20 and 110° of arc. If more than one sextant observation is being made simultaneously, position the observers on the boat as close together as possible to minimize parallax into the adjacent angles of observation. Also, the offset between the position point and the position where the water depth measurement is being made must be taken into account **(1)**.

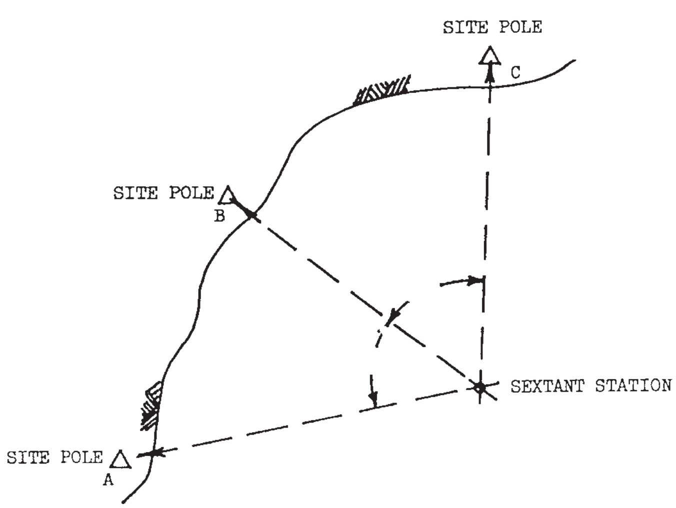

FIG. 10 Sextant Resectioning

PROCEDURE C—ELECTRONIC POSITIONING

18. Scope

18.1 This procedure explains the measurement of horizontal position using electronic positioning systems (EPS). It is electronic distance measurement (EDM) equipment using microwave, visible light, laser light, and infrared light bandwidths.

18.2 Description of techniques and equipment are general in nature. Techniques and equipment may need to be modified for use in specific field conditions.

19. Significance and Use

19.1 Electronic positioning systems offer a broader variety of positioning techniques than available with mechanical and optical methods. This includes automation of angle and distance measurements, position measurement over much longer distances, and potential for on-site microcomputer data storage and processing. In addition to using positioning procedures that are adaptions of those used in optical positioning, the electronic positioning systems permit range-range boat tracking and fully integrated positioning systems.

20. Signal Frequency Selection

20.1 All EPS equipment discussed within this guide is limited to that operating in the super high frequency range (3 to 30 GHz), in contrast to lower frequency systems commonly used for ocean navigation. A classification of various electronic positioning systems is given in Table 4. The higher frequency range provides the needed level of accuracy required for measuring boat positions over distances up to 3 to 5 miles (5 to 8 KM). Most of the techniques applied are adaptations of those used with optically based systems. The techniques vary from shore based range-azimuth systems (in which the stadia rod is replaced with a reflector station) to the more sophisticated boat-based electronic transponder based systems in which distance is measured electronically from the boat to two or more transponders stationed on shore. The position of the boat is calculated on the basis of a trigonometric solution using the measurements between the EDM equipment and the shore based transponders **(8)**. The output from electronic positioning system can be in digital or analog form, but nearly always in a form compatible with automated processing systems. Some

TABLE 4 Electronic Positioning Systems (7)

Bandwidth	Symbol	Frequency	System
Very low frequency	VLF	10 to 30 KHz	Omega
Low frequency	LF	30 to 300 KHz	Loran-C
Medium frequency	MF	300 to 3000 KHz	Raydist, Decca
High frequency	HF	30 to 30 MHz	
Very high frequency	VHF	30 to 300 MHz	
Ultra high frequency	UHF	300 to 3000 MHz	Del Norte
L-Band			NAVSTAR GPS
Super high frequency	SHF	3 to 30 GHz	(Microwave EPS)
C-Band			Motorola
S-Band			Cubic
X-Band			Del Norte
Visible light	...	...	(EDM) [A]
Laser light	...	...	(EDM) [A]
Infrared light	...	...	(EDM), [A] Polarfix

[A] EDM—Electronic distance measuring instrument.

