1 INTRODUCTION

1.1 DEFINITION OF SURVEYING

In a traditional sense, surveying may be defined as the art and science of making and analyzing measurements made on, above or below the surface of the earth, and the processing of these measurements into some positional form such as maps and coordinates. It also includes the opposite activities that involve the establishment of the positions on, above or below the surface of the earth of points which have been previously located on a plan or a map by a design engineer. The measurements include both angles and distances performed in the horizontal, as well as, the vertical direction. They also include positional data (coordinates) obtained using modern positioning technology such as Global Positioning Systems.

In a broader sense, surveying is defined as the art and science of obtaining reliable quantified and qualified measurements; the interpretation of those measurements, and the meaningful presentation of the results.

1.2 DEFINITION OF A SURVEYOR

The International Federation of Surveyors defined the surveyor as a professional person with the academic qualifications and technical expertise to practice the science of measurement; to assemble and assess land and geographic related information; to use that information for the purpose of planning and implementing the efficient administration of the land, the sea and structures thereon; and to instigate the advancement and development of such practices.

Practice of the surveyor's profession may involve one or more of the following activities, which may occur, on, above or below the surface of the land or the sea and may be carried out in association with other professionals.

1. The determination of the size and shape of the earth and the measurement of all data needed to define the size, position, shape and contour of any part of the earth's surface.

2. The positioning of objects in space and the positioning and monitoring of physical features, structures and engineering works on, above or below the surface of the earth.
3. The determination of the position of the boundaries of public or private land, including national and international boundaries, and the registration of those lands with the appropriate authorities.

4. The design, establishment and administration of land and geographic information systems and the collection, storage, analysis and management of data within those systems.

5. The study of the natural and social environment, the measurement of land and marine resources and the use of the data in the planning of development in urban, rural and regional areas.

6. The planning, development and redevelopment of property, whether urban or rural or whether land or buildings.

7. The assessment of value and the management of property, whether urban or rural and whether land or buildings.

8. The planning, measurement and management of construction works including the estimation costs.

9. The production of plans, maps, files, charts and reports.

In the application of the foregoing activities, surveyors take into account the relevant legal, economic, environmental and social aspects affecting each project.

1.3 IMPORTANCE AND USES OF SURVEYING

Surveying is a subject of high importance because it affects many aspects of the human activities. Since old times, it has been closely related to the prosperity and welfare of mankind. Briefly, it deals with:

- Locating and describing property boundaries for area measurement, dispute resolution between neighbors, etc.
- The preparation of plans associated with the work of the civil engineer, architect, builder and town planner.
- The making of maps and plans for military, geographical, geological, agricultural and other purposes.

1.4 HISTORICAL CONNECTION BETWEEN CIVIL ENGINEERING AND SURVEYING

All civil engineering activities require the use of measured data, both in the field and in the office. For example, a typical civil engineering project first requires that a map or other scaled representation be made of a portion of the earth's surface. The land or engineering surveyor makes the field measurements for such a map. After the design of the project by a civil engineer, it must be "staked" by surveyors or surveying technicians so as to guide the contractor through the construction phase. Most civil engineering projects require the location of real property boundaries, and this requires the services of a land surveyor. Therefore, the tasks of civil engineering and surveying are very closely connected.

1.5 THE FIGURE OF THE EARTH AND ITS RELATION TO SURVEY MEASUREMENTS

As mentioned in the introduction, surveying can be simply defined earlier as earth measurements, and as such, an understanding of the size and shape of the earth is necessary.

The ancient Greeks were among the first to take interest in the dimensions of the earth. In the 6th century (BC), Pythagoras suggested that the earth is spherical. Eratosthenes, on the other hand, was perhaps the first one to take measurements and calculate the size of this assumed sphere. His method can be summarized as follows (Figure 1.1):

a. The distance between the cities of Aswan and Alexandria in Egypt was estimated to be 5000 Stadia (each stadia ≈ 185.2 m). This was based on the fact that a camel will cross the distance between the two cities in 50 days, with an average speed of 100 stadia/day.

b. Eratosthenes measured the central angle opposite to this distance as follows:

   1) On the longest day of the year, he noticed that sun rays at noon are perpendicular at a well located in Aswan. This means that the extension of these rays would go through the center of the assumed spherical earth.

