CIVIL ENGINEERING

Surveying and Geology

Comprehensive Theory
with Solved Examples *and* Practice Questions

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CHAPTER

1

Fundamentals of Surveying

1.1 INTRODUCTION

- Surveying is the science of determining the relative positions of different features on ground, along with their elevations.
- The relative positions are determined by measuring the horizontal distances, horizontal angles, vertical distances and the vertical angles.
- After taking observations in the field, computations are done in office to prepare topographic map or plan of the area.
- These maps or plans are needed for various purposes like computing the volume of earth work, volume of reservoir, finalizing the alignment of canal, railway line or highway and for this, sufficient number of points and lines have to be located on the plan.
- The new developments that would be impossible without accurate surveys include testing equipment like rocket tracks, accelerators for atomic research, as well as control for both position and direction of rockets, intercontinental missiles and space craft.

1.2 OBJECTIVE OF SURVEYING

The objectives of surveying can be stated as follows:

(a) Collect and record data of the relative positions of points on the surface of the earth.

(b) Compute areas and volumes using data collected from survey, required for various purposes.

(c) Prepare the plans and maps required for various activities.

(d) Layout the various engineering works in correct positions.

(e) Check the accuracy of built up structures.

1.3 TYPE OF SURVEY

1.3.1 Classification of Survey Based on Accuracy Desired

(a) **Plane Survey:** In this type of survey, the mean surface of earth is assumed to be flat and not the curved one. Here, the level lines are regarded as straight lines and the angle between any two such lines is taken as the plane angle and not the spherical angle.

This type of survey is used when the area under consideration is of small extent. (less than 250 km^2).

Almost all surveys for various engineering projects like construction of dams, highways, railway lines, canals etc. use plane survey.

(b) **Geodetic Survey:** In this type of survey, the shape or the curvature of earth is taken into account in order to have a higher degree of precision. Such surveys are required for surveying large areas (more than 250 km^2) and measurements are required to be made with the highest possible order of precision. Here, a line connecting the two points is an arc and not the straight line. This distance between the two points is corrected for curvature and then plotted on the plan. The angle between the two lines is the spherical angle. Thus all this requires a high level of computation work.

Geodetic survey is needed to fix the widely spaced control points that are later on used as necessary control points for fixing the minor control points.

1.3.2 Classification of Survey Based on Place of Survey

(a) **Land Survey:** It is the survey which is being done on land to prepare plans and maps of a given area. It involves running of survey lines and determining their length and directions thereby sub dividing the area into definite shapes and sizes and calculating their areas etc. in order to set up a structure.

(b) **Hydrographic Survey:** It involves survey of water bodies like streams, sea, ponds etc. The basic purpose of this survey is to design water navigation system by determining the shore line. Apart from this, this survey is done to determine the amount of water stored by a water body, water supply, under water construction etc.

(c) **Underground Survey:** This survey is required for construction of tunnels for highways, railways, water transport, mines etc. Here in this survey, transfer of surface line coordinates to the underground line etc. are done.

(d) **Aerial Survey:** This survey is carried out above ground by taking the aerial photographs with cameras fitted to airplanes, helicopters etc. This survey is particularly required for preparing large scale maps of an area, for development of projects in areas where ground survey is difficult or too much time consuming.

1.3.3 Classification of Survey Based on Instrument Used

(a) **Chain Survey:** Here, only the linear measurements are made with a chain (or a tape) and no angular measurements are made. This survey is of limited use, since it requires clear ground without any obstruction like intervening trees, buildings, rivers etc. This survey is particularly useful for laying of sewer lines, water supply lines, construction of roads etc.

(b) **Compass Surveying** : In this survey, horizontal angles are measured with the help of a magnetic compass. Magnetic compass works on the principle that a freely suspended magnetic needle points in the magnetic north-south direction. A compass together with a chain or tape, can be used to survey a given area by many methods such as traversing.

(c) **Leveling:** Here, relative, elevations of different points are determined. A graduated staff and a level are used for this purpose. Almost all projects require determination of the elevation of the different points and this is achieved by leveling.