EDM's are also equipped with a microprocessor capable of preprocessing the raw data. This includes removing skew in the data stemming from the boats travel during the measurement, as well as smoothing of the data to eliminate poor signals due to low signal-to-noise ratio, and errors associated with instrument instability **(1)**.

21. Measurement Principals

21.1 EDM instruments operate by transmitting electromagnetic wave energy (the carrier signal) to a receiver station or responder where it is retransmitted as a return signal back to the transmitting station. The delay time or phase shift in the signals (depending on the type of equipment used) provides a measure of distance between the two stations. Special care must be made to avoid the influence of intervening objects between the transmitter and receiving stations, such as trees, hills, buildings and other structures, due to high absorption of the wave energy. EDM's operate either as pulsed wave systems or as carrier phase systems.

21.2 In pulse systems (see Fig. 11) the transmitting station sends out a coded electromagnetic pulse traveling at the velocity of sound to a repeater station where the signal is then amplified and retransmitted to the transmitting station. Distance between the two stations should be computed by the time comparison techniques and is equal to the velocity of sound, approximately 1050 ft/s (350 m/s), times one half the sum of the round trip travel time plus equipment delays. The master device is set up at one end of the distance to be measured. This device creates a beam of electromagnetic radiation, either incandescent light, laser, infrared, or microwave, that serves as a carrier for the waves used for measurement. The beam is directed toward a reflector (in the case of light beams) or a repeater (in the case of microwave) at the other end of the distance where it is reflected to the master station. Signals from the master station are coded such that each specific transponder responds only to the specific transmission intended for it. This coding occurs in the number or spacing of single pulses in a series, or by the interval in the pulses **(1)**.

21.3 Carrier phase systems (see Fig. 12) operate by transmitting a series of waves of constant amplitude and frequency in the form of infra-red or laser light. The receiving stations retransmit the signal back to the originating stations but with a slight phase shift. Distances between the two stations is determined by the phase comparison technique in which the distance is determined as a function of the difference between the outgoing and incoming signals, and the wave length of the signal **(1)**.

