UNIT-1

Surveying

Unit Specifics
Through this unit we have discussed the following aspects:

- Principle of Surveying and historical background
- Various types of surveying
- Various maps and their characteristics
- Linear, angular and graphical methods of surveying and their utility
- Types of levels, including auto levels and digital levels, and their salient features
- Levelling observation methods
- Contour mapping and utility
- Magnetic bearing and compasses
- Measurements of magnetic bearing
- Various types of theodolites and their salient features
- Theodolite observation methods for taking horizontal and vertical angles
- Plane table survey
- Traverse, Triangulation and Trilateration
- Traversing with theodolites
- Error adjustments
- Types of triangulations and associated processes
- Numerical problems

In addition to the basic principle of surveying, the working of levels, compass and theodolites has been explained. The practical utility of these surveying equipment is presented for field data collection required for creating maps, as well as making these observations error free. Once the data is collected and corrected, topographic maps can be created by plane table survey methods in the field. Thenatic maps may be created from high resolution images, cutting down the requirements of large manpower and funds. Questions of short and long answer types are given following lower and higher order of Bloom's taxonomy, and a list of references and suggested readings is given in the unit so that the students can go through them for acquiring additional in-depth knowledge.

Rationale
This unit provides details of various types of surveying, maps, levels, compass and theodolites. Each of these equipments are used for a specific purpose of data collection required for creating maps. It explains various components of level, compass, plane table, and theodolite. Working of these equipments using various methods has been explained so that the students make use of these equipment in the field. Various methods used in the field and errors associated are also given. In levelling, angular observations, and traversing, errors and their minimisation are also discussed so that the users can minimise the errors from the field data. The computed coordinates of the surveyed points provide good

horizontal and vertical control for civil engineering projects. Plane table survey will further enhance the understanding of map making processes.

Pre-Requisite
Mathematics: geometry and trigonometry, Earth surface.

Unit Outcomes
List of outcomes of this unit is as follows:
U1-O1: Describe various types of Land survey, Maps, Levels, Compasses, and Theodolites
U1-O2: Explain the essential components and characteristics of Maps, Levels, Compasses, and Theodolites
U1-O3: Realize the role of Maps, Levels, Compasses, and Theodolites for field data collection
U1-O4: Describe various methods of data collection using, Levels, Compasses, and Theodolites, and apply corrections to observations
U1-O5: Apply the parameters collected in the field for providing horizontal and vertical controls, and creating the maps.

Unit-1 Outcomes	**Expected Mapping with Programme Outcomes** *(1- Weak correlation; 2- Medium correlation; 3- Strong correlation)*					
	CO-1	**CO-2**	**CO-3**	**CO-4**	**CO-5**	**CO-6**
U1-O1	2	2	3	2	1	2
U1-O2	3	1	2	1	2	-
U1-O3	2	3	2	3	-	3
U1-O4	2	2	3	2	2	-
U1-O5	2	3	2	1	-	2

1.0 Introduction

Surveying is a core subject of civil engineering and it has an important role to play. It is the starting point of many projects, such as roads and railways, buildings, bridges, pipelines, transmission lines, dams, and many more (Schofield, 1984). Surveying is "*the technique of accurately determining the relative position of natural and man-made features above or below the surface of the Earth, by means of direct or indirect elevation, distance and angular measurements*". According to the American Congress on Surveying and Mapping (ACSM), '*Surveying is the science and art of making all essential measurements to determine the relative position of points or physical and cultural details above, on, or beneath the surface of the Earth, and to depict them in a usable form, or to establish the position of points or details*'.

Surveying is a means of making accurate measurements of the Earth's surfaces, including the interpretation of data so as to make it usable, and establishment of relative position and size (Survey Manual, 2014). It involves largely the field work which is done to capture and storage of field data using instruments and techniques specific for the type of survey work. Surveying also includes the technique of establishing the points by pre-determined angular and linear measurements. Thus, surveying has two distinct functions: (i) to determine the relative horizontal and vertical positions of the objects/features for the process of mapping, and (ii) to demarcate the land boundaries, establish the points to exactly layout the project on the ground, and control the construction work of a project.

The word 'Map' originates from the Latin word '*mappa*', means a tablecloth or napkin where 3-dimensional Earth features are represented on 2-dimensional cloth or paper. A map represents the 2D projection of the 3D terrain surveyed, which could be utilised to draw plans and sections to compute the area of land, or volume of a land mass or layout of an engineering structure. In land surveying, data are collected by using field surveying equipment and represented graphically on a piece of paper, called 'Map'. As the surveying technology grew, advanced materials, electronics, sensors and software are introduced in data collection, and analysis (Garg, 2021). These measurements may be used for the representation of different features in different forms. These features/details may be represented in analogue form as a topographic map with contours, plan or chart, or in digital form, such as a Digital Terrain Model (DTM).