   2) At the same time during the longest day of the next year, he measured the shadow (s) of a perpendicular pole of height h (Figure 1.1) which is located in Alexandria. To make sure that it was the same time, he watched the shadow of the pole around noon until it became the shortest, and measured it. Using Equation 1.1, he then calculated angle α, and found it to be 7.2°.

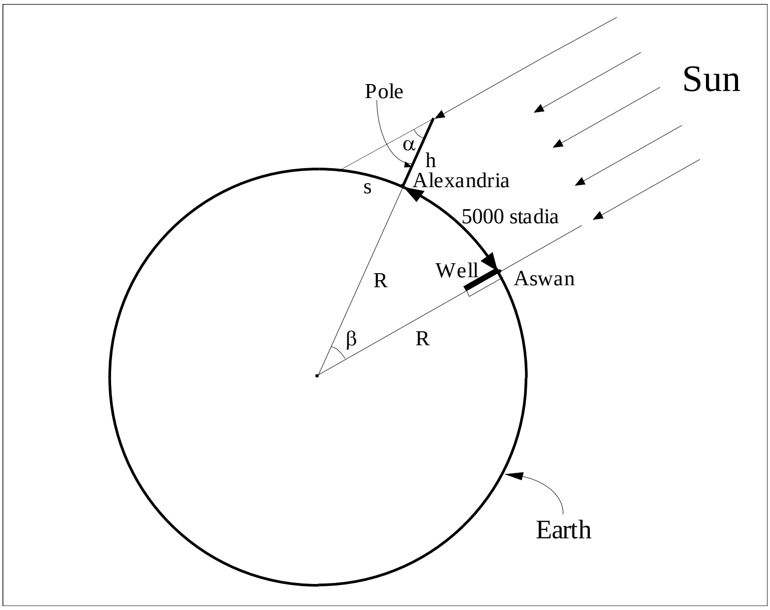

FIGURE 1.1: Eratosthenes method for measuring the earth's perimeter.

$$\tan\alpha = \frac{s}{h} \qquad \text{(1.1)}$$

3) Under the assumption that sun rays are parallel, the central angle β would be equal to the angle α = 7.2°, and from Figure 1.1:

$$\frac{\beta}{360} = \frac{5000\ \text{stadia}}{L} \qquad \text{(1.2)}$$

Where L is the earth's perimeter. From this equation Eratosthenes found that L = 250,000 stadia (≈ 46,300 km). This value, which was reached by elementary measurements, is only 16% larger than the value known today using advanced and accurate technology.

After that, the idea of flat earth dominated until the 15th century, when Columbus supported again the idea of the spherical earth. In the 16th century Magellan proved this hypothesis by sailing around the world. Recent accurate measurements showed that the earth has an ellipsoidal shape.

The surface of the earth is irregular and impossible to be represented by a simple mathematical model. If it is assumed that the earth masses above the mean sea level are removed, and the land areas below mean sea level (e.g., Jerico) are filled, the resulting surface is termed ***Geoid***. This surface has equal gravitational potential at all its points with the direction of gravity being perpendicular to the surface at all these points.

If the earth had a uniform density and the topographic variations did not exist, the Geoid would have the shape of an ellipsoid of revolution. However, it does not. The effects of density on the Geoid are summarized in Figure 1.2.

