Elementary Surveying

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PREFACE

In this fourth edition of ELEMENTARY SURVEYING, changes have been made in every chapter except Chapter 21. Suggestions made by users of the book have been incorporated in the new edition, along with clarifying sentences (some in italics) in many places where experience indicated that they would be helpful. Some of the more important improvements are as follows:

Chapter 2, Theory of Measurements and Errors, has been almost completely rewritten and its coverage greatly expanded.

More complete discussions are given for the Tellurometer, Geodimeter, Electrotape, and other new equipment in Chapter 4, Linear Measurements. Material on the subtense bar has been moved to Chapter 4, and a brief introduction given to triangulation and trilateration. The approach to tape corrections has been revised to better show the signs involved.

Precision requirements and permissible closures are given greater emphasis in several chapters.

A two-page isogonic chart replaces the single-page drawing, and other material on the compass has been upgraded.

Noteforms have been improved by making a few changes.

The uses and advantages of the principle of reversion have been noted throughout the book, where appropriate, instead of just in the chapter on adjustments.

Astronomical data have been brought up to date in examples and tabulations, and source notes added in the illustrations.

The use of second differences in checking parabolic curves has been included.

A larger number of problems and questions at the end of each chapter (totaling about 650) cover a wider range. Where feasible, consecutive odd- and even-numbered problems are similar, except for data. Some problems are carried through several chapters so that progressive steps in their completion can be followed.

As in the third edition, emphasis is placed upon the theory of errors and optics; correlation of theory and practical field methods;

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elimination of typical errors and mistakes; significant figures; use of basic values such as sin 1 min = 0.0003 and sin 1° = 0.01¾ in solving ordinary problems without tables or slide rule; and the interdependence of field, computation, and mapping requirements.

Engineers, architects, geologists, and foresters must be able to make measurements and to analyze the precision and accuracy of the results obtained by other people. They should be qualified to properly locate and set machinery; to lay out houses, buildings, and other common structures; and to understand and prepare simple topographic maps. Each of these areas is discussed, and proper field procedures to obtain a desired precision are noted.

A few cost figures are introduced so that students will learn early in their college work to associate the three bases of engineering practice—theory, application, and costs. All surveying is a constant fight to eliminate or isolate errors and mistakes. In each chapter the student is reminded of this point, through lists of typical errors and mistakes.

Although the third and fourth editions retain the title ELEMENTARY SURVEYING, the material goes beyond the elementary stage in length and scope. The large number of chapters, however, permits inclusion or omission of subjects to correspond with the class time available for students in civil engineering, other engineering curricula, architecture, geology, and forestry. It might be noted that the easy-reading qualities of the third edition have been retained by keeping short lines for ready scanning and fewer lines per page.

Chapters are arranged in the order found most convenient at numerous colleges. Fundamental material is collected in the first sixteen chapters comprising Part I. Theory and use of the four fundamental surveying instruments—the tape, level, transit, and plane table—are described in detail, and new types of equipment are noted. Any chapter following Chapter 11 can be omitted without loss of continuity, although many of them are short enough to be suitable for a single assignment.

Limited coverage of such subjects as photogrammetry, field astronomy, boundary surveys, and industrial applications of surveying methods is given in Part II to fit the programs offered at some colleges. For example, the brief chapter on boundary surveys

is intended to make students aware of a few of the problems involved in the survey and transfer of property, and the legal requirements of professional registration. Some instructors give broad survey-type courses and want their students to get an over-all view of the many facets of the profession. It is believed that the arrangement and scope of material presented herein will meet that need.

Taping, leveling, and transit work are taken up in that order because students find it easier to acquire some facility with the equipment in that sequence, and because this arrangement permits the start and continuation of field work with a minimum of lecture time. The suggested order of field assignments given in Appendix A makes it possible to begin effective computation and drafting-room problems after just a few periods in the field if bad weather is encountered.

The difficulty in getting through all of the preliminary material (basic conceptions of the profession, history, theory of errors, and methods of notekeeping) before commencing field work during the first week is recognized. Nevertheless the authors feel that these topics must precede the theory and use of instruments.

The subject of notes and noteforms—an important part of surveying and engineering—is discussed in a separate chapter. Most of the sample noteforms are collected in Appendix A instead of being scattered throughout the text.

Suggestions and criticism will be greatly appreciated.

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University Park, New Mexico
September, 1961

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CONTENTS

PART I

1. INTRODUCTION 1

Definition of surveying. Importance of surveying. Training for all engineers. History of surveying. Types of surveys. Present status of surveying. The surveying profession. Problems.