As surveying allows us to acquire data on the relative positions, horizontal distances, and elevations of points, the objectives of surveying can be stated as follows (Schofiled, 1984; Basak, 2017):

1. Collect and record data about the relative positions of points/objects on the surface of the Earth.
2. Establish horizontal and vertical controls required for accurate mapping and subsequently for construction.
3. Prepare maps required for various civil engineering projects.
4. Compute areas and volumes of earthwork, required in various projects.
5. Layout of various engineering works on the ground using survey data.

1.1 Importance of Land Surveying

Ever since the mankind acquired the sense of possessing the land and property, the art of surveying and mapping came into existence (Survey Manual, 2014). In the early days, the demarcation of land and defining the boundaries were extremely difficult tasks, and done as rough representation using conventional devices. With the growth of knowledge, skill and technology, development of surveying instruments and techniques of data collection and analysis improved considerably. Today, surveying is of vital importance as accurate planning and design of all civil engineering projects (Garg, 2021), such as railways, highways, tunneling, irrigation canal, dams, reservoirs, sewerage works, airports, seaports, building complex, etc. are based upon the quality of surveying measurements.

The knowledge of surveying is advantageous in many phases of civil engineering. The first task in surveying is to prepare a detailed topographical map of the area, and then either draw the sections of the best possible alignment, or compute the amount of earthwork or plan the structures on the map, depending upon the nature of the project (Chandra, 2007). The geographic and economic feasibility of the engineering project cannot be properly ascertained without undertaking a detailed survey work. Thus, the knowledge of surveying is fundamental and very useful to civil engineering professionals.

Surveying helps demarcating the land boundaries accurately on the ground. Surveying is essential to fix the national and state boundaries, map rivers and lakes, prepare maps of coastlines, etc. It is important to know the exact shape and size of the land boundary for acquisition of land or paying compensation to the land owners, and planning the construction. Many land properties have noticeable problems, mainly due to improper surveys, miscalculations in past surveys, titles of the land, error in measurements, etc. Also many land properties are created from multiple divisions of a larger piece of land over the years; and with every additional division, the risk of miscalculation/error in demarcation increases. The dispute in land measurements may lead to court cases to decide about the land ownerships. Many such problem can thus be detected on time through proper survey, and actions are taken on the basis of facts and figures provided by surveying measurements.

Surveying is also important in archaeology, geology, geophysics, landscape architecture, astronomy, meteorology, and seismology, including military engineering. Civil engineers must know the accuracy achieved in design and layout processes, as well as in construction. In addition to understanding the limits of accuracy, surveyors and engineers must know at what precision field data is to be collected to justify the accuracy. In particular, civil engineers must have a thorough understanding of the methods and instruments used, including their capabilities and limitations. This knowledge is best obtained by making observations with the kinds of modern equipment generally used in practice.

Civil engineers play an integral role in land development from planning and designing to the final construction of roads, buildings, bridges, dams, canals, stadium, buildings and utilities, and subsequently their maintenance and/or upgradation. The first and foremost requirement therefore is to have an accurate mapping of the land, as surveyors are the first to work at any construction site. For example, in a multipurpose building project (smart city), designing the project, planning the structures accurately and safely, and ensuring the buildings to be constructed as per specifications; all are the responsibilities of civil engineers. Since surveying measurements are used for providing horizontal and vertical controls on the ground, these are required not only for layout of structure accurately on the ground for construction purpose, but also useful to control the accuracy of entire construction of the structures (Duggal, 2004). These controls can also be used to make the actual estimate of the construction of structures while making payment to the contractor.

The role of surveying as a professional activity is expanding to include other techniques and skills, under one umbrella, known as Geospatial technology. The surveying professional are slowly adapting the modern approaches of data collection, data analysis and mapping in digital environment. These surveying approaches require a good working knowledge of photogrammetry, remote sensing, laser scanners, Global Positioning Systems (GPS), Unmanned Aerial Vehicles (UAVs), computer cartography, Geographical Information Systems (GIS), and associated software to analyse the data, generate detailed maps, visualize the terrain from satellite images, or integrate multiple geo-referenced databases (Garg, 2019).

1.2 Basic Principles of Surveying

There are two basic principles of surveying which are to be followed for accurate and systematic survey measurements on the Earth surface. These are given below.

