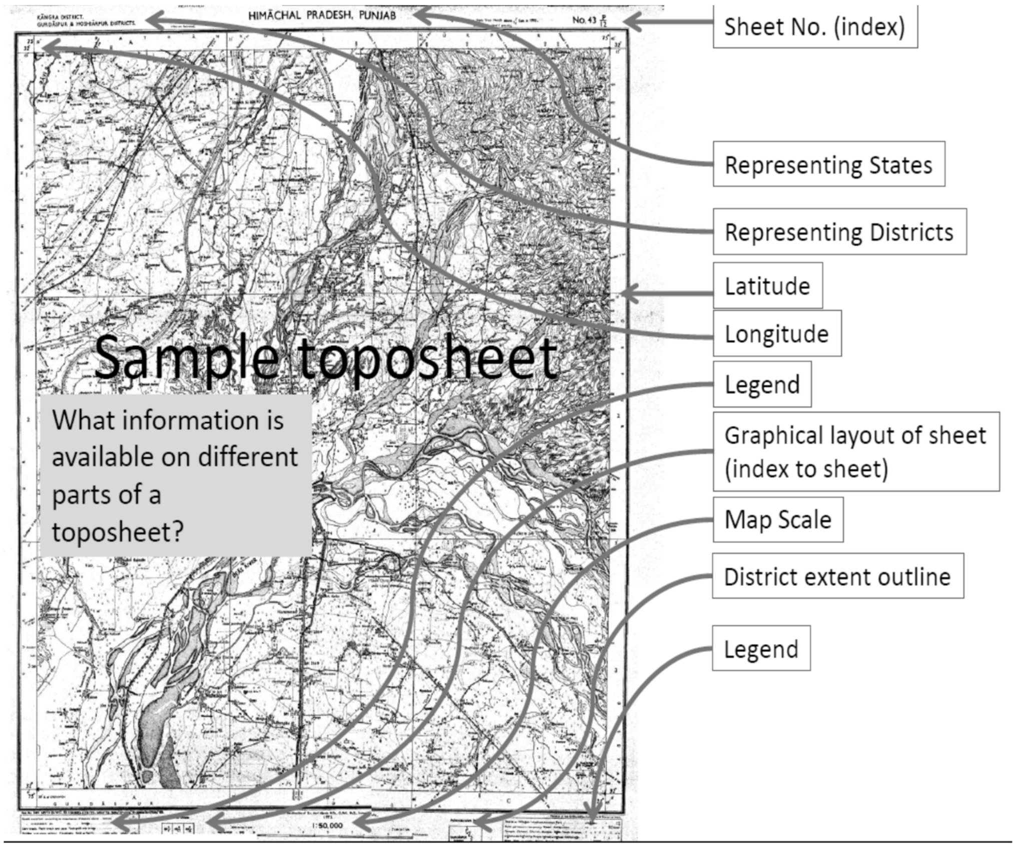

Figure 1.6 A typical toposheet

Table 1.3 Various engineering maps and their scales (Garg, 2021)

Type of purpose of survey	**Scale**	**R.F.**
(a) Topographic survey		
1. Building sites	1 cm = 10 m or less	$\frac{1}{1000}$ *or less*
2. Town planning schemes, reservoirs etc.	1 cm = 50 m or 100 m	$\frac{1}{5000}$ *to* $\frac{1}{10000}$
3. Location surveys	1 cm = 50 m or 200 m	$\frac{1}{5000}$ *to* $\frac{1}{20000}$
4. Small scale topographic maps	1 cm = 0.25 km or 2.5 km	$\frac{1}{25000}$ *to* $\frac{1}{250000}$
(b) Cadastral maps	1 cm = 5 m or 0.5 km	$\frac{1}{500}$ *to* $\frac{1}{5000}$
(c) Geographical maps	1 cm = 5 km to 160 km	$\frac{1}{500000}$ *to* $\frac{1}{16000000}$
(d) Longitudinal sections		
1. Horizontal scale	1 cm = 10 m to 200 m	$\frac{1}{1000}$ *to* $\frac{1}{20000}$
2. Vertical scale	1 cm = 1m to 2 m	$\frac{1}{100}$ *to* $\frac{1}{200}$
(e) Cross-sections $\left(\begin{matrix}\text{Both horizontal and}\\ \text{vertical scales equal}\end{matrix}\right)$	1 cm = 1m to 2 m	$\frac{1}{100}$ *to* $\frac{1}{200}$

The plotting accuracy of a map can be determined with a simple concept. Cartographically, any line on a map is drawn with a thickness of 0.25 mm, which is considered to be the least dimension of a smallest dot. It means the thickness of the line or dot on the ground can be computed by multiplying the least dimension of 0.25 mm with the scale of map.