(d) **Plane Table survey:** In this, survey, observations and plotting are done simultaneously in the field. The advantage of this method is that there is least possibility of omitting any important measurement since the actual field being surveyed is in view on the plot in the field itself. The drawbacks of this method are that it cannot be done in humid or rainy weather and the carrying of plane table apparatus is cumbersome.

(e) **Theodolite Survey:** In this type of survey horizontal and vertical angles are measured with the help of theodolite. A theodolite is a very precise instrument used for measuring horizontal and vertical angles. Theodolite survey can be broadly classified into two types:

  (i) Traverse survey

  (ii) Triangulation survey

(f) **Triangulation:** This method of survey is used for large areas. The entire area is divided into a network of triangles and any one side of any of the triangles so formed is measured very precisely. This line is referred to as **baseline.** All the angles of the network are measured. The lengths of the sides of the triangles are then computed using the laws of triangles.

(g) **Tacheometry:** Here, in this type of survey, both the horizontal distance and the vertical distance are measured by sighting a graduated staff with a transit telescope fitted with an analytic lens. It is particularly useful when direct measurement of horizontal distances are not possible.

(h) **EDM Survey:** EDM refers to Electronic Distance Measurement and in this method of survey, distances are measured electronically using wave propagation, reflection and subsequent reception of the reflected wave. Some of the examples of EDM instruments are tellurometer, distomat, geodiameter etc.

(i) **Total Station Survey:** Total station is the combination of conventional transit theodolite with EDM instrument. It reads and records the horizontal and vertical distances together with slope distances. This instrument also computes the Cartesian coordinates of the observed points, slope corrections, elevation of remote objects etc. Survey carried out using total station is referred to as total station survey.

(j) **Satellite Survey:** In this method of survey, information about the land or space is determined using satellite based navigation system like the GPS (Global Positioning System). Another method is the Remote Sensing wherein the data about an object is acquired using the sensors placed on satellite.

NOTE Trilateration is the type of triangulation in which all the three sides of each triangle are measured accurately with the help of EDM instrument. Then angles are computed indirectly from the known sides of the triangles.

1.3.4 Classification of Survey based on Purpose

(a) **Geological Survey:** In this type of survey, information about both the surface and sub-surface is acquired for assessing the extent of different reserves like the minerals, rocks etc. It is also used for locating the faults, folds and other unconformities in the ground. This survey helps in determining the type of foundation, soil treatment required etc.

(b) **Geographical Survey:** This survey is done for preparation of geographical maps depicting the land use efficiency, irrigation intensity, surface drainage, slope profile, contours, national boundaries etc.

(c) **Engineering Survey:** This survey is required to be done for acquiring information for the planning and design of engineering projects like the highways, dams, railway line, water supply design, reservoirs, bridges etc. It involves topographic survey of the area, earthwork measurement etc.

(d) **Cadastral Survey:** These are done to establish boundary of properties for legal purposes. These are also called public land survey.

(e) **Defence Survey:** Such surveys are done for military purpose. They provide strategic information for deciding the future course of action. Aerial and topographical maps of the area are prepared which gives crucial information about the existing roads, airports, ordnance depots etc.

(f) **Mine Survey:** This requires both the surface and the underground surveys. It involves making the surface map and doing the underground survey for locating the reserves of minerals.

(g) **Route Survey:** It is a sort of linear survey for deciding the alignment of a highway or a railway.

(h) **Archaeological Survey:** This is done to gather information about the ancient monuments, towns, villages, kingdoms, past civilizations, temples, forts etc. buried underground due to natural forces like earthquakes, landslides, floods etc. It gives an idea about the past history, culture and development of the civilization that existed in the past. These provide vital links on understanding the evolution of the present civilisation as well as human beings.