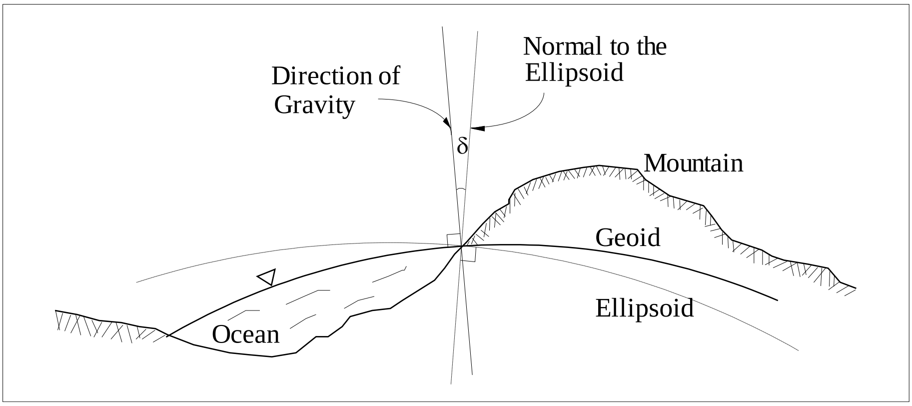

FIGURE 1.2: Relationship between actual ground surface, Geoid and Ellipsoid.

The Geoid, in turn, is also difficult to be represented by a simple mathematical model (equation). However, a mathematical reference frame is necessary to carry out computations of positions, distances and directions. Therefore depending on the area to be surveyed, the following systems are used:

1) For areas > 500 km^2 (especially in Geodetic Surveying), the ellipsoid is used for reference. This ellipsoid has the following properties (Figure 1.3):

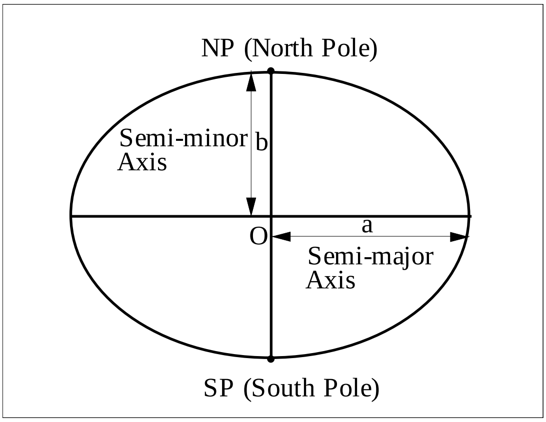

FIGURE 1.3: Ellipsoid of revolution.

- a: Semi-major axis
- b: Semi-minor axis
- f: flattening $= \frac{a - b}{a}$ . . . .(1.3)
- e: eccentricity, where:

$$e^2 = \left(1 - \frac{b^2}{a^2}\right) = 2f - f^2 \qquad \text{. . . . .(1.4)}$$

Typical values of these variables are:
a = 6378135 m, b = 6356750.5 m,
f = 1/298.26, e = 0.08181881066

2) 50 km^2 < Areas < 500 km^2: Since the value of the flattening (f) is too small, the ellipsoid is replaced by a sphere which has an average radius of R = 6372200 m.

3) For areas less than 50 km^2, it is accurate enough to neglect the curvature of the earth and replace the curved earth surface with a plane.

1.6 TYPES OF SURVEYING

Several different types of surveying can be identified which, although they all use the same basic principles and instrumentation, vary in the intention and end products. These can be divided into three main categories depending on the size of the survey, the method of surveying, or the purpose of surveying.

a) Size of the survey area:

Depending on the area to be surveyed, surveying can be divided in two main types:

1) Geodetic Surveying. When the area to be surveyed is large, such as the surveys of countries, the effect of earth curvature must be taken into consideration and, as a result, knowledge of spherical geometry is required. In this type of surveying, the measurements are done with great care and accuracy, and the scale of the resulting map is usually small (1:100,000 or smaller).

2) Plane Surveying. When the area to be measured is small, the effect of earth curvature is ignored, and the plotted measurements will represent the projection on a horizontal plane of the surveyed area. A horizontal plane is one, which is normal to the direction of gravity, as defined by a plumb bob at a point, and owing to the curvature of the earth, such a plane will in fact be tangential to the earth's surface at that point.

b) Method of surveying:

When the method of surveying is of concern, surveying can be divided into two types:

1) Ground Surveying. In this branch of surveying, the features to be surveyed and mapped are directly measured by physically touching them. Equipment like tapes, ranging rods, levels, theodolites, etc. are used.