Plotting accuracy = 0.25 mm x scale of mapping (1.1)

At 1:1,200 scale, the plotting accuracy will be 0.25x1200= 300 mm= 30 cm. So, 30 cm is the maximum allowable error which could be presented in 1: 1,200 scale maps. A feature smaller than 30 cm on the ground can't be theoretically shown on this map.

1.8 Survey Stations

To survey the boundary of an area, the stations taken along the boundary of an area as controlling points are known as *survey stations*. Figure 1.7 shows the survey stations (P, Q, R and S) marked by black dot enclosed by circle. These stations are definite points on the Earth whose locations have been determined by surveying methods. Their location is marked on the ground over which survey instruments are kept to take the observations. Angular, linear, bearing and height observations may be taken at these stations, depending upon the purpose of survey. These stations are selected by the surveyors at commanding positions in an optimal manner, keeping in view the following criteria:

(i) Survey stations should be visible from at least two or more other survey stations.
(ii) As far as possible, survey stations must be situated so as to cover minimum elevation and maximum elevation of the area.
(iii) The criteria for selecting the survey stations is that lines joining them should not make obtuse angle (>120^0) or acute angle (<30^0) with each other.
(iv) Survey stations should be as few as possible, as more the stations more will be the observational work.
(v) Survey stations should be avoided at busy locations as it might affect the smoot measurement of survey observations.

The purpose of survey stations is to provide horizontal control (planimetry, X and Y) and vertical control (Z) during mapping work. In surveying, it is important to know the absolute position of a point/object with respect to a given origin, or its relative position with respect to a known point/object. The position information can be expressed as (X, Y and Z) in linear coordinate system or as (Ø, λ and Z) in polar coordinate system. When expressed as X, Y, generally it is referred to as the grid coordinates or Easting/Northing, and Z represents the elevation of the point above a known or fixed datum (i.e., mean sea level). When a point is expressed in terms of (Ø, λ), it refers to latitude and longitude of that point.

The horizontal control is provided by two or more stations on the ground which are precisely fixed in position by distance and direction. It provides the basis for controlling the scale of the surveyed map as well as locating the various topographic features present in the area. The most common methods used to locate a point/feature in the field are by measuring: one angle and the adjacent distance, or two distances, or two angles. For small areas, horizontal control for topographic work is usually established by a traverse, but sometimes for a very small area mapping, two survey stations making a single line may also be used. Vertical control is provided by the Bench Marks (BMs) in or near the area to be surveyed. It is required to correctly represent elevations on a surveyed map, and is usually established by lines of levels, starting and closing on BMs.

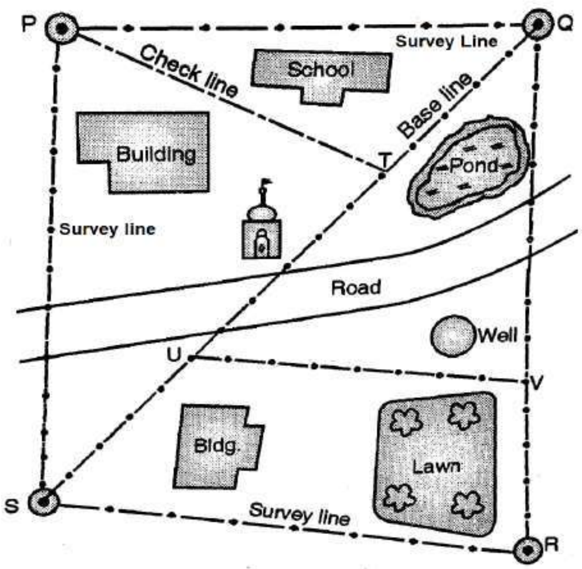

Figure 1.7 Survey stations and survey lines

1.9 Survey Lines

The lines joining the survey stations are called survey lines, as shown in Figure 1.7 (lines PQ, QR, RS, SP). The longest survey line (QS) is called as the base line whose distance is measured very accurately, and used for computational work as well as cross checking the measurements. It is the most important line in surveying, as it fixes up the directions of all other lines. Since the accuracy of whole survey work depends upon the accuracy of base line, it should be laid-off on a fairly level ground, if possible. As far as possible, a base line should be taken roughly through the middle of the area on which the framework of triangles covering the major portion of the area may be designed. There could be more than one base line depending upon the size of the area to be surveyed; one is used for computation and the other is used as check line (PT). The survey lines should be as few as possible such that the framework may be plotted. The survey lines should be measured in an order so as to unnecessary avoid walking between the stations to and fro.

