SURVEY ENGINEERING

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Summary

Surveying is the most traditional and even now an essential and crucial science and art

for human living environments and developments. It is divided into two broad categories: geodetic and plane surveying. This chapter is concerned mainly with plane surveying, which assumes, except for leveling, that the surface of the earth is horizontal. Surveying is generally classified into control survey, topographic survey, and other surveys for specific purposes. The control survey establishes precise horizontal and vertical positions of reference monuments, which serve as the control framework for subordinate survey projects. In the past, triangulation was used for control surveys as a unique reliable method. Since the emergence of electronic distance measurement (EDM) instrument, however, traversing has been a standard technique for control surveys. At present, Global Positioning System (GPS) is getting widely in use. The topographic survey is carried out for making topographic maps, which determines the positions of the natural and man-made features and the configuration of the terrain. In the past, ground survey techniques such as plane table survey were used for these purposes. After World War II, aerial photogrammetry replaced them especially if extensive areas were to be investigated. For relatively small areas, total station, which incorporates an EDM device, an electronic theodolite, and an onboard microprocessor in the same unit, is now a standard device. In addition, a branch of GPS called real-time kinematic GPS is expected to be a new technique for topographic surveys. A satellite that has a sensor of one meter of spatial resolution was successfully launched in 1999, and other satellites with similar spatial resolution are being planned. It is expected that satellite remote sensing with high spatial resolution would serve as an alternative method to aerial photogrammetry. This chapter provides an overview of these trends of surveying together with the historical backgrounds.

1. Introduction

Surveying is the science, art, and technology of determining the locations of natural and man-made features on or near the surface of the earth, and presenting thus derived information in the form of numerical database, map, diagram and the other information media. It often involves subsequent data manipulation and analysis for design and planning of a variety of engineering works.

1.1. Brief Historical Review

From earliest times surveying has been an essential art in the development of the human environment. It is quite certain that surveying has its origin in ancient Egypt. It can be easily imagined that humans needed some knowledge on surveying for the agricultural settlements, for instance, measurement of land boundaries and leveling for irrigation. Besides, the Great Pyramids in ancient Egypt could never have been constructed without knowledge of surveying. Many sciences including mathematics, astronomy, optics, aeronautics etc. have indeed made progress through needs for surveying, and surveying has benefited and developed through these sciences. Astronomical developments and invention of triangulation enabled the precise measurement of the form of the earth and made it possible to make continent and country scale topographic maps. The evolution of the least squares method by F. C. Gauss theoretically improved the error adjustment of measurement data. Photogrammetry made it possible to make topographic maps in remarkably short time and less expense. Surveying is still making progress together with such latest developments as electronics and space technology.

Recently the positioning and observation of the earth have been possible by using satellites. Surveying can therefore be considered one of the most traditional as well as cutting-edge sciences and technologies.

1.2 Geodetic Surveying and Plane Surveying

The principal art of surveying is the measurement of locations of points, i.e. positioning. The technology of positioning is scientifically based on geodesy. Geodesy is the science that treats of investigations of the form of the earth's surface and the relative locations of points on or near the earth. It is well known that the earth is an oblate spheroid, the length of its polar axis being somewhat less than that of its equatorial axis. To determine the positions of points, geodesists have traditionally approximated the form of the earth with an ellipsoid of revolution, which is called reference ellipsoid. Geodetic coordinate positions of points are established in terms of longitude and latitude based on the adopted reference ellipsoid. Thus, the type of surveying which takes into account the shape of the earth is referred to as geodetic surveying.

On the other hand, the area where we carry out surveying for an actual task, e.g., determination of land boundaries and civil engineering work, is often very small portion of the earth. In such a case, the spheroidal shape of the earth may be neglected in the area concerned, and the surface of the earth may be reasonably assumed to be a plane. The type of surveying based on these assumptions is defined as plane surveying. The position of a point is given by rectangular coordinates that are defined in the fixed plane coordinate system, which is in general established for the area in question by the country. This chapter is mainly concerned with the plane surveying.