2) Remote Surveying. In this type of surveying, the features are first photographed or sensed using a camera or a sensor, and then information about them is collected indirectly by doing measurements on the photographs or images.

c) Purpose of surveying:

Depending on the purpose and the end product of the surveying process, surveying can be divided into several types. These include:

1) Cadastral or Land Surveying. This branch of surveying deals with property boundaries, areas, as well as, land subdivision and consolidation.

2) Topographic Surveying. This includes all the operations leading to the production of topographic maps. A topographic map is one, which portrays the shape and elevation of the terrain. This includes both natural and man-made features such as drainage features, natural vegetation, transportation facilities, rivers, lakes, cities, towns, as well as, any other features that may be of interest to the map users.

3) Hydrographic Surveying. The principal purpose of this type of surveying is to gather information about water bodies. This information is essential for the preparation of nautical charts which, in turn, delineate the submarine topography or bathymetry of a given water area and portray other significant features, as well as, those of the shore area.

4) Route Surveying. This includes all the surveying and mapping activities that are performed for the planning, design and construction of any route of transportation, such as highways, railroads, canals, etc.

5) Construction Surveying. These are the operations performed to layout, locate and monitor public and private engineering projects.

6) Mine Surveying. This type of surveying deals with the control, location and mapping of underground and surface works related to mining operations.

1.7 UNITS OF MEASUREMENT

In surveying, units of measurement are those that are used for the representation of measured lengths, areas, volumes and angles. These units are:

A) *Units of Length Measurement:*

1 - English System: inch (in, "), foot (ft, '), yard (yd), and mile
1 foot = 12 inches
1 yard = 3 ft
1 mile = 5280 ft

2 - Metric System: centimeter (cm), meter (m) and kilometer (km)
1 meter = 100 cm
1 kilometer = 1000 m

B) *Units of Area Measurement:*

1 - English System: ft^2, acre
1 acre = 43560 ft^2

2 - Metric System: m^2, donum, hectare (ha) and km^2
1 donum = 1,000 m^2
1 hectare = 10,000 m^2
1 km^2 = 1,000,000 m^2 = 100 ha

C) *Units of Volume Measurement:*

1 - English System: in^3, ft^3, yd^3
1 ft^3 = 1728 in^3
1 yd^3 = 27 ft^3

2 - Metric System: cm^3, liter, m^3
1 m^3 = 1,000,000 cm^3
1 m^3 = 1,000 liters

D) *Units of Angle Measurement:*

Three systems or units for angle measurement are used in surveying. These are:

1. The Sexagesimal System (النظام الستيني). In this system, the circle is divided into 360°, each degree (°) is divided into 60 minutes ('), and each minute is divided into 60 seconds ('') ⇒ 1° = 60' = 3600''. Example: 213° 24' 47''

2. The Decimal or Centesimal System (النظام العشري أو المئوي). In this system, the circle is divided into 400 equal parts called grads (g). Each grad is then divided into 100 simal minutes (c), and each simal minute is divided into 100 centesimal seconds (cc) ⇒ $1^g = 100^c = 10,000^{cc}$. Example: $128^g\ 60^c\ 81^{cc}$

3. The Radian System (نظام الراديان). The radian is defined as the central angle opposite to a circular arc whose length is equal to its radius. The whole perimeter of the circle will be opposite to a central angle equal to 2π (π = 3.141592654). Therefore, $2\pi = 360° = 400^g$.

Relation between the units of measurement:

1 inch = 2.54 cm
1 ft = 30.48 cm = 0.3048 m

International system of units:

For simplicity, the following international units are used.
- Meter (m) for distances
- Square meter (m^2) for areas
- Cubic meter (m^3) for volumes
- Radian for angles.

EXAMPLE 1.1:

How many kilometers are there in a mile?

