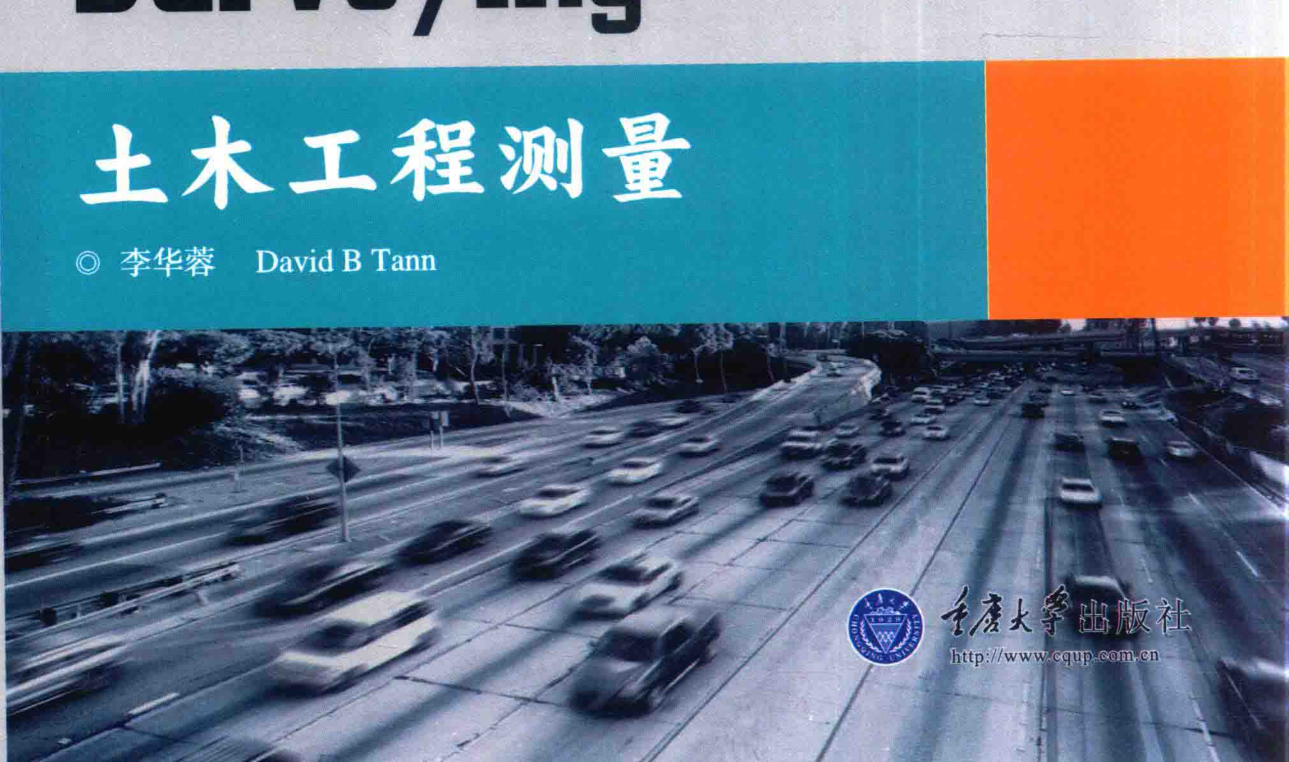
Civil Engineering Surveying

土木工程测量

◎ 李华蓉　David B Tann



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内容提要

本书是根据我国土木工程专业培养目标，参照最新的国家标准规范及规程，以加强基础、注重实用为原则编写的特色英文教材。全书共分 10 个章节，第 1 章至第 5 章主要介绍工程测量学的基本原理和方法，包括测量误差、水准测量、角度测量及距离测量的基础知识。第 6 章介绍测量的坐标系统和方位角。第 7 章介绍控制测量。第 8 章介绍地形图的基本知识及测绘方法。第 9 章介绍放样工作。第 10 章介绍道路与桥梁工程测量。本书侧重基本概念与方法，强调典型工程案例分析，并注重新仪器、新方法和新技术的介绍。

本书全面而系统地介绍了国内外的测量技术，可作为土木工程专业、建筑专业、道路专业的通识教材，同时也可供相关专业的生产技术人员参考。

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I wish to express my great thanks and appreciation to my husband, Yi Zhao and my sisters, Chunmei and Fenghua, for their endless love, encouragement and support without which I would not have been able to complete the manuscripts.