2. THEORY OF MEASUREMENTS AND ERRORS 11

Measurements in general. Types of measurements made in surveying. Units of measurement. Direct and indirect measurements. Errors in measurements. Sources of errors in making measurements. Types of errors. Magnitude of errors. Elimination of errors. Scope of probability. Occurrence of accidental errors. General laws of probability. The probability equation. The most probable value; the mean. The standard deviation or standard error. Interpretation of standard error. Probable error. General probability. The error of a sum. The error of a series. The error of the mean. Applications. Adjustments. Significant figures. Rounding off numbers. Methods of computation. Problems.

3. SURVEYING FIELD NOTES 40

General. Requirements of good notes. Types of field books. Kinds of notes. Arrangement of notes. Suggestions on recording notes. Problems.

4. LINEAR MEASUREMENTS 48

General. Methods of making linear measurements. Odometer readings. Pacing. Taping. Tachymetry. Subtense bar. Electronic devices. Care of taping equipment. Taping on level ground. Horizontal measurements on uneven ground. Slope measurements. Stationing. Sources of error in taping. Incorrect length of tape. Temperature. Pull. Sag. Alignment. Tape not horizontal. Plumbing. Incorrect marking. Interpolation. Summary of effects of taping errors. Mistakes or blunders. Tape problems. Laying out a right angle with a tape. Measuring an angle with a tape by the chord method. Measuring an angle with a tape by the tangent method. Laying off angles. Tape survey of a field. Solution of a taping problem. Problems.

5. LEVELING 87
General. Definitions. Curvature and refraction. Methods of determining differences in elevation. Types of leveling instruments. Level vials. Telescopes. Optics. Level bar and supports. Leveling head. Wye level. Dumpy level. Tripods. Tilting level. European instruments. Hand level. Leveling rods. Philadelphia rod. Verniers. Setting up the level. Holding the rod. Theory of leveling. Types of leveling. Differential leveling. Reciprocal leveling. Profile leveling. Drawing and use of the profile. Barometric leveling. Borrow-pit or cross-section leveling. Use of the hand level. Size of field party. Signals. Precision. Adjustment of simple level circuits. Sources of error in leveling. Mistakes. Reduction of errors and elimination of mistakes. Problems.

6. ANGLES, BEARINGS, AND AZIMUTHS 137
General. Units of angle measurement. Measurement of angles. Measurement of direction. Bearings. Azimuths. Comparison of bearings and azimuths. Calculation of bearings. Sources of error. Mistakes. Problems.

7. THE COMPASS 147
General. Theory of the compass. Magnetic declination. Variations in magnetic declination. Local attraction. The surveyor's compass. The forester's and geologist's compass. Brunton compass. Typical problems. Sources of error in compass work. Mistakes. Problems.

8. THE TRANSIT 161
General. The American transit. Upper plate. Lower plate. Leveling head. Scales. Verniers. Method of reading verniers. Properties of an American-type engineer's transit. Other American instruments. Setting up and handling the transit. Operation of the transit. Measuring direct angles by repetition. Closing the horizon. Laying off an angle. Deflection angles. Azimuths. Sights and marks. Prolonging a straight line. Prolonging a line past an obstacle. Balancing in. Random line. Measurement of a vertical angle. European theodolites. Sources of error in transit work. Mistakes. Problems.

9. TRAVERSING 198
Definition and uses. Methods of running a traverse. Traversing by compass bearings. Traversing by direct angles. Traversing by deflection angles. Traversing by azimuths. Measurement of lengths. Selection of traverse hubs. Organization of field party. Traverse notes. Angle closure. Sources of error. Mistakes. Problems.

10. TRAVERSE COMPUTATIONS 208
Purpose. Balancing angles. Computation of bearings. Latitudes and departures. The transit rule. The compass rule. Application

of the rules. Other methods of computing latitudes and departures. Coordinates. Lengths and bearings from latitudes and departures, or coordinates. Coordinate computations in boundary measurements. Traverse orientation by coordinates. Statewide coordinate systems. Sources of error in traverse computations. Mistakes. Problems.

11. AREA 223
General. Methods of measuring area. Area by division into triangles. Area by offsets from straight lines. Area by double-meridian-distance method. Area by coordinates. Area from a map by triangles. Area by coordinate squares. Measurement of area by planimeter. Sources of error. Mistakes. Problems.

