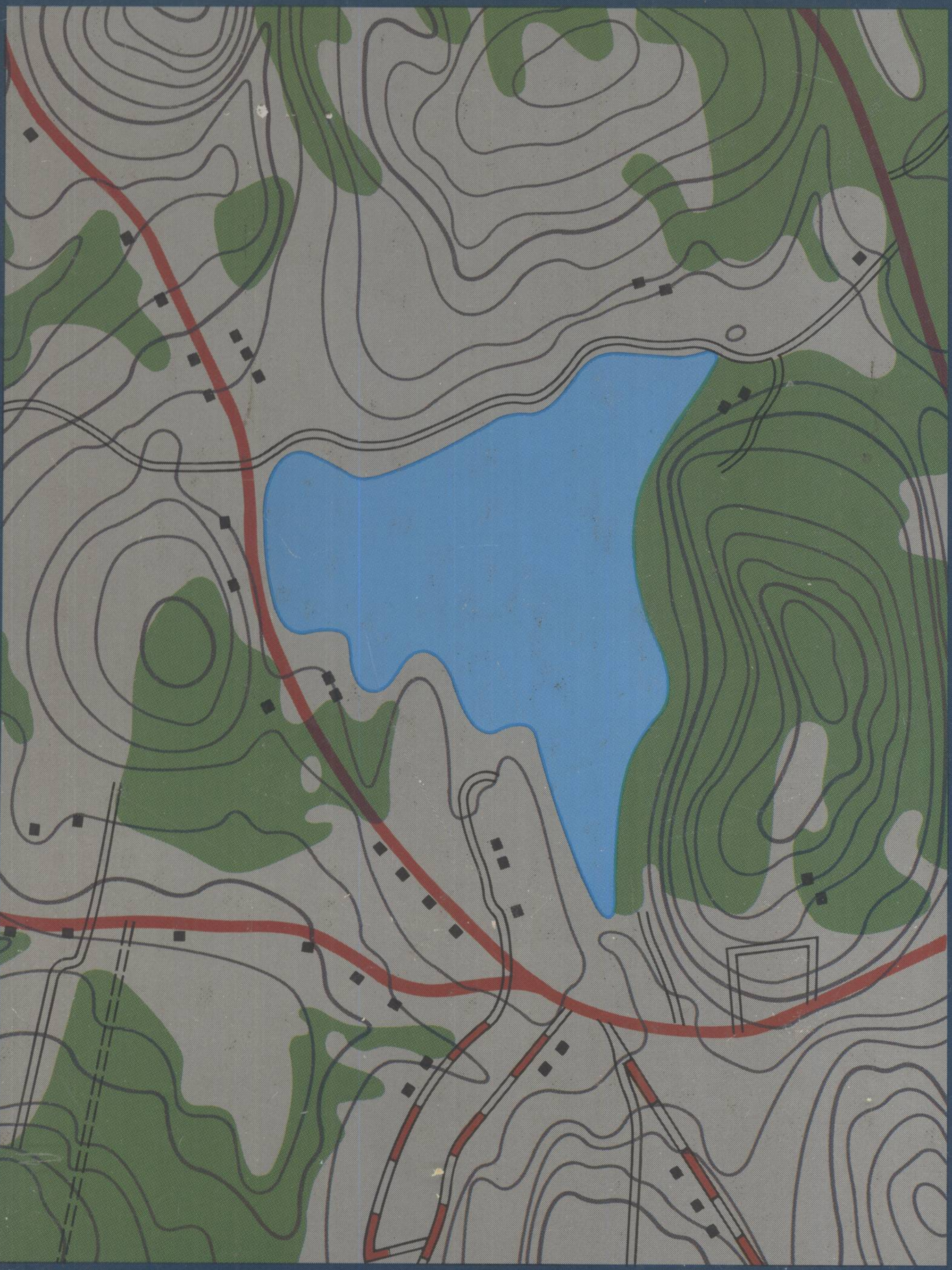
Surveying

Seventh Edition



Francis H. Moffitt / Harry Bouchard

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SEVENTH EDITION

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The late
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HARPER & ROW, PUBLISHERS, New York
Cambridge, Philadelphia, San Francisco,
London, Mexico City, São Paulo, Sydney
1817

Sponsoring Editor: Cliff Robichaud
Project Editor: Pamela Landau
Designer: Robert Sugar
Production Manager: Marion Palen
Compositor: Composition House Ltd.
Printer & Binder: Halliday Lithograph Corp.
Art Studio: J & R Technical Services, Inc.