Preface

To produce highly employable graduates who possess the attributes required of professionals in the modern, interconnected world, it is increasingly important for higher education institutions to appreciate the multi-cultural environments and business interdependence nature between nations, and adopt an internationalized approach to education. With China's close interactions with the rest of the world, Chinese universities are actively engaged in the internationalization process by ensuring that the curriculum is industrial relevant, and by providing the students and staff with suitable opportunities for enhanced learning and teaching, through offering information on and support to students who are considering studying or working internally as part of their career planning.

To this end, more and more original English textbooks are being introduced into specialized science, technology and engineering courses at Chinese universities. There are great advantages in using original English textbooks as they are; however, it is inevitable that such an approach has resulted in a number of problems some of which require urgent solution. The differences between nations in standards and codes of design and practice, to start with, need to be addressed. It is thus important to have available English textbooks about both Chinese and international standards, and development characteristics. Within this context this book is prepared and the authors' aim is to present the English textbook in a Chinese sequential and lucid manner, containing all the essentials of practical civil engineering surveying in the Chinese context.

The subject matter in this textbook is covered in ten chapters, not only are fundamental topics such as levelling, angle measurement, distance measurement using tapes and how to carry out traversing and compute coordinates, calculations required for curves, areas and volumes are included, it also covers advanced equipment and techniques that are used in engineering surveying. These latest survey instruments, methods and digital technologies such as electronic theodolites and total stations, digital levels, laser scanners, GPS, GIS and so on, are also introduced.

The textbook has presented a set of comprehensive, updated and thoroughly integrated domestic and international, traditional and latest surveying techniques. The words civil engineering in the title of the book, ***Civil Engineering Surveying***, in meant to be generic for all involved in the construction industry, so the textbook is suitable for use by all civil engineering, building, transport and construction students. It will also be beneficial to any other students who undertake surveying as an elective subject. Practicing engineers and those professionals engaged in site surveying and construction industry will also find the book a useful reference text.

Huarong Li and David B Tann

March 2015

Contents

Chapter 1 Introduction

1.1 Surveying

Surveying has been with us for several thousand years; it is the science of determining the position of features in both the natural and built environment on or below the surface of the Earth and to represent these on a map. Surveying also includes staking out the lines and grades needed for the construction of buildings, roads, dams, and other structures. In addition to these field measurements, surveying includes the computation of areas, volumes, and other quantities, as well as the preparation of necessary maps and diagrams.

In the past few decades there have been great advancements in the technologies used for measuring, collecting, recording, and displaying information concerning the earth. Contemporary surveying is considered to make distance measurements with steel tapes, angle measurements with transits (or theodolites), and elevation measurements with levels. Many on site think that surveying is a labor-intensive method that uses old-fashioned instruments for taking measurements and requires never-ending calculations to be done. Although theodolites, levels and tapes are still used and engineering surveying will always require some calculations to be carried out, the way in which surveys are conducted for civil engineering and construction projects has been transformed in recent years.

Today the surveyor uses electronic instruments to automatically measure, display, and record distances and positions of points. For example, most measurements of distance, angle and height are made using total stations and digital levels similar to those shown in Figure 1.1. Computers are used to process the measured data and automatically or semi automatically produce needed maps and tables with tremendous speed. For example, the CASS software based on AutoCAD can provide several methods to plot electronic maps as showing in Figure 1.2.

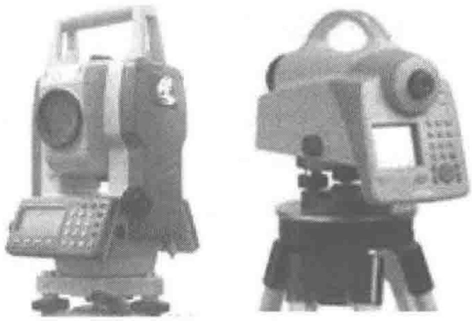

Figure 1.1 Total station and digital level

These developments have contributed to great progress in many other areas including geographic information systems (GIS), land information systems (LIS), the global positioning system (GPS), remote sensing (RS) and others. Not surprisingly, all of these new technologies have resulted in some changes to the way in which engineering surveying is carried out. Until now, the main purposes of engineering surveying have been to supply the survey data required for preparing maps and plans for site surveys, together with all aspects of dimensional control and