1.2.1 Working from whole to part

This is a fundamental and most important principle of surveying. Almost all survey works are required to follow this principle, particularly larger (whole) areas. In working from whole to part, a large (whole) area is divided into smaller parts by providing horizontal controls throughout the area. The smallest part of the area will consist of a triangle. If surveying is done without dividing into smaller parts, any error occurred in a part gets magnified at the end of entire survey work, and the error becomes large which can't be accepted for a good work. Whereas, on the other hand, any error occurred in smaller parts (triangle) is adjusted independently, and at the end of survey no error is left. Thus, the basic objective of this principle is to adjust the error locally within each small figure (triangle) independently and preventing the accumulation of errors.

In India, for large area survey works, Survey of India (SoI), Dehradun, established the control points very accurately at large distances by using triangulation method. From these control points, smaller areas are surveyed by setting out a network of triangles. Such sub-division continues with reference to the previously established systems of points, till all the details are surveyed.

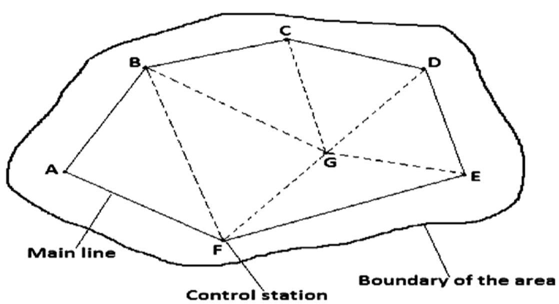
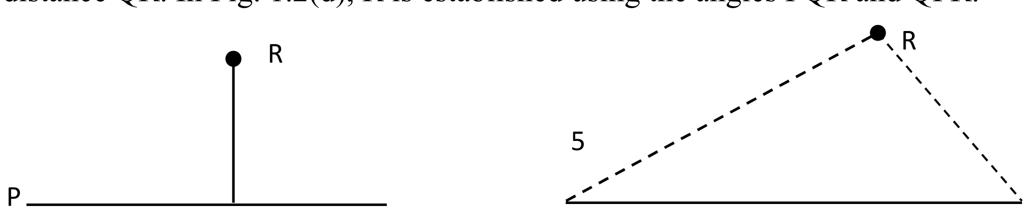


Figure 1.1 First principle of surveying: working from whole to part

1.2.2 Establishing a point by at least two independent measurements

Horizontal control points in surveying are located by linear and/or angular measurements. If two control points are established by surveying measurements, a new point (third point) can be established with the help of these two known control points by taking two linear or two angular measurements, or by one linear and one angular measurement. In other words, indirectly the location of the new point is established using the geometry or trigonometry of the triangle formed by these three points.

In Figure 1.2a, let P and Q be two control points, and a new point R is to be established by means of observations from points P and Q. Point R can be established using the distances PR, and R'R. In Fig. 1.2(b), R is established using the distances PR and QR. In Fig. 1.2(c), R is established by the angle RPQ and distances PR or by establishing angle RPQ and distance QR. In Fig. 1.2(d), R is established using the angles PQR and QPR.



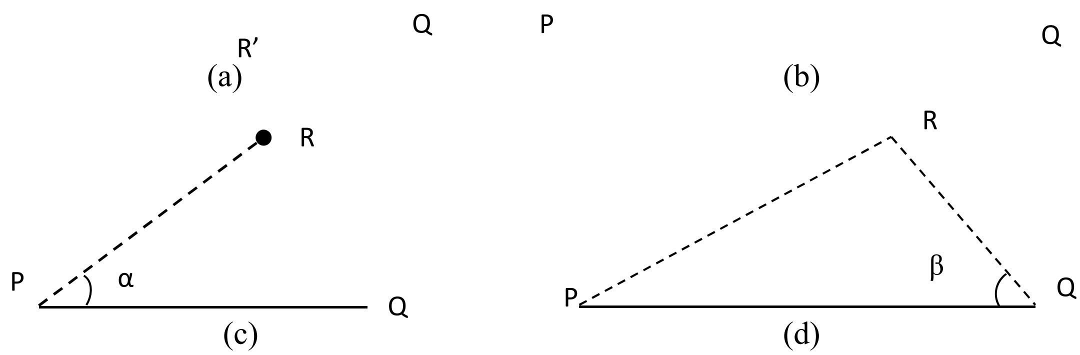


Figure 1.2 Second principle of surveying

1.3 History of Mapping: Indian Perspective

As early as 1400 BCE, evidence of some form of boundary surveying has been found in the fertile valleys and plains of the Tigris, Euphrates, and Nile rivers. In India, evidence of map making skills has been found in the *Brahmand Purana* as far back as the 5th century (Chadha, 1991). Knowledge of land was presented in graphical form which described the extent and shape of territories. The art of surveying and techniques of mensuration of areas are described in *Sulva Sutra* (science of mensuration) and in the *Arth Shastra* of Chanakya, written in the 3rd century BC. In the 5th century, Aryabhatta, who wrote *Surya Siddhant*, calculated the Earth's circumference to be 25,080 miles- less than 200 miles off modern measurements of the equator (Phillimore, 1945).