Surveying, Seventh Edition

Library of Congress Cataloging in Publication Data

Moffitt, Francis H.
Surveying.

(The Harper & Row series in civil engineering)
Includes bibliographies and index.
1. Surveying. I. Bouchard, Harry, 1889–1954.
II. Title. III. Series.
TA545.B7 1982 526.9 81-6826
ISBN 0-06-044559-9 AACR2

Surveying

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Preface

Since the publication of the sixth edition of this textbook in 1975, the practice of surveying has been greatly influenced by spaceage technology. This technology has been applied to the further development, refinement, and miniaturization of electronic distance meters (EDM's), the incorporation of electronic angular measurement capabilities in these instruments, and the automatic storage and processing of survey data by built-in microprocessors. Application of refined inertial guidance and navigation systems to surveying problems has resulted in revolutionary surveying systems which permit large survey projects to be executed with speeds unheard of just a decade ago.

The Navy Navigation Satellite System referred to as Transit now allows the surveyor to determine the position and elevation of any point on earth to an accuracy of one-half metre with the appropriate ground receivers which are constantly being improved. This system of orbiting satellites will become increasingly important to the surveyor in the future as more and more satellites are placed in orbit to give even better positioning accuracy. Positioning by satellite observations has been introduced in Chapter 10, which discusses horizontal control networks.

This seventh edition introduces these new concepts of surveying to students in order they may keep abreast of new technology and be prepared for future developments. The latest EDM's with their capabilities of measuring horizontal and vertical angles have been introduced in Chapters 2 and 4. The principle of the gyroscope as it relates to the determination of directions using the gyrotheodolite is explained in Chapter 7. The gyroscope is also discussed in a new chapter (Chapter 9) on inertial surveying along with the concept of accelerometers for measuring horizontal and vertical displacements.

Discussion of many of the tacheometric instruments described in previous editions of this textbook has been eliminated because the author feels that modern lightweight EDM's have practically displaced these instruments for the rapid measurement of distances.

All logarithmic calculations have been eliminated, in addition to the stadia tables and the tables of trigonometric functions. Modern handheld calculators are capable of generating logarithms where needed, and the trigonometric functions required in surveying computations. They are much more efficient than table lookup. All of the calculations required in the main part of the text can be performed on handheld calculators likely used by the student. Some of the more advanced handheld calculators are required for the reduction of matrix equations found in the appendix on least-squares adjustments (Appendix A).

Minor additions found in this edition include expansion on the use of the metric system, coordinate transformations for use in running random traverses, locating slope stakes by inversing construction lines, the universal transverse Mercator system of rectangular coordinates, modern photogrammetric instruments, descriptions by metes and bounds, subdivision surveys, and the adjustment of intersection and resection surveys by least squares.

The bibliographies at the ends of the chapters have been brought up to date (1980) to reflect the rapidly changing techniques employed in surveying. It is through the selected reading of articles listed in the bibliography that students can expand their knowledge of the principles and practice of surveying. The listings rely quite heavily on publications of the American Congress on Surveying and Mapping[1] and the Canadian Institute of Surveying.[2] These publications are most likely to be found in the college library, or can be obtained through the two societies.

The author wishes to express thanks to all of the teachers and students who have offered comment, criticism, and suggestions relating to the sixth edition. Special acknowledgment is given to Dr. James M. Anderson, Mr. Leslie F. Gregerson, Mr. Sean Curry, Mr. Chris Crawford, Mr. Moir D. Hoag, and Mr. James R. Barr for their help during the preparation of the manuscript of this edition. Finally, the author wishes to thank the instrument manufacturers and the federal agencies who generously furnished many of the photographs and illustrations used in this edition.