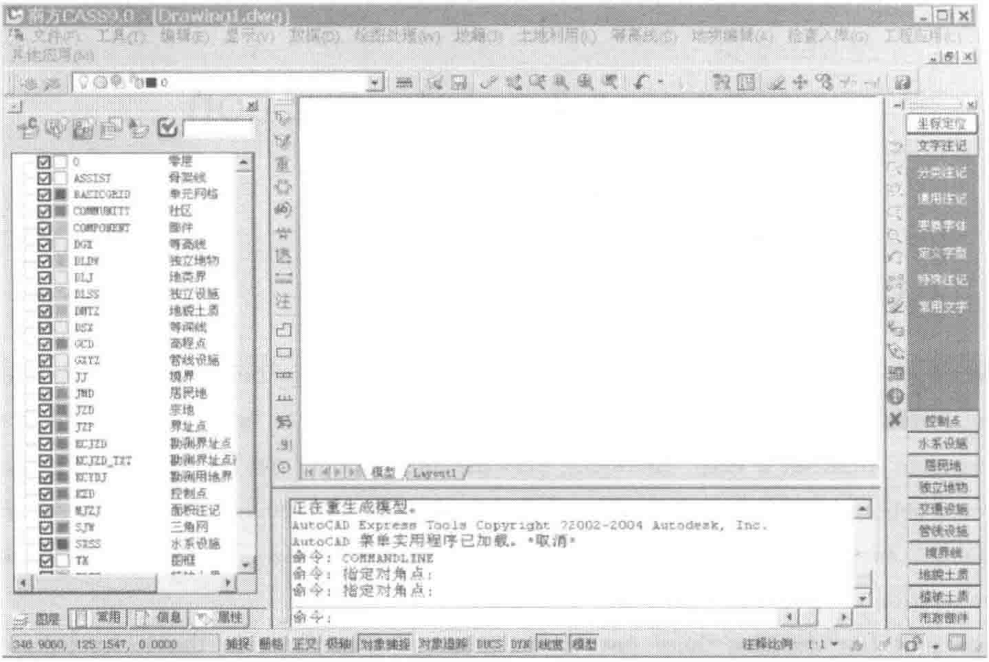

Figure 1.2 CASS software

setting out on site. However, even though they are still relevant, there is now much more emphasis on providing survey data and managing this for both engineering and built environments. As a result many persons have long had a feeling that the word surveying was not adequate to represent all these new activities along with the traditional work of the surveyor.

In 1988 the Canadian Association of Aerial Surveyors introduced the term ***geomatics*** to encompass the disciplines of surveying, mapping, remote sensing, and geographic information systems. Surveying is considered to be a part of this new discipline. Geomatics is a word quite new to the English language and one which is not yet found in either the Oxford or Webster dictionaries.

There are quite a few definitions of geomatics floating around as might be expected considering the term's relative infancy. With each of the definitions, however, there is a common theme and that is "working with spatial data". The "spatial" here refers to space and the "spatial data" refers to data that can be linked to specific locations in geographic space. In this text, we adopted the following definition given by the UK Royal Institution of Chartered Surveyors (the RICS):

Geomatics is the science and study of spatially related information and is particularly concerned with the collection, manipulation and presentation of the natural, social and economic geography of the natural and built environments

The term geomatics is rapidly being accepted in the English speaking world particularly in the colleges and universities of the United Stated, Canada, Australia, and the United Kingdom.

Although this text is primarily concerned with surveying, the reader needs to understand that surveying is part of the very large, modern and growing field of geomatics.

1.2 Types of surveys

This section is devoted to a brief description of the various types of surveys which include land surveys, topographic surveys, route surveys, city surveys, construction surveys, hydrographic surveys, marine surveys, mine surveys, photogrammetric surveys, remote sensing and as-built surveys, etc.

Land surveys are the oldest type of surveys and have been performed since earliest recorded history. They are normally plane surveys made for locating property lines, subdividing land into smaller parts, determining land areas, and providing any other information involving the transfer of land from one owner to another. These surveys are also called ***property surveys***, ***boundary surveys***, or ***cadastral surveys.*** Today, the term cadastral is usually used with regard to surveys of public lands.

Topographic surveys are made for locating objects and measuring the relief, roughness, or three-dimensional variations of the earth's surface. Detailed information is obtained pertaining to elevations as well as to the locations of constructed and natural features (buildings, roads, streams, etc.) and the entire information is plotted on maps (called topographic maps).