Official surveying and mapping has been in practice in India, since way back 16th century. Raja Todar Mal during Akbar’s and Sher Shah Suri regime introduced agriculture land measurements, termed as *cadastral survey*, which was done with foot and iron chains (Satyaprakash, 2010). Drawing used to be prepared cartographically with free-hand and scales. In India, the revenue maps were earlier prepared on a piece of cloth, called *'Khasra'* maps. These maps were earlier prepared by a method of distance measurement, known as pacing, which gave an idea of boundary and dimensions of land and property. Later, iron chains of 20 ft and 30 ft long were used to improve the distance measurement accuracy. *Khasra* maps and chains are used even today by many *Patwaris* and Village Development Officers for demarcation of property and collection of revenue.

The Indian terrain was completely mapped by the painstaking efforts of distinguished surveyors, such as Mr. Lambton and Sir George Everest (Phillimore, 1945). The angle-measuring instruments, called Theodolites, were developed to study the astronomy that were based on arcs of large radii, making such instruments too large for field use. The 36 inch theodolite used in the Indian triangulation is shown in Figure 1.3.

A 16 inch diameter Transit Theodolite with magnifiers, which has been used for measuring horizontal and vertical angles for the alignment, layout and construction of Ganga Canal, was designed and manufactured by the Canal Foundry (now known as Canal Workshop), Roorkee. (Late) Prof. H. Williams in 1937 carried out modifications in the Theodolite which was used for teaching and training to Engineers as well as for taking observations. Surveyor Compass with 1^0 least count was developed and manufactured at Roorkee to find out the bearing and direction required for the construction of Ganga Canal. In this Compass, numerals have been shown in English as well as Arbi languages.

Figure 1.3 The 36 inch theodolite used in the Indian triangulation (Keay, 1983)

The East India Company, after the Agra famine in 1937-38 where about one million people died, felt the need to build an irrigation system in the Doab region (Meerut to Allahabad zone) with support from skilled hands. Colonel Cautley was given the charge of constructing the Ganga canal. He suggested to James Thomason, the then Lieutenant-Governor of the North-West provinces, about the need to train locals in civil engineering for completing their ongoing projects. The students were to be trained systematically in surveying, leveling and drawing with proper infrastructure. This led to the foundation of the country's first-ever engineering college at Roorkee on September 23, 1847.

The Survey of India (SoI), under the Department of Science & Technology, is the oldest scientific department of the Govt. of India, which was set up in 1767 to help consolidate the territories of the British East India Company (Chadha, 1991). The SoI is the principal mapping agency of the country. The great trigonometric series spanning the country from north to south and east to west are some of the best geodetic control series available in the world. The foremost topographical survey in the south was the one carried out by Colin Mackenzie in Kanara and Mysore. The SoI is fully equipped with digital devices and software to ensure that the country's domain is explored and mapped suitably using the latest technology. It has oriented the technology to meet the needs of defense forces, planners and scientists in the field of geo-sciences, land and resource management, and many scientific programs of the country.

From the 19th century, the use of trigonometric method marked a historic moment in the process of surveying. This was the first time that a purely geometric method was utilised for making geographical calculations. The method of measurement through triangulation was conceived by the EIC officer William Lambdon and later under his successor George

Everest, which became the responsibility of the SoI. One of the greatest accomplishments of the trigonometric survey was the measurement of Mount Everest, K2 and Kanchenjunga.

As human brain is always engaged in development of new procedures to overcome the shortcomings, a rapid growth has taken place since then. Digital maps became the authentic tools to claim the ownership. Over the past, several changes have occurred in surveying and mapping field, resulting in the techniques today which are fully automated and software based from data collection to analysis to mapping.

1.4 Types of Surveying

The two broad types of land survey used are plane surveying and geodetic surveying, depending upon whether the spherical shape of the Earth is taken into account or not (Punmia et al., 2016). These are briefly described below.

1.4.1 Plane surveying

In plane surveying, the Earth surface is considered as a plane surface, and its spheroidal shape is neglected. For small projects covering area less than 250 sq.km, Earth curvature is not accounted for distance measurements. The line joining any two stations is considered to be straight, and three points will make a plain triangle. Surveys for engineering projects fall under this category. Plane surveying uses normal instruments, like measuring tape, theodolite, level, etc., and the survey accuracy is low.