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[1] American Congress on Surveying and Mapping, 210 Little Falls Street, Falls Church, Virginia 22046. (703) 241-2446.

[2] Canadian Institute of Surveying, Box 5378, Station F, Ottawa, Ontario, Canada, K2C, 3J1.

Contents

Chapter 1
Introduction

1-1. SURVEYING The purpose of surveying is to locate the positions of points on or near the surface of the earth. Some surveys involve the measurement of distances and angles for the following reasons: (1) to determine horizontal positions of arbitrary points on the earth's surface; (2) to determine elevations of arbitrary points above or below a reference surface, such as mean sea level; (3) to determine the configuration of the ground; (4) to determine the directions of lines; (5) to determine the lengths of lines; (6) to determine the positions of boundary lines; and (7) to determine the areas of tracts bounded by given lines. Such measurements are data-gathering measurements.

In other surveys it is required to lay off distances and angles to locate construction lines for buildings, bridges, highways, and other engineering works, and to establish the positions of boundary lines on the ground. These distances and angles constitute layout measurements.

A survey made to establish the horizontal or vertical positions of arbitrary points is known as a *control survey*. A survey made to determine the lengths and directions of boundary lines and the area of the tract bounded by these lines, or a survey made to establish the positions of boundary lines on the ground is termed a *cadastral, land, boundary*, or *property survey*. A survey conducted to determine the configuration of the ground is termed a *topographic survey.* The determination of the configuration of the bottom of a body of water is a *hydrographic survey.* Surveys executed to locate or lay out engineering works are known as *construction surveys.* A survey performed by means of aerial photography is called an *aerial survey* or a *photogrammetric survey.*

The successful execution of a survey depends on surveying instruments of a rather high degree of precision and refinement, and also on the proper use and handling of these instruments in the field. All surveys involve some computations, which may be made directly in the field, or performed in the office, or in both places.

Some types of surveys require very few computations, whereas others involve lengthy and tedious computations. In the study of surveying, therefore, the student not only must become familiar with the field operational techniques, but must also learn the mathematics applied in surveying computations.

1-2. BASIC DEFINITIONS In order to gain a clear understanding of the procedures for making surveying measurements on the earth's surface, it is necessary to be familiar with the meanings of certain basic terms. The terms discussed here have reference to the actual figure of the earth.

An *oblate spheroid,* also called an *ellipsoid of revolution,* is a solid obtained by rotating an ellipse on its shorter axis. The idealized figure of the earth is an oblate spheroid in which the earth's rotational axis serves as the shorter or minor axis. Because of its relief, the earth's surface is not a true spheroid. However, an imaginary surface representing a mean sea level extending over its entire surface very nearly approximates a spheroid. This imaginary surface is used as the figure on which surveys of large extent are computed.

A *vertical line* at any point on the earth's surface is the line that follows the direction of gravity at that point. It is the direction which a string will assume if a weight is attached to the string and the string is suspended freely at the point. At a given point there is only one vertical line. The earth's center of gravity cannot be considered to be located at its geometric center, because vertical lines passing through several different points on the surface of the earth do not intersect in that point. In fact, all vertical lines do not intersect in any common point. A vertical line is not necessarily normal to the surface of the earth, nor even to the idealized spheroid. The angle between the vertical line and the normal to the spheroid at a point is called the *deflection of the vertical.*

A *horizontal line* at a point is any line that is perpendicular to the vertical line at the point. At any point there are an unlimited number of horizontal lines.

A *horizontal plane* at a point is the plane that is perpendicular to the vertical line at the point. There is only one horizontal plane through a given point.

A *vertical plane* at a point is any plane that contains the vertical line at the point. There are an unlimited number of vertical planes at a given point.

A *level surface* is a continuous surface that is at all points perpendicular to the direction of gravity. It is exemplified by the surface of a large body of water at complete rest (unaffected by tidal action).

A *horizontal distance* between two given points is the distance between the points projected onto a horizontal plane. The horizontal plane, however, can be defined at only one point. For a survey the reference point may be taken as any one of the several points of the survey.