Route surveys involve the determination of the relief and the location of natural and artificial objects along a proposed route for a highway, railroad, canal, pipeline, power line, or other utility. They may further involve the location or staking out of the facility and the calculation of earthwork quantities.

City or municipal surveys are made within a given municipality for the purpose of laying out streets, planning sewer systems, preparing maps, and so on. When the term is used, it usually brings to mind topographic surveys in or near a city for the purpose of planning urban expansions or improvements.

Construction surveys are made for purposes of locating structures and providing required elevation points during their construction. They are needed to control every type of construction project. It has been estimated that 60% of surveys done in China is construction surveying.

Hydrographic surveys pertain to lakes, streams, and other bodies of water. Shorelines are charted, shapes of areas beneath water surface, are determined, water flow of streams is estimated, and other information needed relative to navigation, flood control, and development of water resources is obtained. These surveys are usually made by a governmental agency, for example, the National Administration of Surveying, Mapping and Geoinformation, the Ministry of Water Resources of the People's Republic of China.

Marine surveys are related to hydrographic surveys, but they are thought to cover a broader area. They include the surveying necessary for offshore platforms, the theory of tides, and the preparation of hydrographic maps and charts.

Mine surveys are made to obtain the relative positions and elevations of underground shafts, geological formations, and so on, and to determine quantities and establish lines and grades for work to be done.

Forestry and geological surveys are probably much more common than the average layperson realizes. Foresters use surveying for boundary locations, timber cruising, topography, and so on. Similarly, surveying has applications in the preparation of geological maps.

Photogrammetric surveys are those in which photographs (generally aerial) are used in conjunction with limited ground surveys (the latter being used to establish or locate certain control points visible from the air). Photogrammetry is extremely valuable because of the speed with which it can be applied, the economy, the applications to areas difficult to access, the great detail provided, and so on. Its use is becoming more extensive each year and is today used for a very large percentage of those surveys which involve significant acreage.

Remote sensing is another type of aerial survey. It makes use of cameras or sensors that are transported either in aircraft or in artificial satellites. Photogrammetry and remote sensing technology is the technology development of a frontier technology. After 40 years of development, in our country the technology of photogrammetry and remote sensing has obtained a series of progresses, for example, successfully manufacturing a series of sensor, launching more than 50 Earth Observation Satellites which comprise the four civil series of Earth Observation Satellites System using in atmosphere, marine, resources and environmental disaster reduction. The total amount of accumulated image data is up to 660TB, covering the national land and sea areas in our country and neighboring countries and the area 1,500 square kilometers.

As-built surveys are made after a construction project is complete to provide positions and dimensions of the features of the project as they were actually strutted. Such surveys not only provide a record of what was constructed but also provide a check to see if the work proceeded according to the design plan.

The usual construction project is subject to numerous changes from the original plans due to design changes as well as to problems encountered in the field, such as underground pipes and conduits, unexpected foundation conditions, and other situations. As a result, the as-built survey becomes a very important document that must be preserved for future repairs, expansions, and modifications. For example, just imagine how important it is to know the precise location of water and sewer lines.

Control surveys are reference surveys. For a particular control survey a number of points are established and their horizontal and vertical positions are determined. The points are established so that other work can conveniently be referenced or oriented to them.

The horizontal and vertical control, form a network over the area to be surveyed. For a particular project the horizontal control is probably tied to property lines, road center lines, and other prominent features. Vertical control consists of a set of relatively permanent points that form the bench marks, the elevation of these points above or below sea level is then determined.

In the decades to come, undoubtedly other special types of surveying will be developed. Surveyors might very well have to establish boundaries under the ocean, in the Arctic and Antarctic, and even on the Moon, the Mars and other planets. Great skills and judgment by the surveying profession will undoubtedly be required to handle these tasks.

1.3 Plane surveys and Geodetic surveys

1.3.1 Plane surveys

In large-scale mapping projects, adjustments are made for the curvature of the earth and for the fact that north-south lines passing through different points on the earth' s surface converge at the north and south poles. Thus, these lines are not parallel to each other except at the equator (see Figure 1.3), plane surveys, however, are made on such small areas that the effect of these factors may be neglected. The earth is considered to be a flat surface and north-south lines are assumed to be parallel. Calculations for a plane surface are relatively simple, since the surveyor is able to use plane geometry and plane trigonometry.