1.4.2 Geodetic surveying

This type of surveying takes into account the true shape of the Earth. Earth curvature correction is applied to the observations. The triangle formed by any three points is considered as spherical. Geodetic surveys are carried out for areas greater than 250 sq.km. For large areas, degree of accuracy of measurements is high, and therefore geodetic survey requires sophisticated and high precision equipment, like the GPS, Total Station. Geodetic survey is used to provide control points to which small surveys can be connected.

1.5 Classification of Survey

Surveys can be further classified into several categories depending on the purpose, instruments, techniques used, etc. These classifications are shown in Table 1.1.

Table 1.1 Classification of surveys based on

Instruments	**Place**	**Methods**	**Purpose**
Chain or tape	Land	Levelling	Topographic
Level	Water	Trigonometrical levelling	Geodetic
Theodolite	Underground	Traversing	Engineering
Compass	Aerial	Tachometry	Route
Tachometer		Triangulation	Cadastral
EDM		Trilateration	City
Total Station			Mine
Plane Table			Geology
GPS			Underground utility
GPR			Hydrographic
Laser scanners			
Aerial			

Satellite			
UAV/Drone			

1.5.1 Types of survey based on instruments

Earlier, measurements of distances and directions were mainly used to prepare maps of the area, and surveys were classified based upon the instruments used. Chains, tapes, levels, magnetic compasses, and theodolites were popularly used, either single or in combination with other equipment. With the advancement in electronics and digital technology, many modern instruments are now available for data collection and mapping, which are capable to collect the data alone, and no other instrument is generally required, for example Total station, Laser scanners and GPS. Figure 1.4 shows the images of some of these equipment.

(a) Chains

In chain survey, a metallic chain is used to measure the linear distances. The chain traversing is done by dividing the small area to be surveyed into a number of triangles. Using the sides of the triangles by chain surveying, other details are worked out. Chains meant for survey work are available in length of 20 or 30 m. Later, chains due to their inaccuracy, difficulty to use, and wear & tear in the field, were replaced by the tapes. In addition, many corrections are applied while making the long distance measurements with chain.

(b) Tapes

Many different varieties of measuring tapes are available, with different materials, lengths and designs. The most common type of tape is made of fibre glass reinforced plastic tapes and those with stainless steel. Steel tapes stretch very little, and are little expensive but gets kinks easily if not handled properly. Steel tapes also get rust very quickly. Measurements over 30 m are not recommended as that length of tape is difficult to manage and the sag in the tape makes the measurements inaccurate.

(c) Levels

A level instrument is used to find the difference in elevation between the points. It is used along with a graduated rod, known as the leveling staff. If we link the observations to a known point, the elevation of other unknown points can be determined.

(d) Theodolites

A theodolite is used to measure horizontal and vertical angles. Theodolites are frequently used to carry out traversing where angles and distances are measured simultaneously. These angle are required to establish horizontal and vertical controls in the area. Theodolites can also be used for prolongation of a line, alignment work, and levelling work.

(e) Compass

A magnetic compass works on the principle that a freely suspended needle points in the magnetic north-south direction (reference direction). This instrument gives the direction of a line with respect to reference direction. A compass, together with a chain or tape or Total Station, can be used to survey a given area using methods, such as traversing.

(f) Techeometer

A tacheometer is similar to a theodolite but has an anallactic lens and a stadia diaphragm having three horizontal hairs. The readings taken on a levelling staff against all the three cross hairs enable the horizontal distances to be computed. The central wire reading is linked to some Bench Mark (BM) to determine the elevation.

(g) EDM

The Electronic Distance Measuring (EDM) device measures the slope distance between EDM instrument and a prism (reflector). The EDM generates infrared (IR) or microwave which travels through the atmosphere and strikes the reflector kept at an unknown point. The instrument measures the travel time of return beam, and computes the distance (distance= velocity x time). The phase difference between the instrument station and the reflector station is also used to compute the slope distance. For details of EDM refer to Unit-3.