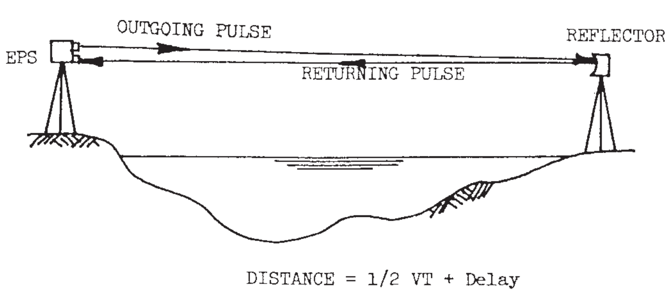

FIG. 11 Pulsing Distance Measurement

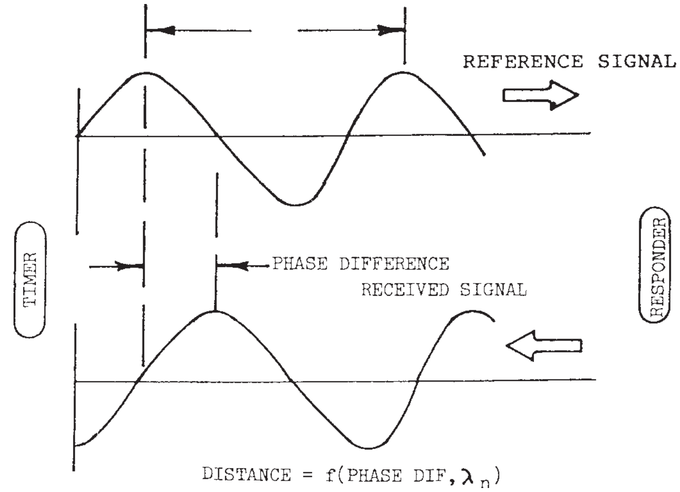

FIG. 12 Phase Comparison Measurement

21.4 EDM equipment of this nature is complex and requires not only an experienced operator but adherence to equipment limitations regarding accuracy, repeatability, and resolution. On-board equipment should be placed directly over or as near as possible to the measurement point. The shore-based transponders should be set so that the two range lines will intersect the boat with an angle as close to 90° as possible; moreover, the transponders must be accurately tied into an appropriate grid system **(5)**. If a transit or theodolite is mounted on the tripod with the EDM, the two need to be in alignment. Sighting objects used in the alignment must be at least 1000 ft (305 m) from the instruments when the adjustments are made. The length of time to make the distance measurement needs to be kept to a minimum and as close to the other types of data being collected as possible. Care needs to be taken to compensate the distance readings for temperature and density effects, although this isn't normally a major error source **(9)**.

21.5 Shore repeater stations are referred to as transponders, trisponders or responders, depending on the equipment manufacturer. Some EDM's also use a passive radar reflector—a specially shaped reflector designed to send back a high percentage of the incident energy **(9)**.

21.6 The advent of the microprocessor has made it possible for electronic instruments (referred to as total-stations) to measure both angles and distance, with the added capability in some instruments to calculate coordinates from azimuth and distance. Some also offer the capability of internally storing data in built-in memory units, externally in data recorders, or microcomputers. This includes the capability to key-in atmospheric temperature and pressure for automatic calculation of atmospheric correction factor and automatic correction of distance readings. Others can also correct distance and angle readings for errors stemming from unlevel instruments. Transmitting signals may be microwave, those that employ phase-comparison techniques, or laser which use the pulse mode of operation **(9)**.

21.7 Total-station survey systems come in a wide range of instruments, but three general types are available: manual, semi-automatic, and automatic. Differences depend on the whether the vertical angle (or zenith angle) is read manually or automatically and how the data is recorded. For manual total-stations, distance and angle measurements are read using a conventional theodolite. Slope reduction is accomplished by keying the vertical angle into an onboard or hand held calculator. In the semi-automatic total station, distances are read optically and the vertical angle is measured by a sensor. Slope reduction is accomplished automatically within the unit. The automatic total station electronically reads both the horizontal and vertical angle, makes the necessary computations automatically, and stores the results in either internal or external computer **(10)**. The choice of which instrument to use depends on the accuracy requirements of the project, the availability of equipment, cost, and the extent of automation affordable.

21.8 Components of a total station generally consist of (*a*) a distancer for measuring slope distance between two points; (*b*) a conventional or electronic theodolite for measuring horizontal and vertical angles; (*c*) a microprocessor for performing limited computational tasks such as determining horizontal measurements from slope measurements and calculating coordinate measurements from a bearing and a distance; (*d*) a digital control panel using a dot-matrix digital display and a 3 to 15-key keyboard to facilitate input of a variety of measurement functions; and (*e*) a data recorder for automatically collecting field data. The data recorder may be a 32 kilobyte or better replaceable memory card mounted to the theodolite for automatic data storage; an external electronic hand held notebook (similar in appearance to a small calculator) for storing field observations; or an external microcomputer used both for data storage and specialized field processing of the data **(10)**. All total-stations include a battery pack capable of operating the equipment for several hours.

21.9 Some total-stations come equipped with a continuous tangent drive that simplifies the process of tracking a moving boat for hydrographic survey work. A conventional theodolite with mounted EDM equipment, coupled with an electronic field notebook, has been the preferred system for this type of work. The latter is not considered to be a total-station unless equipped with an electronic (digitized) theodolite **(11)**. Automatic total stations have greater accuracy over manual methods providing a high accuracy of horizontal and vertical measurements. The improvements in robotics, computation speed, and radio communications have made the automated total stations a compact and preferred system for both stationary and moving measurements providing necessary accuracies for measuring and monitoring elevation changes of the moving survey vessel.