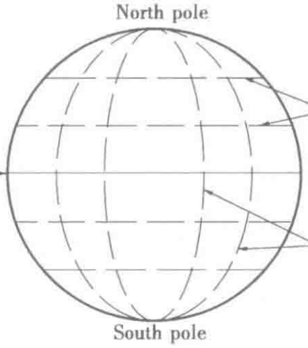

Figure 1.3 North-south lines and East-west lines for the Earth

Surveys for farms, subdivisions, buildings, and in fact most constructed works are plane surveys. They should, however, be limited to areas of a few square kilometers at most. They are not considered to be sufficiently accurate for establishing state and national boundaries which involve very large areas.

It can be shown that an arc along the earth's curved surface of 10km in length is only approximately 0.8cm longer than the plane or chord distance between its ends. As a result, it probably seems to the reader that such discrepancies are insignificant. Direction discrepancies due to the convergence of north-south lines are, however, much more significant than are distance discrepancies.

1.3.2 Geodetic surveys

Geodetic surveys are those that are adjusted for the curved shape of the earth' s surface. (The earth is an oblate spheroid whose radius at the equator is about 21.7km greater than its polar radius.) Since they allow for earth' s curvature, geodetic surveys can be applied to both small and large areas. The equipment used and the methods of measurement applied are about the same as they are for plane surveys. Elevations are handled in the same manner for both plane and geodetic surveys. They are expressed in terms of vertical distances above or below a reference curved surface, usually mean sea level (MSL).

Most geodetic surveys are made by government agencies, such as the National administration of Surveying, Mapping and Geoinformation. Although only a relatively small number of surveyors are employed by the National Geodetic Surveys, their work is extremely important to all other surveyors. They have established a network of reference points throughout China that provides very precise information on horizontal and vertical locations. On this network all sorts of other surveys (plane and geodetic) of lesser precision are based.

1.4 How to carry out surveys

1.4.1 Basic measurements in surveying

The surface of the earth over any engineering site is really only a collection of points lying at different heights. The aim of surveying is to determine the 3D coordinates of points (X, Y, H). Due to the different coordinate systems, the coordinate values of the same point will change, it is difficult to directly measure the coordinates in the field. However, the geometrical relationships between two points don't change, we can take sufficient measurements, linear and/or angular, to relate any one unknown point to any two other known points, and finally calculate the 3D coordinates of the unknown point, which is the surveying essence.

In Figure 1.4(a) and 1.4(b), the three points A, B and C are taken to lie on a horizontal plane on account of the assumption above. Their relative positions can be fixed in a number of ways, depending largely upon the area covered by the points. In Fig. 1.4(a), the area is small and can be surveyed by using plane surveys only. In Fig. 1.4(b), the area is much larger in extent and angle measurements would be required.

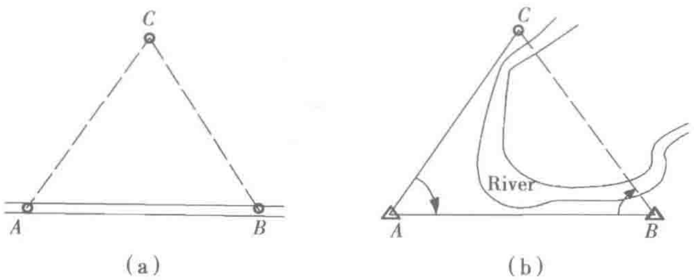

Figure 1.4 Measurement of a point

In Fig. 1.4(a), in order to determine the desired point C, the lengths AB, AC, and BC are all measured in the field which is called ***trilateration***. Length AB is then drawn to scale on paper, and arcs representing the lengths AC and BC are drawn using compasses to intersect in the point C. The coordinates of the point C can be calculated through mathematics.

In Fig. 1.4(b), the line AB, known as the baseline, is measured by tape or by electromagnetic means (EDM). Angles CAB and CBA are measured using a theodolite or total station, which is known as ***traversing***. The survey could then be drawn to scale with scale rule and protractor but would almost certainly be calculated and plotted using rectangular coordinates.

When points lie on different plane, it is necessary to determine the difference in elevation between two points (See Figure 1.5). The difference in elevation is measured by level or by theodolite. The elevation of the desired point is then calculated by the elevation of known point adding the difference.