1.4 PRINCIPLES OF SURVEYING

The two basic principles of surveying are as follows:

(a) Work from whole to part

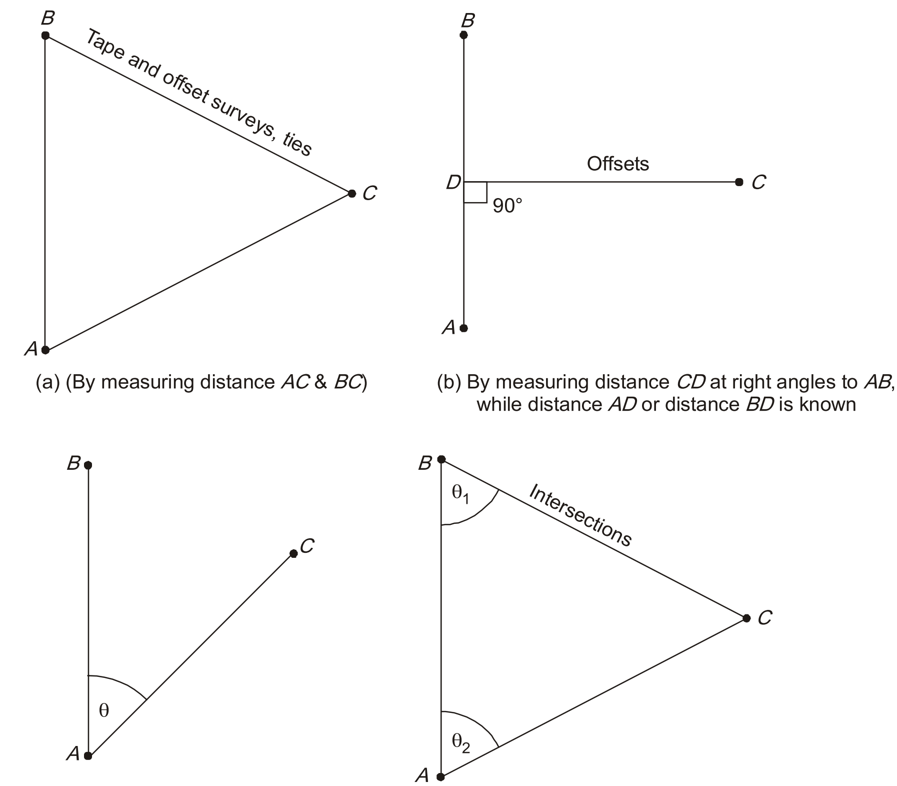
(b) Locate a point by at least two measurements (linear or angular).

1.4.1 Work from Whole to Part

- It is the first principle of surveying.
- By this principle, it means that the surveyor should first establish the large frame work consisting of main control points, accurately.
- In between the large frame work so established, subsidiary small frame works can be established by a relatively less accurate survey. By doing so, the errors in small frame work get localized and are not magnified and thus the accumulation of errors gets confined.
- In the reverse process of working from part to whole, small errors get magnified due to accumulation of errors from small frame work to large frame work.

1.4.2 Locate a point by atleast two measurements

- According to this principle, the new point (station) should always be fixed by atleast two measurements (linear or angular) from a fixed reference point.
- Take two control points A and B and the distance between them is accurately measured. By using A and B, two control points whose positions are already known on the plan, the position of C can be plotted by any of the following methods:



(a) (By measuring distance *AC* & *BC*)

(b) By measuring distance *CD* at right angles to *AB*, while distance *AD* or distance *BD* is known

(c) By measuring distance *AC* and angles θ

(d) By measuring angle θ_1,& angle θ_2

Fig. Location of unknown point from two known points

1.5 UNITS OF MEASUREMENT

- There are many units of measurement that are prevalent worldwide like the CGS System, FPS System, MKS System but the standard one is the **SI System**.
- Past records of all survey works are usually in FPS System. Thus to use those records and any other records that are in different units, those have to be converted into SI unit or other unit that is in use.