12. STADIA 238
General. Measurement by stadia for horizontal sights. Measurement by stadia for inclined sights. Stadia rods. Beaman arc. Instruments with movable stadia lines. Field notes. Field procedure. Stadia traverses. Topography. Stadia leveling. Precision. Sources of error in stadia work. Mistakes. Problems.

13. TOPOGRAPHIC SURVEYS 254
General. Control for topographic surveys. Topographic details. Methods of locating points in the field. Location of lines. Location of lines from a single point. Contours. Characteristics of contours. Methods of obtaining topography. Transit-tape method. Transit-stadia method. Plane-table method. Coordinate squares. Offsets from the center line. Photogrammetry. Solution of field method. Specifications for topographic surveys. Sources of error in topographic surveys. Mistakes. Problems.

14. MAPPING 270
General. Mapping agencies. Map drafting. Plotting the traverse. Advantages and disadvantages of the different methods. Plotting details. Plotting contours. Topographic symbols. Locating the traverse on a map sheet. Meridian arrow. Title. Notes. Paper. Sources of error in mapping. Mistakes. Problems.

15. THE PLANE TABLE 285
General. Description of the plane table. Use of the plane table. Setting up and orienting the plane table. Traversing. Radiation method. Intersection, or graphical-triangulation, method. Resection. The two-point problem. The three-point problem. Leveling. Advantages and disadvantages of the plane table. Plane-table pointers. Sources of error in plane-table work. Mistakes. Problems.

16. ADJUSTMENT OF INSTRUMENTS 304
General. Tapes. Principle of reversion. Adjustment of the wye level. Adjustment of the dumpy level. Adjustment of the transit. Adjustment of the plane-table alidade. Adjustment of the Beaman

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stadia arc. Adjustment of the hand level. Sources of error in adjustment of instruments. Mistakes. Problems.

PART II

17. DETERMINATION OF MERIDIAN 320
General. Methods of determining azimuth. Shadow method. Meridian by equal altitudes of the sun. Meridian from Polaris at culmination. Definitions. Time. Star positions. Observation on Polaris at culmination. Computations for time of culmination. Observation on Polaris at elongation. Computations for an observation at elongation. Observation on Polaris at any hour angle. Practical suggestions on Polaris observations. Comparison of solar and Polaris observations. Methods of observing the sun. Required quantities in determining azimuth by direct solar observation. Notes and computations for a solar observation. Sources of error in meridian observations. Mistakes. Problems.

18. PHOTOGRAMMETRY 342
General. Aerial photogrammetry. Scale of a vertical photograph. Image displacement. Stereoscopic vision. Parallax. Measuring stereoscopes. Stereoscopic plotting instruments. Mosaics. Radial-line plotting. Flight mission. Sources of error in photogrammetry. Mistakes. Problems.

19. BOUNDARY SURVEYS 370
General. Basis of land titles. Property description by metes and bounds. Property description by block-and-lot system. Property description by coordinates. Field work. Registration of title. Sources of error. Mistakes. Problems.

20. SURVEYS OF THE PUBLIC LANDS 382
General. Instructions for survey of the public lands. Initial point. Principal meridian. Base line. Standard parallels (correction lines). Guide meridians. Township exteriors; meridional (range) lines and latitudinal (township) lines. Designation of townships. Subdivision of a quadrangle into townships. Subdivision of a township into sections. Subdivision of sections. Fractional sections. Notes. Outline of subdivision steps. Marking corners. Witness corner. Meander corners. Lost and obliterated corners. Precision of public-lands surveys. Descriptions by township, section, and smaller subdivision. Sources of error. Mistakes. Problems.

21. CONSTRUCTION SURVEYS 404
General. Staking out a pipeline. Staking out grades. Staking out a building. Staking out a highway. Sources of error. Mistakes. Problems.

22. CIRCULAR CURVES 411

General. Degree of curve. Derivation of formulas. Sample computation. Curve layout. Setups on the curve. Sight distance on horizontal curves. Compound and reverse curves; special problems. Sources of error. Mistakes. Problems.

23. PARABOLIC CURVES 423

General. Computations for an equal-tangent curve. Computations for an unequal-tangent curve. High or low point on a vertical curve. Sight distance. Sources of error. Mistakes. Problems.

24. VOLUMES 429

General. Methods of measurement. The cross-section method. Types of cross sections. End-area formulas. Prismoidal formula. Unit-area, or borrow-pit, method. Contour-area method. Sources of error. Mistakes. Problems.