22. Range-Range Tracking (Electronic Positioning Systems)

22.1 Shore stations used for range-range tracking (see Fig. 13) should be placed at locations on high points of land and within clear view of the boat as the boat proceeds along the full length of its course. Each station should be established with at least third order survey accuracy, and each should have a common grid coordinate system and a common reference datum plane. The angle between the recorder on the boat and the imaginary lines extending from the receiver to any two shore stations should not be less than 30° or greater than 150°. For maximum accuracy, the angle of intersection should be the

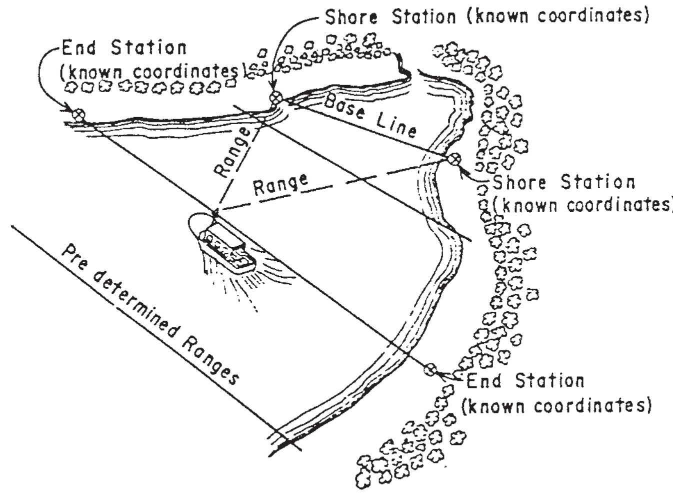

FIG. 13 Range-Range Tracking

largest angle possible. The boat must not be permitted to approach or cross the baseline while the system is in operation. Care also needs to be taken to ensure that the boat remains within an 80° horizontal signal beam broadcast from the shore stations. The vertical angle observed between a horizontal line and an on-board receiver should not exceed 7.5°. Distances between the shore stations and the boat should not be less than 300 ft (91 m) during the time the system is being operated.

23. Instrument Operator Errors

23.1 Calibrate EDM equipment frequently to assure reliable and accurate results. Systematic errors associated with EDM instrument maladjustments include scale, zero, and cyclic errors. These are normally considered to be relatively small, however, when compared to operator and other non-instrument errors.

23.2 Scale errors result when the modulation and design frequencies of the instrument do not correspond correctly. The magnitude of this error is expressed in parts per million (ppm) and should be negligible (<1 ppm). It varies in proportion to measurement distance and, under extreme cases, can be as much as 20 to 30 ppm (20 to 30 mm/km) **(6)**.

23.3 Zero error is equivalent to the difference between the true distance and the measured distance between two points minus errors associated with scale, cycle, and atmospheric sources. It represents a constant error and does not increase with distance. The error source stems from the fact that the instruments or reflectors internal measurement center, or both, do not coincide with the instrument's physical center **(6)**.

23.4 Cyclic errors are cyclic over the modulation wavelength and thus derive their name. Generally speaking they are small compared to other sources of error and originate from internal electronic interference between the transmitter and receiver circuitry **(6)**.

23.5 Instrument calibration is best left to a laboratory specialist but can be done in the field using known baseline length and unknown baseline length techniques. Of the two, only the latter provides a value for scale error **(6)**.

24. Fully Integrated Systems

24.1 Fully integrated positioning systems consist of a boat equipped with electronic positioning equipment, an onboard computer processor (either to serve as a control center for tracking the boats position at any instant of time or as a data logger for storing range data), track plotting equipment, and an electronic data storage unit, either magnetic tape, microcomputer disk, or cassette recorder. All electronic positioners utilize a propagated wave transmitted between the survey boat and a permanent point such as an electromagnetic wave transponder located near the water's edge, or an acoustic wave transponder actually in the water **(5)**.