(a) Chain

(b) Tape

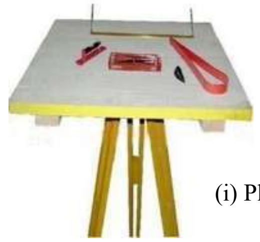
(c) Level and Staff

(d) Theodolite

(e) Compass

(g) EDM

(h) Total Station



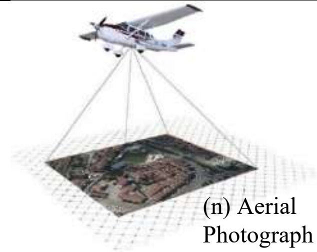
(i) Plane Table

(j) GNSS

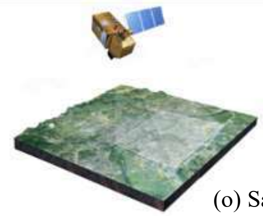
k) GPR

(l) Laser Scanner

(m) UAV/Drone



(n) Aerial Photograph



(o) Satellite Image

Figure 1.4 Surveying based on equipment and tools

(h) Total Station

A total station is a combination of an electronic theodolite and an EDM. Horizontal distances and horizontal & vertical angles are determined using a total station. Total station equipment is used all forms of surveys requiring a very high level of precession. A total station can display and store the field data, and transfer the data to a computer for further processing. For details of Total Stations refer to Unit-3.

(i) Plane Table

A plane table is like a drawing board, which is used in the field to prepare a map of the area at desired scale. In plane table survey, fieldwork and plotting work proceed simultaneously. It is used along with an alidade which provides the direction towards the object to be plotted, and with a chain or tape, and tacheometer or a Total Station to measure the distance and elevation of the objects/features.

(j) GNSS

The Global Navigation Satellite System (GNSS) device (receiver) is very useful in surveying and mapping. Depending on the type of receiver, it shall receive signals from the various GNSS constellations such as Global Positioning System (GPS), GLONASS, GALILEO satellites and provides 3D coordinates of the point on the Earth surface, anytime, where observations have been taken (Garg, 2019). These 3D coordinates can be used in software to process and generate a map as well creation of digital elevation model (DEM). For details of GNSS refer to Unit-3.

(k) GPR

The Ground Penetrating Radar (GPR) device emits radar beams that penetrate into the ground to a certain depth, depending on the wavelength and frequency of antenna of radar beam (Garg, 2021). It will display the return signals from the objects which are below the Earth surface. Any underground utility, buried structures & objects, ground water table, etc., can be mapped with the GPR. Mapping all the underground utility is necessary in all modern townships, including smart cities. For details of GPS refer to Garg (2021).

(l) Laser Scanners

Laser scanners emit laser beams that strike to the objects and return back to the instrument. The instrument provides 3D coordinates of the objects which could be used to generate the DEM of the area (Garg, 2021). There are two types of laser scanners; terrestrial (ground based) and aerial laser scanners, and depending on the use, 3D models and maps or profiles can be generated for the area. For details of Laser Scanners refer to Garg (2021).

(m) UAVs/Drones

The Unmanned Aerial Vehicle (UAV) or drone are low flying aircrafts used for collecting very high-resolution images of laser point cloud data (Garg, 2020). These data are very helpful to generate DEM of the area. Today, UAVs have large number of applications in mapping, monitoring and management of civil engineering and other projects. For details of UAVs/Drones refer to Garg (2020).

(n) Aircrafts

In aerial photogrammetry, aerial photographs are acquired and used for preparation of various thematic maps at different scales. Manual photogrammetric techniques require simple equipment, such as stereoscopes, parallax bar, analytical plotting devices, whereas the digital photogrammetric methods require sophisticated devices (workstations) and photogrammetric software to create various kind of maps (Garg, 2019). For details of photogrammetry refer to Unit-4.

(o) Remote Sensing Satellites

Large number of satellite images are available from various satellites, which can be processed through image processing software or in GIS environment to generate maps at different scales (Garg, 2019). Using different time images in GIS, a change scenario can be generated which is very helpful in planning, designing and monitoring various civil engineering projects. In addition, GIS can be used to make a query form the exhaustive database which otherwise is not possible. For details of remote sensing refer to Unit-5.

1.5.2 Types of survey based on purpose

(a) Control surveys

These are carried out to establish a network of horizontal and vertical controls that serve as a reference framework for completing the survey work with desired accuracy. Many control surveys performed today are done using Total Station and GPS instruments.

(b) Topographic surveys

They are carried out to determine the locations of natural and man-made features, and their elevations and representation on a map.

(c) Land boundary and cadastral surveys

These are used to establish property lines and corners of the property. The term cadastral is applied to surveys of the public lands systems.

(d) Hydrographic surveys

They are used to define shorelines and depths of lakes, streams, oceans, reservoirs, and other bodies of water.

(e) Alignment surveys

These are conducted to plan, design, and construct highways, railroads, pipelines, and other linear projects.