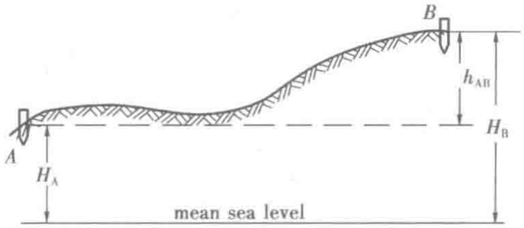

Figure 1.5 Surveying of the difference in elevation

Thus, in surveying, three basic quantities are measured — heights, angles and distances.

1.4.2 Process of surveying

The survey could be carried out by any of the methods described above. Survey work is generally carried out in three parts, (1) control surveys, (2) detail surveys and (3) setting out.

1. Control surveys

All types of engineering survey are based on control networks which consist of a series of fixed points located throughout a site whose positions are determined on some coordinate system. The process of measuring and defining the positions of the points is known as a ***control survey***. The points are called control points.

A control survey is often based on local ***horizontal control***, as points on a two-dimensional horizontal plane which covers the site, and ***vertical control***, which is the third dimension perpendicular to the chosen horizontal datum. In these control surveys, horizontal angles and distances are measured for horizontal control and vertical angles and distances for vertical control.

Many different methods can be used to carry out a control survey for construction work.

- For small sites

This type of control survey falls within the category of ***plane surveying***, in which a flat horizontal surface is used to define the local shape of the Earth (ignoring its curvature) with the vertical always taken to be perpendicular to this. The reason for adopting a flat rather than curved surface for surveying is to simplify the calculation of horizontal position by plane trigonometry. Heights are easily defined to be vertically above (or below) a chosen horizontal datum, but they can be related to mean sea level.

Data for local control survey of this type can be obtained and processed by a variety of methods. For example, a total station can be used to observe horizontal control in the form of a traverse, with levelling providing the vertical control. Alternatively, a three-dimensional traverse can also be measured. The field and office procedures used in this type of control survey are described in several chapters of ***Surveying for Civil Engineering***, from Chapter 3 Levelling through to Chapter 7 Control survey for small regions.

- For large sites

For large sites, there comes a point in a control survey when the assumptions made in plane surveying are no longer valid and the curvature of the Earth has to be accounted for. This limit occurs when a site is greater than 10 ~ 15km in extent in any direction. The type of surveying that accounts for the shape of the Earth is known as ***geodetic surveying*** and geodetic coordinates are used to define the positions of control points for projects that cover very large areas.

The positions of control points for geodetic surveys are obtained using methods based on GPS (Global Position Systems). A GPS receiver determines position using data transmitted from orbiting satellites, initially in a three-dimensional space-related satellite coordinate system. Using well-established ***formulae***, the satellite position is transformed into a three-dimensional geocentric coordinate system physically related to the Earth. Again using well-established formulae, the geocentric coordinates are then transformed into three-dimensional geodetic coordinates based on a global or regional datum and assumed shape of the Earth. Although this appears to be a complicated process, GPS receivers and computers are capable of performing all the necessary measurements and calculations to determine position for geodetic surveys. As a result, satellite surveying systems have provided a practical solution to the problem of determining the positions of control points over large areas, and methods based on GPS are used extensively for providing geodetic survey control.

The coordinates of points in a geodetic control survey are defined very differently from those in plane surveying because they are based on a curved surface and are three-dimensional rather than having different horizontal and vertical components. Compared to plane coordinates and heights, geodetic coordinates are difficult to use in everyday tasks in surveying, and it is always more convenient to try to plane coordinates and separate heights based on mean sea level, even for projects that cover large areas. To be able to use plane coordinates over a large area and account for Earth curvature requires a two-dimensional ***map projection*** to represent the three-dimensional shape of the Earth. Once a map projection is defined, it is possible to convert geodetic coordinates into plane coordinates which is described in Chapter 6. To be able to use heights over a large area, a geoid model is used to convert geodetic coordinates into heights based on mean sea level. In this way, it is possible to have position defined for lager areas in the same way as for plane surveys, with all the advantages this has (see Chapter 3).

For example, Figure 1.6 shows hill, house, river, bridge and road covering about one hectare of ground, which would be considered to be a medium sized site. In order to map the site, control survey is first established over the whole site to form a sound geometrical figure. Points A, B, C, D, E, and F are marked out as control points, and one of the above methods is used to determine the coordinates of control points.

2. Detail surveys

Following a control survey, the next stage in an engineering survey is to produce scale plans and other data to describe a site; the process for this is called detail surveying, topographic surveying or mapping.