2. Fundamentals of Plane Surveying

2.1. Plane Coordinate System

Geodetic coordinates and plane coordinates are connected to each other. It is because the plane coordinates are established by projecting, mathematically, the geodetic coordinates on the surface of a cone or of a cylinder (or, in some cases, both). It is certain that the surface of a cone or of a cylinder can then be developed to a plane.

It should be noted that, since the surface of the ellipsoid is curved, no map projection can be made without any distortions. The Lambert conformal conic projection is often used as a projection on a cone. Distortions of this projection occur in the north-south direction; hence, it is used for regions with relatively short north-south dimensions. The projection on a cylinder is known as the Transverse Mercator projection. It is used for regions with relatively long north-south dimensions.

Since the geodetic coordinates are related to the plane coordinates, the products of the geodetic surveying are made available for the use in the plane surveying. Each country has determined accurately the geodetic coordinates, i.e. longitude and latitude, of a large number of points across the territory, and has established the stations marked by ground monuments. The plane coordinates of these points can be represented by map projections; hence, they are utilized as the control points in the plane surveying.

2.2. Vertical Datum

To determine the three-dimensional position of a point, it is necessary to define another dimension other than geodetic coordinates (longitude and latitude) or plane coordinates. This is information about height. The height of a point is defined as the elevation both in the cases of geodetic surveying and plane surveying. The elevation is the vertical distance from a reference level surface, which is called the vertical datum or the vertical datum surface. The geoid, which is an equipotential surface that passes through the mean sea level, is in general regarded as the vertical datum. The mean sea level is determined, normally by each country, as the average height of the sea's surface for all stages of the tide over a long period. It should be noted that the geoid is different from the reference ellipsoid. Since the geoid is an equipotential surface, it is undulated due to the uneven distribution of the earth's mass. Because of this, the geoid is different from the reference ellipsoid, which is mathematically defined as the ellipsoid of revolution.

Each country has established a large number of marked points whose elevations are known. These points are called bench marks. In plane surveying, it is assumed that some bench marks exist in the surveying area.

2.3. Errors in Surveying and Their Adjustments

As to be mentioned below, surveying is basically done by the various types of measurements: distance, angle, height, and their combination. Errors in these measurements are inevitable even if surveyors excise full care in making measurements. These errors are of two types: systematic and random. Systematic errors, as the name suggests, are errors that conform to a pattern or system. For example, a tape for measuring distance is known to be a certain length at some standard temperature. If the temperature when the taping is made is different from this standard temperature, a systematic error will occur. Systematic errors are generally eliminated by correcting theoretically or, sometimes empirically, measured values. Random errors, often called accidental errors, on the other hand do not follow a systematic pattern and are entirely based on the probability theory. Errors in measurements in fact include both systematic and random errors. Systematic parts of errors are usually eliminated first, and the remaining parts are regarded as random errors.

These random errors are statistically adjusted, and then most probable values of measurements are obtained. Since it can be reasonably assumed that random errors conform to a normal distribution (or Gaussian distribution), the most theoretically acceptable method for adjusting random errors is the least squares method. With this method, it becomes possible not only to obtain most probable values but also to statistically test the significance of them.

It should be noted that a random error can never be defined by a single observation. Now assume that a distance along a line is measured by a single trial of taping. Since only one value for the distance is obtained, there is no information about the possible error. If the distance is measured two times, the two values (usually different) will provide information on the error. Likewise, next, assume that a figure of a triangle is obtained by measuring three sides of the triangles. Also in this case, the shape of this triangle is uniquely specified and the error cannot be discussed. If, in addition to distances of three sides, one or more angles of the triangle are measured, the shape of the triangle will not be in general uniquely fixed, and the errors will be visible. In order to identify the existence of errors and to adjust these errors reasonably, redundant observations (i.e., more observations than are necessary to uniquely specify a value or a figure) are required. It is required to make as many redundant observations as possible, to adjust the errors with the least squares method, and to test the statistical significance. This is the best method to carry out highly accurate and reliable surveying. Especially, it is extremely necessary for control surveys, which are conducted to give control frameworks for subsequent surveys such as topographic surveys and engineering surveys.