24.2 System components include a console, data processor, a system operator's terminal, an on-board receiver-transmitter for sending and receiving microwave signals, a tape recorder for storing range profile data, and a track indicator for positioning the boat on-line. Electronic measurements of water depth may also be included as part of the system. Two or more shore stations serve as the transmitting units, each powered with a portable, 24-volt ac power source or rechargeable battery pack. The batteries should be capable of operating for 8 to 10 h between charges.

25. Calibration of Electronic Positioning Equipment

25.1 All commercial electronic positioning equipment is calibrated in the laboratory at standardized air conditions for temperature, pressure and humidity. Changes in these parameters in the field result in very minor changes in calibration **(9)**.

25.2 Regularly check positioning equipment in the field to ensure equipment accuracy by comparing readings from the equipment with known locations of boat position. Make the calibration procedure at the beginning and end of the workday by simultaneously establishing a positional "fix" using EPS and optical equipment, and then comparing the results.

26. EPS Accuracy and Repeatability

26.1 Positioning errors associated with electronic positioning equipment stem from (*a*) errors in the accuracy of the positioning equipment, (*b*) errors associated with the location of the antenna, transmitter, or stadia rod in relationship to the point of measurement being considered, that is, depth of water, sediment sample, velocity measurement, and etc; (*c*) errors in the relative position of the boat with respect to shore transponders; (*d*) errors relating to timing effects; (*e*) errors associated with location of shore station transformers; and (*f*) errors stemming from temperature and density effects on the velocity of electromagnetic wave propagation. Additional sources of error stem from the pitch, roll, yaw and heave motions of the boat.

26.2 Care should be taken to correct for slant range errors that result when the boat is too near an elevated shoreline. This should be done trigonometrically by correcting the horizontal distance, if the magnitude of the correction exceeds 2 m.

27. Global Positioning Systems

27.1 A Global Positioning System (GPS) is a satellite-based EDM system used in determining Cartesian coordinates (x, y, z) of a position by means of radio signals from a NAVSTAR satellite. NAVSTAR is an acronym for Navigation Satellite Timing and Ranging Satellite **(12)** with the first satellite of this type placed in orbit in 1978. Although relatively new and still undergoing technological advancements, GPS-based systems are generally considered to be more accurate and less costly to use than conventual survey methods for obtaining positions of either static monuments or moving platforms. They have the added advantage of being uneffected by weather conditions other than for safety considerations during severe electrical storms. GPS-based systems are rapidly becoming the "referred positioning systems for establishing control monument locations for use in hydrographic surveying and topographic mapping, boundary demarcation, and construction alignment work may be performed using conventional surveying instruments and procedures" **(13)**.

27.1.1 GPS has rapidly become the standard positioning instrument for hydrographic survey systems. **(7)**.

27.2 Positioning of a ground receiver station relies on the processing of signals using two different methods: point positioning (see Fig. 14) and relative positioning (see Fig. 15). These are also referred to, respectively, as absolute and differential positioning. In both methods, range measurements from the receiver station to the satellite station is performed by tracking either the phase of the satellite's carrier signal or the phase code modulated on the carrier signal.

27.3 For point or absolute positioning, a single ground-based GPS receiver is set up at a location of interest and measures the travel time for signals to pass from a minimum of three satellites to the receiver. This process is similar in concept to phase comparison EDM land or hydrographic surveying techniques. At least three satellites are required to provide the *x, y, z* coordinates of the receiver stations and a fourth is needed to resolve timing variations. These measurements permit approximate ranges (that is, distances from the satellites to the receiver) to be computed and reprocessed mathematically through intersection geometry to arrive at the Cartesian (x, y, z) coordinates of the GPS station relative to the center of the earth. These coordinates, in turn, can be further processed with computer software to provide the geodetic coordinates (that is, latitude, longitude, and height) of the position. Corrections for clock errors between the satellites and the receiver and signal propagation delays due to atmospheric conditions are included as part of the computations.