(f) Construction surveys
They provide line, grade, control elevations, horizontal positions, dimensions, and configurations for construction operations. They are also used for computing the bill and quantities of construction.

(g) Mine surveys
These are performed above and below the ground to guide tunnelling and other operations associated with mining. These surveys are carried out for mineral and energy resource exploration.

1.6 Maps

One of the basic objectives of surveying is to finally prepare various types of maps useful for engineering works (Survey Manual, 2014). Maps are graphical representation of Earth surface features to some scale. Two broad types of maps; planimetric and topographic, are prepared as a result of surveys. The former, called plan map, depicts the natural and cultural features in their plan (x-y) views only, while the latter includes planimetric features, and the elevation (z) of ground surface. The topography represents the shape, configuration, relief, slope, roughness, or three-dimensional characteristics of the Earth's surface. Both types of maps are used by a larger community, such as engineers and planners to determine the most desirable and economical locations of projects, such as highways, rails, roads, canals, pipelines, transmission lines, reservoirs, and other facilities; by architects in housing and landscape design; by geologists to investigate the mineral, oil, water, stable slopes, and other resources; by foresters to locate wildlife, forest fire-control routes, identifying new sites for plantations; and by archeologists, geographers, and scientists in numerous fields.

Maps depict the locations as well a relief of natural and cultural features on the Earth's surface (Garg, 2021). Natural features normally shown on maps include forests, vegetation, rivers, lakes, snow, oceans, etc., while cultural features are the man-made features and include roads, rails, buildings, bridges, tower, canal etc. Traditionally, engineering maps have been prepared using manual drafting methods and plane table survey. With the availability of digital data from total station, GPS, laser scanners and digital images form photogrammetry and remote sensing, now the majority of maps are produced using computers, computer-aided drafting (CAD), and GIS software.

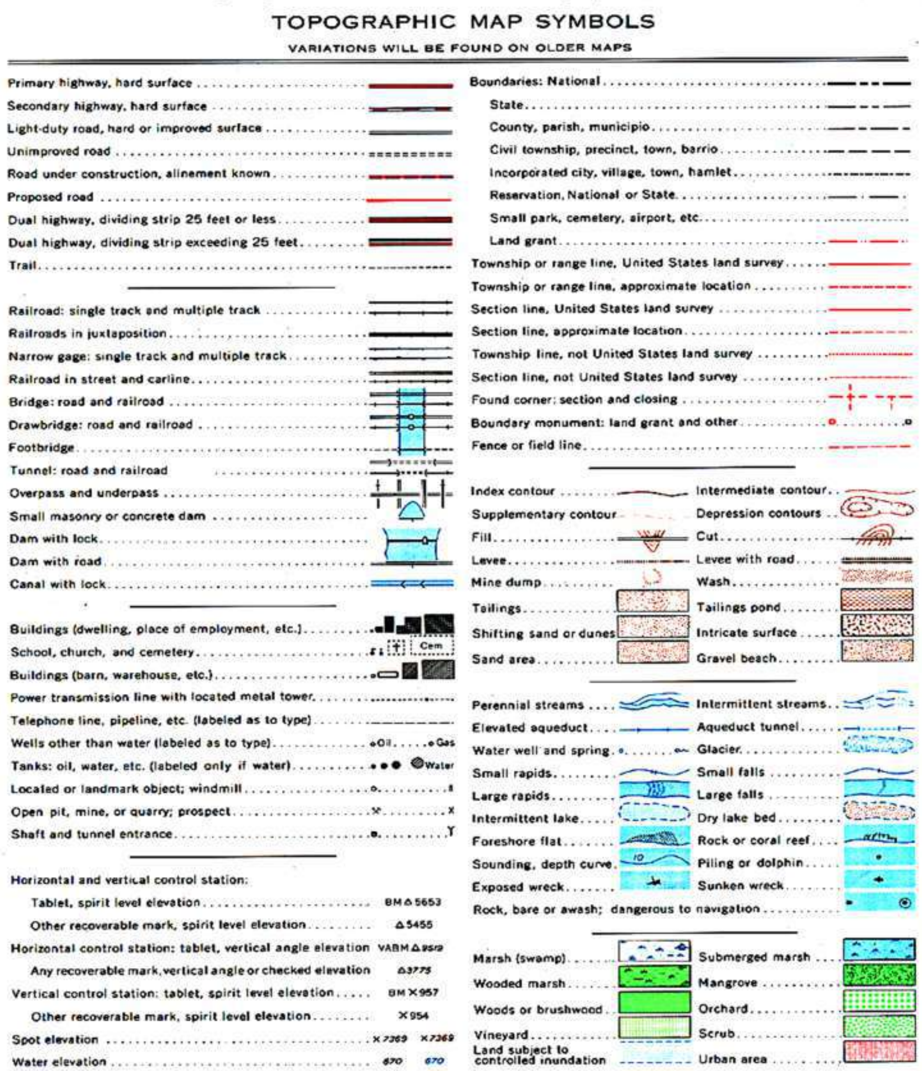
The natural and cultural features on the maps are depicted graphically by points, lines and polygons, with different symbols and colours. For example, the relief of the Earth includes its hills, valleys, plains, slopes and other surface irregularities, which are represented in the form of contour lines. A map will also have the names of places, rivers and legends to identify the different objects. The standard symbols and colours used for various natural and man-made objects, are shown in Table 1.2. For example, contours as burnt sienna, buildings as light red, water as persian blue, trees and vegetation as green, agricultural land as yellow, etc.