3. Basic Survey Measurements

3.1. Introduction

Plane surveying is traditionally concerned with the field measurements of three fundamental quantities: (1) distance between two points; (2) the angle subtended at a point; and (3) the height of a point above some datum, normally mean sea level. From these measurements it is then possible to compute the three-dimensional positions of points.

The Global Positioning System (See *Global Positioning System*) can perform the three-dimensional positioning, in general, with much greater accuracy and speed. In the mapping field, aerial photogrammetry (See *Photogrammetry*) has been a standard technique for the positioning of the natural and man-made features because of its efficiency. However, both GPS and aerial photogrammetry often confront some unavoidable constraints of overhead obstructions such as buildings and trees. That is precisely why conventional surveying methods based on measurements of distance, angle, and height are still essential for plane surveying.

3.2. Distance Measurement

Distance measurements are carried out by many different methods. These include pacing, odometer, stadia (tacheometry), subtense bar, taping, electronic distance measurement (EDM) and others. Of these, taping and EDM are the most commonly used methods by surveyors today. In plane surveying the distance between two points means the horizontal distance. If the points are at different elevations, the distance should be measured between the plumb lines at both points; alternatively the physical distance between two points should be corrected to the horizontal distance based on the slope angle.

There are basically two types of tape in common use. Fiberglass tapes are generally used for measurement of short distances. Although not suitable for precise work, these are very convenient and practical for many purposes. For more precise measurement it is required to use steel tapes. In order to accomplish high accuracy with either fiberglass or steel tape, it is necessary to check periodically the graduation on the tape against a standard reference tape, the length of which is known to a higher order of accuracy. In addition, since the measured distance in the field has often length variations caused by differences of temperature and tension in the tape, it is vital to apply appropriate corrections to the measured distance.

Taping has been both the simplest and the most precise method of measuring distance until the development of EDM. In the past, invar tapes, which are made of special nickel-iron steel to reduce length variations caused by differences of temperature, were used for the precise measurement of baselines for triangulation for control surveys to be described later. Nowadays, however, taping is generally confined to the measurement of short distances, especially in the case not requiring highly precise measurement.

The development of EDM equipment is one of the most remarkable advances in surveying since World War II. The EDM determines length by indirectly measuring the time taken by an electromagnetic signal of known velocity to travel from one point (transmitter in EDM instrument) to the other point (reflector as a target) and return. The time can be computed by measuring the phase difference between the transmitted and received signals. Although an observation of the phase difference of signal of unique frequency cannot determine the time, by using several types of signal each with a different frequency, it becomes possible to obtain the travel time through information on phase differences. The first EDM instrument was developed in the late 1940s. Due to advances in electronics and low-power light-emitting diodes during the late 1960s, the devices of EDM made outstanding progress in the aspects of accuracy, price, size (portability), operation (user-friendliness) and others, and have been widely used in surveying.

Prior to the introduction of EDM, distance measurements with high accuracy were made by taping. Precise taping is one of the most difficult surveying tasks, which demand large amount of labor. EDM instruments have made it possible to obtain accurate distance measurements rapidly and easily. The last development in the field of EDM instrumentation is a combination of a digital or electronic theodolite and a microprocessor. The resulting devices are called total stations or electronic tacheometers, which are described later in somewhat more detail.

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Biographical Sketch

Eihan Shimizu is currently Professor at the Department of Civil Engineering of the University of Tokyo, Japan. Professor Shimizu graduated with his Master of Engineering from the Department of Civil Engineering of the University of Tokyo in 1984. After completing his doctorate in Engineering there in 1989, he became Associate Professor at Gifu University, Japan in 1990. Subsequently, he became Associate Professor at the University of Tokyo in 1993 before assuming the position of Professor at the University of Tokyo in 1998. His research interests include satellite remote sensing, image processing, geographic information system (GIS), mathematical cartography, spatial statistical analysis, and regional and urban planning. Professor Shimizu has served as a council member of several Japanese academic societies and associations, such as Japan Society of Photogrammetry and Remote Sensing and GIS Association in Japan. He is currently Secretary General of the Japan Society of Photogrammetry and Remote Sensing.