25. INDUSTRIAL APPLICATIONS 437

General. Basic equipment. Sighting telescope. Alignment telescope. Use of alignment telescope. Positioning a part. The jig transit. Use of the jig transit. The tilting level. Optical micrometers. Use of the optical micrometer. Other equipment. Practical applications. Sources of error in optical tooling. Mistakes. Problems.

APPENDIX A 453

Suggested order of field assignments. Sample noteforms.

APPENDIX B: Tables 483

I. Sample pages from traverse table. II. Stadia reductions. III. Table of distances for subtense bar. IV. Convergency of range lines. V. Azimuths of the secant. VI. Offsets, in links, from the secant to the parallel. VII. Functions of circular curves. VIII. Logarithms of numbers. IX. Logarithmic sines, cosines, tangents, and cotangents. X. Auxiliary table for logarithmic sines. XI. Natural sines and cosines. XII. Natural tangents and cotangents. XIII. Lengths of circular arcs for radius = 1. XIV. Trigonometric formulas for the solution of oblique triangles. XV. Relations between linear and angular errors. XVI. Precision of computed values.

REFERENCES 603

INDEX 607

Chapter 1

INTRODUCTION

1–1. Definition of surveying. Surveying is the science or art of making the measurements necessary to determine the relative positions of points above, on, or beneath the surface of the earth, or to establish such points. The work of the surveyor, which largely consists of making such measurements, can be divided into three parts:

FIELD WORK—Making and recording measurements in the field.

COMPUTING—Making the necessary calculations to determine locations, areas, and volumes.

MAPPING—Plotting the measurements and drawing a map.

1–2. Importance of surveying. Surveying is one of the oldest arts practiced by man, because from the earliest times it has been found necessary to mark boundaries and divide land. It is now indispensable in all branches of engineering. For example, surveys are required prior to and during the planning and construction of highways, railroads, buildings, bridges, missile ranges and launching sites, tunnels, canals, irrigation ditches, dams, drainage works, and water-supply and sewerage systems. They are also essential in laying out pipelines and mine shafts. The use of surveying or surveying methods has become common in the layout of assembly lines and jigs, the fabrication of airplanes, and the placement of equipment, and in many related tasks in aeronautical, agricultural, chemical, electrical, mechanical, and mining engineering, and in geology and forestry. Optical tooling represents an application of surveying in shop practice.

1–3. Training for all engineers. All engineers must know the limits of accuracy possible in construction, plant design and layout, and manufacturing processes, even though someone else does the actual surveying. This knowledge is best obtained by making measurements with the surveying equipment employed in practice, as such measurements will provide a true concept of the theory of errors.

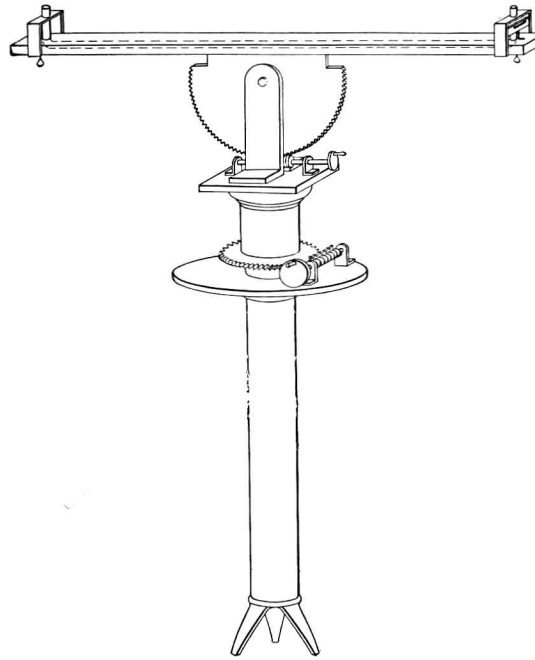

FIG. 1–1. The diopter.[1]

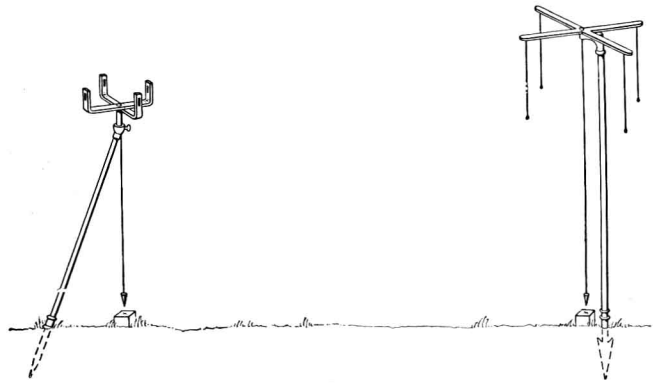

FIG. 1–2. The groma.