1.10 Safety in Surveying

Civil Engineers are generally involved both in field and office work. The field work demands making observations with various types of instruments either; (a) to determine the relative locations of points, or (b) to set out stakes as per plan to guide the construction operations. The office work involves computing and processing the surveyed data from field, and preparing maps, plots, charts, reports, etc. Sometimes, the fieldwork is performed in difficult or unsafe environment (e.g., sites close to landslides, volcanoes, heavy snow cover, forest fire, highways and railroads), so it is important that safety precautions are taken. Construction sites where heavy machinery operate are also hazardous and dangerous. The danger is often enhanced by poor hearing conditions due to excessive noise at the construction site as well as poor visibility caused by the dust, haze and obstructions.

In such situations, wherever possible, survey work should be carried out away from the dangerous sites or using indirect methods of measurements. If it is not possible to avoid, the work must be done with certain safety precautions. To ensure safety, vests of fluorescent yellow color should always be worn, and flagging materials of the same color can be attached to the surveying equipment to make them more visible from a distance. Depending on the work at the site, proper signage may be placed before the work areas so as to inform the working of a survey team ahead. Proper, barricades can also be placed at some sites to divert the traffic around surveying work, or manually people with flags can ask drivers of vehicles to slow or even stop, if necessary.

The *Occupational Safety and Health Administration* (OSHA) of the US Department of Labor (https://www.osha.gov), has developed safety standards and guidelines for various conditions and situations in the field. Depending on the location of survey site and the time of year, weather-related harms, such as frostbite and over-exposure to the sun, which can cause skin cancers, sunburns, and heat stroke, can also affect the field surveys. To overcome these problems, fluids at regular interval should be consumed, large hats can be worn and sunscreen applied. On extremely hot days, surveying should commence at dawn and stop around midday. Other hazards that could be present during field surveys, include wild animals, poisonous snakes, bees, insects, spiders, etc. Surveyors should be knowledgeable about the types of hazards that can be expected in any local area, and always be alert while working at the site. To prevent injury from these sources, protective boots and clothing should be worn and insect spray is used.

Certain tools can also be dangerous, such as saws and axes that are sometimes used for clearing the line of sight. These must always be handled with great care. Also, care must be taken while handling certain surveying instruments, such as long-range poles and levelling rods, especially when working around overhead live wires, to prevent accidental shocks.

Thus, it is important that surveyors always take precautions in the field, and follow the safety guidelines and standards. A first-aid kit should be carried in the field, which include all of the necessary antiseptics, ointments, bandage materials, and other accessories needed to provide first aid during minor accidents/injuries. The survey party should also carry important telephone numbers to call in emergencies/serious situations.

1.11 Units of Measurements

Measurements/observations are assigned specific units. In surveying, most commonly employed units are for length, area, volume, and angle. Two different systems are in use for specifying the units of observed quantities; the *English* (FPS) *system* and *Metric system* (MKS). Because of its widespread adoption, the metric system is also called the *International System of Units* (SI). According to Standards of Weights and Measurements Act, India in 1956 decided to replace English (FPS) system used earlier with the MKS. In 1960, SI unit was approved by the conference of weights and measures. The major difference between MKS and SI is in the use of unit of force. In MKS unit of force is kg-wt (which is commonly called as kg only) while in SI it is newton.

The English system (FPS) has been the officially adopted standard for measurements in the United States for long time, where the linear units in feet and inches are most commonly used. Even today, FPS is used in construction industry. Because civil engineers perform all types of surveys and provide measurements for developing construction plans and guiding building operations, they must understand both the systems of units and be familiar of making conversions between them. The observations must be recorded in their proper units and then conversions are made correctly.