SOLUTION:

$$1 \text{ mile} = 5280 \text{ ft} = 5280 \text{ x } 30.48 \text{ cm}$$
$$= \frac{5280 \text{ x } 30.48}{100 \text{ x } 1000} = 1.609344 \text{ km}$$

EXAMPLE 1.2:

How many acres are there in a hectare?

SOLUTION:

$$1 \text{ hectare} = 10000 \text{ m}^2 = 10000 \text{ x } \left(\frac{100}{30.48}\right)^2 \text{ ft}^2$$
$$= 10000 \text{ x } \left(\frac{100}{30.48}\right)^2 \text{ x } \frac{1}{43560} = 2.471 \text{ acres}$$

EXAMPLE 1.3:

Change the angle 1.5 radians into its equivalent values in both the sexagesimal and centesimal systems.

SOLUTION:

a) Sexagesimal system:

$2\pi = 360°$

$1.5 \text{ radians} = ? \Rightarrow \theta = \frac{1.5 \text{ x } 360}{2\pi} = 85^{\circ}\ 56'\ 37''$

b) Centesimal system:

$2\pi = 400^g$

$1.5 \text{ radians} = ? \Rightarrow \theta = \frac{1.5 \text{ x } 400}{2\pi} = 95^g\ 49^c\ 30^{cc}$

1.8 SCALE OF SURVEYS

A map or plan might be defined as a reproduction, at a reduced ratio, of an orthographic projection of the terrain onto a reference horizontal datum plane. This reduced ratio is what is called "scale", and is used because it is physically and economically not possible and inconvenient to represent the measured lengths on a big sheet of paper as they are without reduction. The scale might differ from one plan to another, but should be uniform throughout the same plan. In a simplified form, scale might be defined as the ratio between a length on a map or a plan to its equivalent length in reality.

Three factors affect the choice of the appropriate scale. These are: the size of area to be mapped, the size of the paper sheet to be used for drawing, and the purpose for which the plan is to be used for. Basic scales may range from 1/10 to 1/1,000,000. The former is appropriate for certain detail drawings, and the latter for small-scale mapping. Some examples on scales and their uses are:

1. Architectural works, building works, location drawings: 1/50, 1/100 and 1/200.

2. Site plans, civil engineering works: 1/500, 1/1,000, 1/1250, 1/2,000 and 1/2,500.

3. Town surveys, highway surveys: 1/1250, 1/2,000, 1/2,500, 1/5,000, 1/10,000, 1/20,000 and 1/50,000.

4. Mapping: 1/25,000, 1/50,000, 1/100,000, 1/200,000, 1/500,000 and 1/1,000,000.

1.9 BASIC GEOMETRIC PRINCIPLES OF SURVEYING

The two traditional geometric principles of Surveying are:

1) Working from the whole to the part. This means that when surveying a large area, a set of control points, which are relatively far from each other, are chosen, and the positions of these points are located with a high degree of accuracy. These points are then used to add more inner points to the network through a process called densification. This working from the whole to the part helps minimize and control the measurement errors (Figure 1.4)

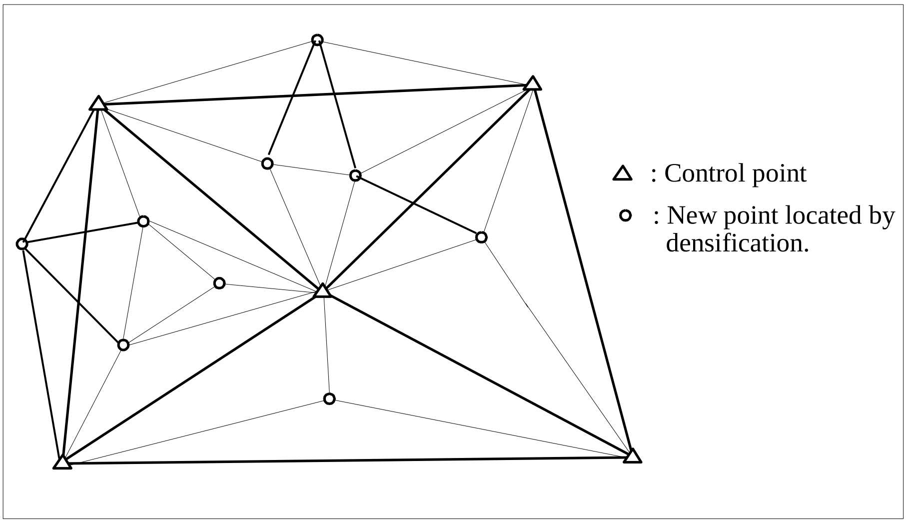

FIGURE 1.4: Working from the whole to the part.