27.4 In relative or differential GPS (DGPS) positioning, two or more receiver stations obtain data from a satellite simultaneously. One station (the reference unit) is placed over a known point (often an NGS coordinate station) and programmed with coordinates of the known point. The second (or mobile unit) is placed at some point of interest. This differential process involves measuring the differences in coordinates between the two receiver stations to arrive at distances and an azimuth of the line between the two stations. It is the relative distance (coordinate difference) between the stations that is of primary interest and not the absolute position of a station. Both stations are simultaneously observing the same satellite, so errors in the satellite position, clock differences, and atmospheric delay estimates are essentially canceled. Although a station might have poor absolute coordinates this is of little

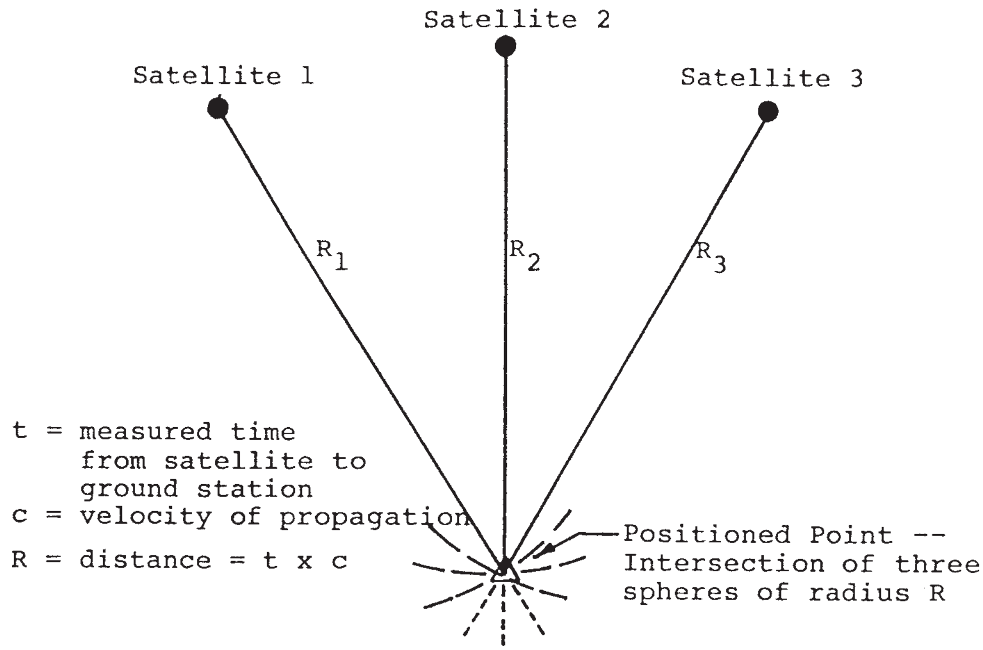

FIG. 14 General GPS Positioning Concept

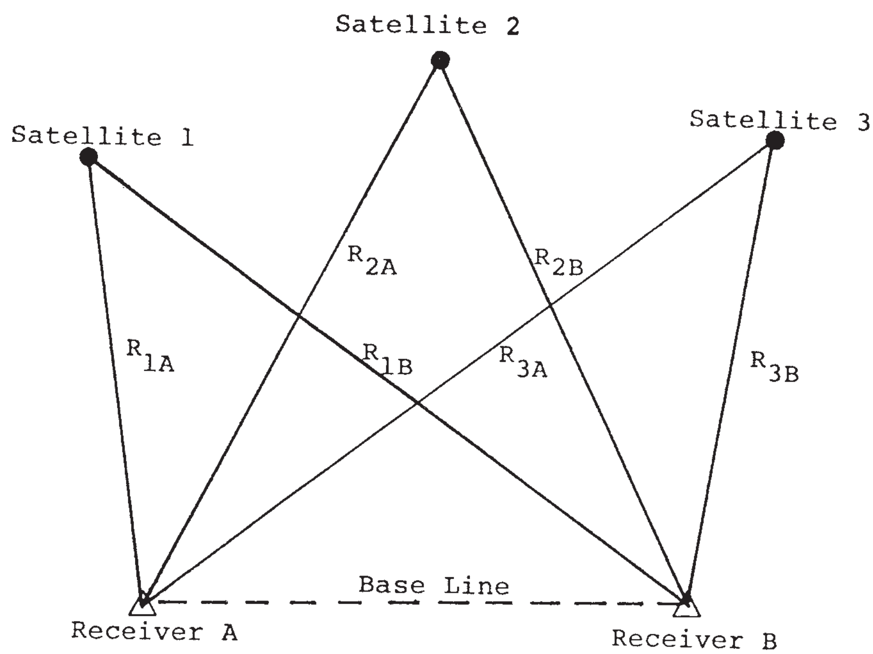

FIG. 15 Relative GPS Positioning

concern since one station is set up over a known point and the coordinate difference is applied to that point to obtain the coordinates of the second point.

27.4.1 Real time DGPS is used in the majority of the hydrographic survey systems for computing positions.

27.4.2 The coordinate difference at the reference unit is broadcasted to the mobile unit for corrected positions in real time.

27.4.3 There are several commercial and government DGPS services that provide real time corrections, or a DGPS reference unit can be set over a known local position.

27.4.4 Depending on the quality of the DGPS units and procedures, real time position accuracies of meter, sub meter, or centimeter are attainable.

27.5 Information transmitted from the NAVSTAR satellites includes two carrier signals referred to as L1 and L2, plus coded messages to enable a receiver station to process the satellite's celestial position and velocity, and other data such as the system time, clock correction parameters, ionospheric delay model parameters, and the satellite's position and health. Both the L1 and the L2 carrier signals correspond to the L-band of the electromagnetic spectrum and have frequencies of