In FPS unit, the length is measured in *foot and inches.*
1 foot = 12 inches
1 yard = 3 feet (ft.)
1 inch = 2.54 cm (basis of international foot)
1 meter (m) = 39.37 inches (basis of U.S. survey foot)
1 rod = 1 pole = 1 perch = 16.5 feet
1 Gunter's chain = 66 feet = 100 links = 4 rods
1 mile = 5280 feet = 80 Gunter's chains
1 nautical mile = 6076.10 feet (nominal length of a minute of latitude, or of longitude at the equator)

In SI unit, the length is measured in *centimeter, meter, and kilometer.*
1 m = 10 dm (*decimeter*)
1 m = 100 cm
1 m = 1000 mm (*millimeter*)
1000 m = 1 km (*kilometer*)
1 km = five eighths of a mile

In the English system, areas are given in *square feet* or *square yards*. The most common unit for large areas is the *acre*.
1 acre = 10 square chains (Gunter's)
1 acre = 43,560 ft^2 (10×66^2)

SI units used for finding the areas are *square meter, square kilometre (km)* and *hectare (ha)*. Large tracts of land, for example, are given in *hectares*. Relations among them are:
1 ha = 100 m×100 m
1 ha = 1×10^4 m^2
1 ha = 2.471 acres
1 square km = 1000 m×1000 m = 10^6 m^2
1 square km = 100 ha

Volumes in the English system can be given in *cubic feet* or *cubic yards*. For very large volumes, for example, the quantity of water in a reservoir is designated in *acre-foot*.
1 acre-foot = 43,560 ft^3 (area of an acre having a depth of 1ft)

In the SI system, *cubic meter* (m^3) is used for volume.

The unit of angle used in surveying is the *degree*, defined as 1/360 of a circle. Degrees, minutes, and seconds, or the radian, are accepted SI units for angles. For measuring angles sexagesimal system is used, where:
1 circumference = 360°

1 degree = 60′ (minutes of arc)
1 minute = 60″ (seconds of arc)

Other methods are also used to subdivide a circle. A *radian* is the angle subtended by an arc of a circle having a length equal to the radius of the circle.
2π rad = 360°
1 rad ≈ 57°17'44.8' ≈ 57.2958°
0.01745 rad ≈ 1°
1 rad ≈ 206,264.8″

The recommended multipliers in SI units are given below:
Giga unit = 1×10^9 units
Mega unit = 1×10^6 units
Kilo unit = 1×10^3 units
Milli unit = 1×10^{-3} unit
Micro unit = 1×10^{-6} unit

1.12 Various Errors in Measurements
All measurements are subject to errors, irrespective of the instrument and method used. The 'true value' of a measured quantity is thus never known. The angular, linear and elevation measurements might have three basic errors present (Punmia et al., 206) ; (i) natural errors, (ii) instrument errors, and (iii) personal errors.

Broadly, these errors will fall under two categories: (a) Systematic or cumulative, and (b) Accidental, random or compensating. Systematic errors can always be identified and corrected because their magnitude and nature (sign) can both be determined. For example, a measuring tape is designed for its standard length under a particular pull and temperature, but if the pull or temperature changes during the field work, its effect on the length (increase or decrease in length) of the tape can be computed. Accidental, random or compensating errors are subject to chance, and hence follow the laws of probability. The magnitude and sign of errors are not known, as they are sometimes positive and sometimes negative, sometimes of small magnitude, and sometimes of large magnitude, and hence can't be determined or eliminated. To minimise it, we take a large number of observations to make an estimate of magnitude of such error that is likely to occur. In fact, there is one more error, i.e., mistake or blunder, but that cannot be classified under any category of error as these are mainly due to the carelessness of the observer. Mistakes can be corrected only if discovered, and comparison of several measurements of the same quantity could be used in isolating the mistakes.

There are two more terms involved when we deal with the errors in measurements; (i) accuracy, and (ii) precision. *Accuracy* is the closeness or nearness of the measurements to the 'true' or 'actual' value of the quantity being measured. The term *precision* (or repeatability) refers to the closeness with which the measurements agree with each other. Statistically, precision can be measured by means of a quantity σ, known as *standard deviation* or *standard error,* and is given by-

$$\sigma = \sqrt{\frac{\sum v^2}{n-1}} \qquad (1.2)$$

Where v^2 is the sum of the squares of the residuals, n is the number of measurements. The smaller the value of σ becomes, the greater is the precision.