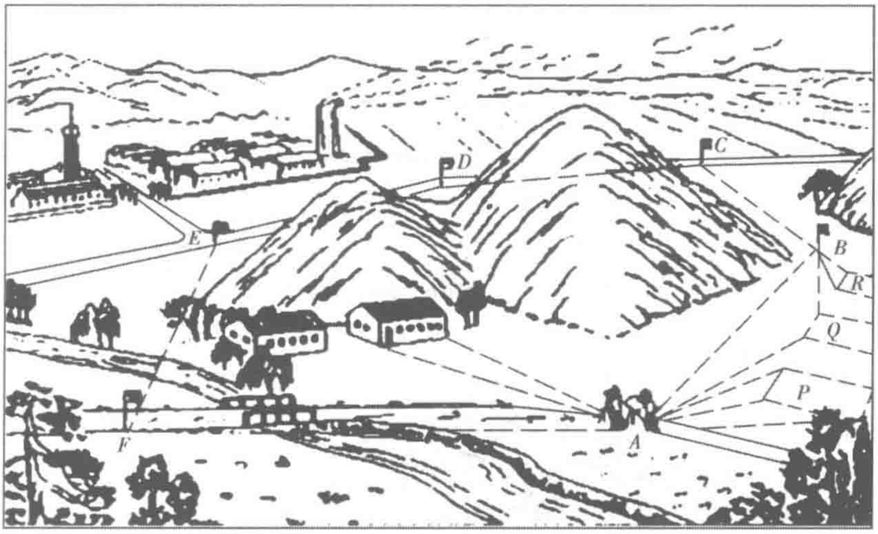

Figure 1.6 Control survey

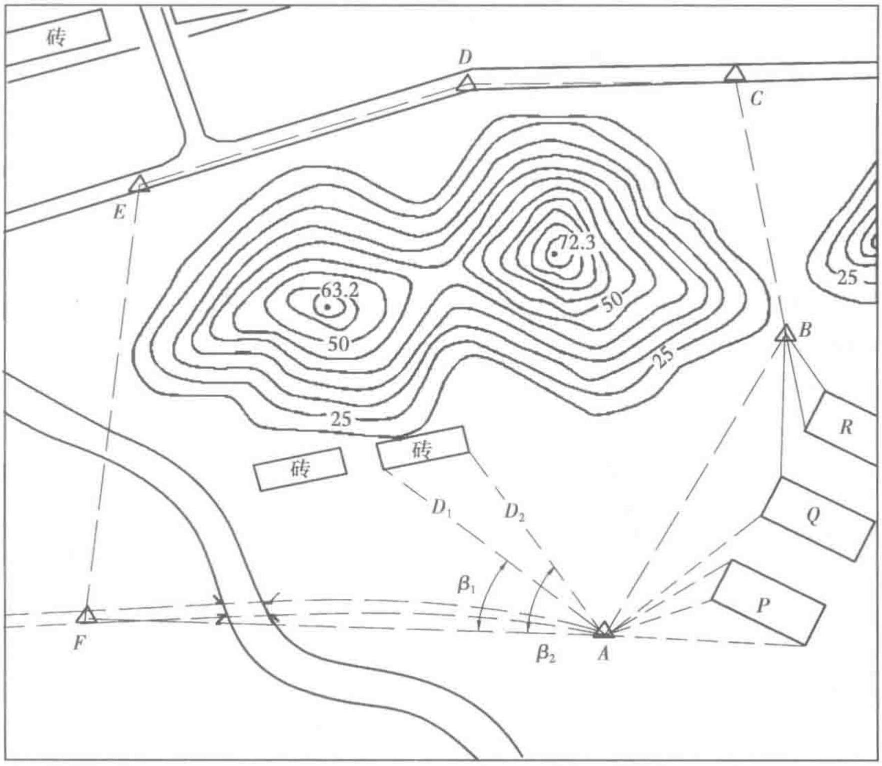

Figure 1.7 Detail surveys

Now Control points have been usually established over the site and a detail survey can be prepared to produce maps, plans and 3D visualization of the site. For small to medium-sized sites, the control points are used as reference points from which measurements are taken with total stations, reflection prisms and GPS receivers to locate the features to be modeled. Figure 1.7 shows a detail survey being carried out with a total station and subsequent data processing in the office.

Without a detail survey of some sort, a construction project could not proceed. For large projects, photogrammetry and remote sensing techniques are used for data capture, but for smaller