1574.42 and 1227.60 MHz, respectively. The L1 signal is modulated with a precise code (P-Code), having precise timing marks every 30 m, and a coarse acquisition code (C/A-Code), having marks every 300 m. The L2 signal, in contrast, is modulated only with the P-Code. Both the C/A and the P-Codes are referred to as pseudo-random noise (PRN). The satellite's celestial position at any point in time is computed or predicted using past tracking data continuously monitored by a master control station on earth and uploaded to the satellite normally at 8-h intervals. Precise information on the satellite's position can be obtained but only at a later date from the National Geodetic Survey or from private sources that maintain their own tracking networks and provide information for a fee. For most hydrographic survey needs the predicted positions are adequate to obtain the needed accuracies **(13)**.

27.6 For precise geodetic and engineering surveying, the distance from a satellite to a receiver station is determined using the L1 and twelve carrier signals transmitted form the satellite, with corrections applied to adjust for error sources and differences in clock timing. The process involves the satellite and the receiver station transmitting an identical (replica) signals at the same time. The two signals are cross-correlated until they are exactly in phase, and the amount by which the receiver signal is moved to achieve this phase shift is the travel time it took for the satellite signal to reach the receiver. When multiplied by the speed of light this value yields the distance between the satellite and the receiver **(12)**.

27.7 Accuracies achieved with a GPS-based system generally range from 100 m (328.1 ft) down to the millimeter (less than a half-inch) level depending on (*a*) the operating mode, (*b*) the process used in tracking the satellite, and (*c*) the static or dynamic (kinematic) environment under which the receiver is operating. Satellite tracking is performed by monitoring either the phase of the satellite's carrier signal or the pulse codes modulated on the carrier signal. Those positioning systems operating in the absolute mode and using code measurements are in the 100 m (328.1 ft) or upper end of the accuracy range. Those using phase measurements and operating kinematically in the differential mode have accuracies generally in the 1 to 5 cm range, with even greater accuracies possible if operating in the static mode **(13)**.

27.7.1 Selective availability (S/A) was a means for U.S. Department of Defense to purposely degrade the satellite signal to create position errors. With S/A turned on, upper end accuracy was 100 m (328.1 ft). As of May 2000, S/A was turned to zero reducing the upper end of the accuracy range from 10 to 20 meters in absolute positioning mode.