1.7 Map Scale

The distance between any two points on a map, measured along a straight line, is called the map distance, while the distance between the same two places on the ground, measured along a straight line, is called the ground distance. The ratio between the map distance and the ground distance is called the scale of map. Map scales are represented in three ways; (i) by ratio or representative fraction (RF) or ratio, such as 1:1200 or 1/1200, (ii) by an equivalence, for example, l in.= 100 ft. (1200 in.), and (iii) graphically using a linear scale.

In defining scale by ratio or RF, same units are used for map distance and corresponding object distance, and thus 1:1200 could mean 1 unit on the map is equivalent to 1200 unit on the ground. An equivalence scale of 1 inch= l00 ft. indicates that 1 inch on the map is equivalent to 100 ft. or 1200 in. on the ground. It is possible to convert from a ratio to an equivalence scale and vise-versa. As an example, 1 inch= 100 ft. is converted to a RF by multiplying 100 ft by 12 which converts it to inches and gives a ratio of 1:1200.

Table 1.2 Colours and symbols of various features on topographic maps (https://geokult.com/2011/09/14/map-symbolisation/)



A linear scale is useful to measure the distance directly from the map. It allows an accurate measurement on the map, as direct measurement on a paper map using numerical scale may not be very accurate due to little contraction or expansion of paper with the climatic conditions. But a linear scale drawn on a map will yield correct result, even after enlargement or reduction of a map. In the graphic or linear scale, map distance is shown using a straight line. The length of the line of a linear scale depends on the size of the map, but is usually between 12 cm and 20 cm that is divided into parts known as primary divisions. The primary units to the left of zero must be exactly the same size or length as the primary units to the right of zero. The first primary division on the left is further sub-divided into smaller parts known as secondary divisions. The starting or zero point of the linear scale should be after the first primary division from the left. The primary divisions are to the right of zero, while the secondary divisions are to the left of zero. The example in Figure 1.5 shows a linear scale where 1 cm on the map equals to 1 km on the ground. Secondary divisions are divided into five equal parts (it may also be divided into 10), and each part represents 200 m on the ground. Thus, the ground distance can be computed using linear scale by measuring that distance on map

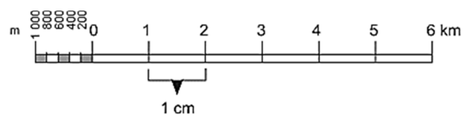


Figure 1.5 A typical linear scale

The Survey of India prepares various maps based on actual survey of land for the whole country. These maps which show the details about landforms, drainage patterns, land use, settlement patterns, transport, forest and cultural features. The topographical maps or topo sheets, prepared by Survey of India, are available at three scales; 1: 25,000, 1: 50,000 and 1: 2,50,000. The topographical maps also show a network of parallels (lines of Latitudes) and meridians (lines of Longitudes), forming grids on the map. These grids are useful to find the location of a place (Latitude, Longitude) on the Earth. Figure 1.6 shows a sample of toposheet (B&W) of Himachal Pradesh region at 1: 50,000 scale, and various associated features.

Map scales may be classified as large, medium, and small scale. Large scale maps are created where relatively high accuracy is needed over small areas, for example design of engineering projects, like dams, airports, stadium, and water & sewage systems. Medium scale maps are often required for projects where large area is involved but moderate accuracy is needed, such as township, proposed transportation systems, and existing facilities. Small scale maps are commonly created for mapping very large areas where a lower order of accuracy will be needed, such as district level maps. Choice of mapping scale would depend on the purpose, size of area, topography and required precision of the finished map, and of course, the time required to complete the mapping work. The scales of various maps normally used in survey work are given in Table 1.3. The greater the number in the denominator the smaller is the scale and vice versa.