2) The position of an unknown point relative to a known line is located by at least two independent measurements. These measurements can be: an angle and a distance (Figure 1.5a), two angles (Figure 1.5b), or two distances. The two distances could be two direct distances (ties) from two points on the line to the unknown point (Figure 1.5c), or a distance and offset to the unknown point (Figure 1.5d).

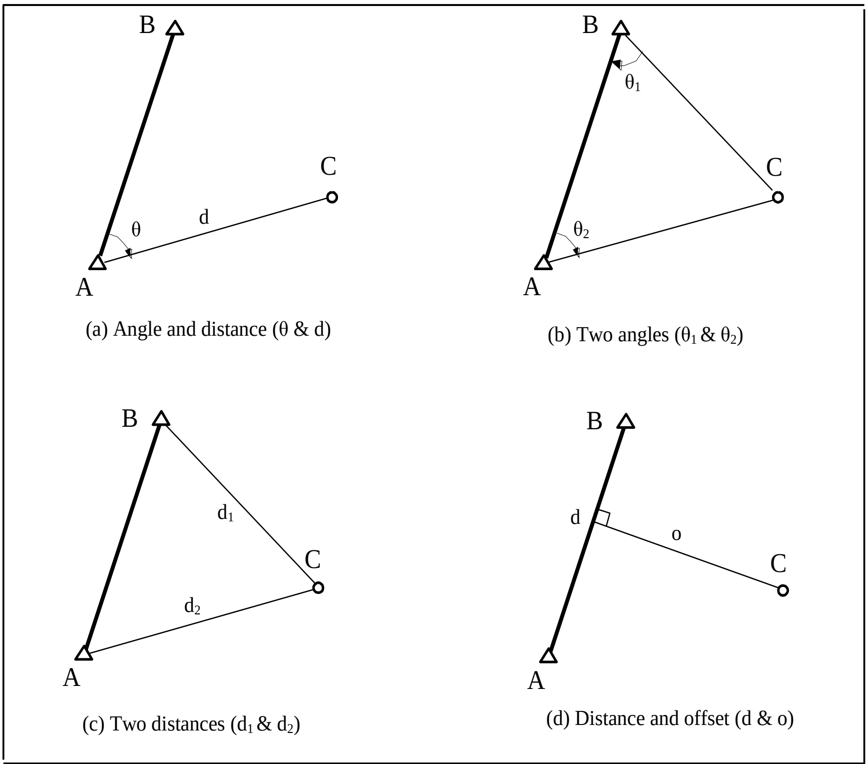

FIGURE 1.5: Methods of locating the position of an unknown point relative to a known line.

Note: The above two principles are no longer of high importance when using Global Positioning Systems – GPS (see Chapter 12) for survey measurements. GPS gives uniform accuracy and does not require inter-visibility between survey points.

PROBLEMS

1.1 What is the relationship between the earth's surface, the Geoid and the Ellipsoid?

1.2 What is the difference between topographic and hydrographic surveying?

1.3 Describe how Eratosthenes managed to measure the perimeter of the earth.

1.4 What is one radian equivalent to in both the decimal and sexagesimal systems?

1.5 Transform the angle 118° 33' 57" into its equivalent values in both the decimal and radian systems.

1.6 How many donums are there in an acre?

1.7 The area of a land parcel is $2780\,m^2$. How much is this area equivalent to in ft^2 and acres?

1.8 What are the basic principles of surveying? Why are these principles not important or valid when using the latest GPS technology?