27.8 GPS error sources include ephemerides error (error associated with the celestial position of the satellite), orbit perturbations, clock stability, ionospheric delays, tropospheric delays, multipath errors, and receiver noise. Table 5 lists the more significant error sources and correlates them to the segment source. The total error budget is summarized as the User Equivalent Range Error (USER) and is estimated using a root mean square (RMS) radial error statistic **(13)**.

27.9 Unlike static GPS-based positioning, the receivers in kinematic positioning can not be turned off between positioning points nor can they be allowed to lose contact with the satellites. The latter is referred to as "holding lock." If lock is lost at any time during the positioning then a complete initialization procedure must be undertaken. This includes either (*a*) returning the remote receiver to its previously occupied position; (*b*) swapping antennas between the master and the remote receivers, after they have been in operation and permitted to exchange data for 45 to 90 s; (*c*) positioning both receivers over known stations whose coordinate difference has been determined to within 5 cm and permitting the two receivers to exchange data for 45 to 90 s; or (*d*) using the somewhat time consuming (approximately 45 min) procedure of deriving an initial baseline vector using standard, static GPS positioning techniques. Other cautions to consider in kinematic positioning include making certain that the measurement of the antenna height above the point of interest is measured precisely, that this height does not change between observation stations, and that the antenna is properly plummed over the point. In addition, care must be taken to make certain that the observation time is of sufficient length, that approximated coordinated stations (if these are used) are not too far from the correct values, that correct satellite combinations have been selected, and that the satellite's ephemerial (celestial position) data stored in the receiving units are updated prior to the positioning **(13)**.

TABLE 5 GPS Range Measurement Accuracy

Segment Source/ Error Source	Absolute Positioning				Differential Positioning (P-CODE), ft (m)	
	C/A-Code Pseudo-Range, ft (m)		P-Code Pseudo-Range, ft (m)			
Space						
Clock stability	9.8	(3.0)	9.8	(3.0)	Negative	(Negative)
Orbit perturbations	3.3	(1.0)	3.3	(1.0)	Negative	(Negative)
Other	0.2	(0.5)	0.2	(0.5)	Negative	(Negative)
Control						
Ephemeris predictions	13.8	(4.2)	13.8	(4.2)	Negative	(Negative)
Other	3.0	(0.9)	3.0	(0.9)	Negative	(Negative)
User						
Ionosphere	24.6	(7.5)	7.5	(2.3)	Negative	(Negative)
Troposphere	6.6	(2.0)	6.6	(2.0)	Negative	(Negative)
Receiver noise	24.6	(7.5)	4.9	(1.5)	4.9	(1.5)
Multipath	3.9	(1.2)	3.9	(1.2)	3.9	(1.2)
Other	1.6	(0.5)	1.6	(0.5)	1.6	(0.5)
1-δ UERE	±41.3	(±12.1)	±21.3	(±6.5)	±6.6	(±2.0)

27.9.1 GPS instrumentation and positioning processing techniques are continuously improving providing quicker and more accurate positions. Users have a responsibility to keep up with the latest technology.

27.9.2 Development of fast static kinematic positioning methods has reduced necessary collection time with some units requiring only eight minutes with six visible satellites.

27.9.3 Real time kinematic (RTK) DGPS is based on DGPS and kinematic techniques. RTK procedures allow movement of a GPS receiver after initialization. RTK GPS initialization can occur with a moving receiver, requiring only a minimum of five satellites.

27.9.4 RTK GPS can provide 2 to 5 centimeter accuracies both horizontally and vertically for a moving receiver.

27.9.5 RTK systems are designed not to exceed 20 kilometers from the reference station to maintain the 2 to 5 centimeter accuracy.

27.9.6 A RTK kinematic control point can be accurately measured in as little as 180 field measurements or as little as three minutes with a one-second collection interval.

28. Keywords

28.1 DGPS; GPS; RTK GPS; total station; transit

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