A *horizontal angle* is an angle measured in a horizontal plane between two vertical planes. In surveying this definition is effective only at the point at which the measurement is made or at any point vertically above or below it.

A *vertical angle* is an angle measured in a vertical plane. By convention, if the angle is measured upward from a horizontal line or plane, it is referred to as a *plus* or *positive* vertical angle, and also as an *elevation* angle. If the angle is measured downward, it is referred to as a *minus* or *negative* vertical angle, and also as a *depression* angle.

A *zenith angle* is also an angle measured in a vertical plane, except that, unlike a vertical angle, the zenith angle is measured down from the upward direction of the plumb line.

The *elevation* of a point is its vertical distance above or below a given reference level surface (see Section 3-1).

The *difference in elevation* between two points is the vertical distance between the two level surfaces containing the two points.

Plane surveying is that branch of surveying wherein all distances and horizontal angles are assumed to be projected onto one horizontal plane. A single reference plane may be selected for a survey where the survey is of limited extent. For the most part this book deals with plane surveying.

Geodetic surveying is that branch of surveying wherein all distances and horizontal angles are projected onto the surface of the reference spheroid that represents mean sea level on the earth.

The surveying operation of leveling takes into account the curvature of the spheroidal surface in both plane and geodetic surveying. The leveling operation determines vertical distances and hence elevations and differences of elevation.

1-3. UNITS OF MEASUREMENT In the United States, the linear unit most commonly used at the present time is the foot and the unit of area is the acre, which is 43,560 ft^2. In most other countries throughout the world distances are expressed in metres. The metre is also used by the National Geodetic Survey of the United States Department of Commerce as well as other federal and state agencies in the United States engaged in establishing control. However, the published results of some of these control survey operations are given in both units, or are available to the user in both units.

On all United States government land surveys, the unit of length is the Gunter's chain, which is 66 ft long and is divided into 100 links, each of which is 0.66 ft or 7.92 in. long. A chain, therefore, equals $\frac{1}{80}$ mile. This is a convenient unit where areas are to be expressed in acres, since 1 acre = 10 square chains. A distance of 2 chains 18 links can also be written as 2.18 chains. Any distance in chains can be readily converted into feet, if desired, by multiplying by 66.

In those portions of the United States that came under Spanish influences another unit, known as the vara, has been used. A vara is about 33 in. long. The exact length varies slightly in different sections of the Southwest, where the lengths of property boundaries are frequently expressed in this unit.

For purposes of computation and plotting, decimal subdivisions of linear units are the most convenient. Most linear distances are therefore expressed in feet and tenths, hundredths, and thousandths of a foot. The principal exception to this practice is in the layout work on a construction job, where the plans of the structures are dimensioned in feet and inches. Tapes are obtainable graduated either decimally or in feet and inches.

Volumes are expressed in either cubic feet or cubic yards.

Angles are measured in degrees (°), minutes (′), and seconds (″). One circumference = 360°; 1° = 60′; 1′ = 60″. In astronomical work some angles are expressed in hours (^{h}), minutes (^{m}), and seconds (^{s}). Since one circumference = $24^h = 360°$, it follows that $1^h = 15°$ and $1° = \frac{1}{15}^h = 4^m$ (see Section 12-4).

Although surveying instruments which measure angles in the sexagesimal system are graduated in degrees, minutes, and seconds, it is necessary, in computations with hand calculators, to convert to degrees and decimal degrees (unless the calculator has provision for this conversion) in order to compute the trigonometric functions of the angles, and then if necessary to convert back to degrees, minutes, and seconds. The number of decimal places to be retained in the decimal degree is a function of the least reading of the instrument or of the given angle. Equivalents of the decimal part of a degree are:

$$0.00001° = 0.036''$$

$$0.0001° = 0.36''$$

$$0.001° = 3.6''$$

$$0.01° = 36''$$

$$0.1° = 6'$$

Thus, if the angle is given to the nearest minute, two decimal places must be retained; if the angle is given to the nearest second, then four decimal places must be retained.