[1] Figures 1–1, 2, 3, and 4 are shown through the courtesy of Professor Edward Noble Stone.

In addition to stressing the need for reasonable limits of accuracy, surveying emphasizes the value of significant figures. An engineer must know when to work to hundredths of a foot instead of to tenths or thousandths, or perhaps the nearest foot, and what precision in field data is necessary to justify carrying out computations to the desired number of decimal places. With experience, he learns how the equipment and personnel available govern procedures and results.

Neat sketches and computations are the mark of an orderly mind, which in turn is an index of sound engineering background and competence. Taking field notes under all sorts of conditions is excellent preparation for the kind of recording and sketching expected of engineers. Additional training having a carry-over value is obtained in arranging computations properly.

1–4. History of surveying. The oldest historical records in existence today which bear directly on the subject of surveying state that this science had its beginning in Egypt. Herodotus says Sesostris (about 1400 B.C.) divided the land of Egypt into plots for the purpose of taxation. The annual floods of the Nile River swept away portions of these plots, and surveyors were appointed to replace the bounds. These early surveyors were called *rope-stretchers*. Their measurements were made by means of ropes with markers at unit distances.

As a consequence of this work the early Greek thinkers developed the science of geometry. Their advance, however, was chiefly along the lines of pure science. Heron stands out prominently for applying science to surveying, about 120 B.C. He was the author of several important treatises of interest to engineers, including one called *The Dioptra*, which related the methods of surveying a field, drawing a plan, and making calculations. This treatise also described one of the first pieces of surveying equipment recorded, the *diopter* (Fig. 1–1). For many years Heron's work was the most authoritative among Greek and Egyptian surveyors.

Real development in the art of surveying came through the practical-minded Romans, whose best-known treatise on surveying was by Frontinus. Although the original manuscript disappeared, copied portions have been preserved. This noted Roman engineer and surveyor, who lived in the first century, was a pioneer in the field and his treatise remained the standard for many years.

The engineering ability of the Romans was demonstrated by their extensive construction work throughout the Empire. The surveying

necessary for this construction resulted in the organization of a surveyors' guild. Ingenious instruments were developed and used. Among these were the *groma* (Fig. 1–2), used for sighting; the *libella* (Fig. 1–3), an A frame with a plumb bob, used for leveling; and the *chorobates* (Fig. 1–4), a horizontal straightedge about 20 ft long, with supporting legs and with a groove on top for water to serve as a level.

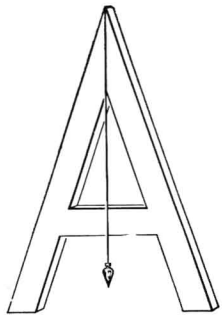

FIG. 1–3. The libella.

One of the oldest Latin manuscripts in existence is the *Codex Acerianus*, written about the sixth century. It contains an account of surveying as practiced by the Romans and includes several pages from Frontinus' treatise. The manuscript was found in the tenth century by Gerbert and served as the basis for his text on geometry, which was largely devoted to surveying.

During the Middle Ages, Greek and Roman science was kept alive by the Arabs. Little progress was made in the art of surveying, and the only writings pertaining to it were called "practical geometry."

In the thirteenth century Von Piso wrote *Practica Geometria*, which contained instructions on surveying. He also wrote *Liber Quadratorum*, dealing chiefly with the *quadrans*, a square brass frame having a 90° angle and other scales marked off on it. A movable pointer was used for sighting. Other instruments of the period were the *astrolabe*, a metal circle with a pointer hinged at its center and held by a ring at the top, and the *cross staff*, a wooden rod about 4 ft long with an adjustable crossarm at right angles to it. The known lengths of the arms of the cross staff permitted distances to be measured by proportion and angles.

In the eighteenth and nineteenth centuries the art of surveying advanced more rapidly. The need for maps and the location of national boundaries caused England and France to make extensive surveys requiring accurate triangulation. Thus geodetic surveying began. The United States Coast and Geodetic Survey was established by an act of Congress in 1807.

Increased land values and the importance of exact boundaries, along with the demand for public improvements in the turnpike, canal, and railroad eras, brought surveying into a prominent position.

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