Length Unit Conversion	
Unit	Conversion factor for m
1 astronomical unit	149597870691
1 angstrom	1×10^{-10}
1 chain	20.1168
1 fathom	1.8288
1 foot	0.3048
1 furlong	201.168
1 inch	0.0254
1 light year	9460730472581000
1 mile	1609.344
1 nautical mile	1852
1 yard	0.9144

Area Unit Conversion	
Unit	Conversion factor for m^2
1 acre	4046.85
1 are	100
1 hectare	10^4
1 ft^2	0.0929
1 $inch^2$	6.4516×10^4
1 $mile^2$	2589988.11
1 $yard^2$	0.8361

Volume Unit Conversion	
Unit	Conversion factor for m^3
1 barrel	0.1589873
1 $yard^3$	0.765
1 US gallon	3.785×10^{-3}
1 UK gallon	4.546×10^{-3}
1 liter	0.001

Pressure Unit Conversion	
Unit	Conversion factor for N/m^2
1 atm	101325
1 bar	1×10^5
1 mm Hg	133.3
1 pound per sq. feet (psf)	47.88
1 pound per sq. inch (psi)	6894.75
1 torr	133.32

1.6 BASICS MEASUREMENTS IN SURVEYING

- In surveying, the direction of gravity is taken as reference for all measurements.
- The direction of gravity is established by suspending a plumb bob freely. This direction of gravity is taken as the vertical direction. Thus horizontal direction is at right angle to the vertical direction.
- Any plane which contains the horizontal line and perpendicular to the vertical direction is called as **horizontal plane**. The plane containing the vertical line is called as **vertical plane**.

In surveying, the following basic measurements made are:

(a) **Horizontal distance:** The horizontal distance is measured in horizontal plane. On slopping ground, the distance between two points is reduced to horizontal equivalent.

(b) **Horizontal angle:** The horizontal angle is measured between two lines in horizontal plane. Theoretically, the angle between two lines can vary from 0° to 360°.

(c) **Vertical distance:** As stated above, the direction of gravity is taken as vertical direction and thus vertical distances are measured in the direction of gravity. The vertical distances are measured to determine the difference of elevations between the various points.

(d) **Vertical angle:** Vertical angle is measured between two lines in vertical plane.

1.6.1 Instruments Used for Various Types of Measurement

(a) **For horizontal distance measurement :** Tape, chain, tacheometer, EDM etc.

(b) **For horizontal angle measurement :** Magnetic compass, theodolites, total station, sextant etc.

(c) **For vertical distance measurement :** Tacheometer, levelling instruments like dumpy level etc.

(d) **For vertical angle measurement :** Sextant, clinometer, theodolite etc.

1.7 PLAN AND MAP

- **Plan:** It is the graphical representation of various features on or near to the earth's surface as projected on a horizontal plane. Plan represents the area on a earth surface. The horizontal distances are measured between the various points on earth surface. Because of small areas involved in surveying as compared to earth's total area, the areas may be regarded as flat surface and the plan is constructed by orthographic projections. A plan is usually drawn on a relatively large scale.
- **Map:** In this, the scale of graphical projection on horizontal plane is small. Due to small scales a map depicts a large number of details as compared to plan. Some additional features are also shown on map like reliefs, contour lines, undulations etc.

- Therefore, a large scale representation of small areas in engineering surveys are called plans whereas small scale representation of large area are called maps.

1.7.1 Scale of Map

- A map is made on a sheet of paper which has limited dimensions.
- On this restricted area, a large number of details have to be shown.
- Thus original distances between various points on earth's surface have to be reduced so that these points can be accommodated on the sheet of paper.
- The ratio of distance between two points on map to corresponding distance on ground is called as **Scale of Map**.

Thus, $$\text{Scale of Map} = \frac{\text{Distance between two points on map}}{\text{Corresponding distance between those two points on ground}}$$

- The scale of map should neither be too small nor too large

  Scales are generally classified as small, medium and large

  Small scale 1 cm = 100 m or more

  Medium scale 1 cm = 10 m to 100 m

  Large scale 1 cm = 10 m or less

  In most of the engineering projects, scale varies from 1 cm = 2.5 m to 1 cm = 100 m.
- A scale may be represented either numerically by engineer's scale or representative fraction or graphically.

NOTE

- Graphical scale has an advantage over numerical scale. Over a period of time, the paper on which map is drawn may shrinks.
- In this case of shrinkage of map, graphical scale also changes with map therefore the ratio is unaffected and distance can be found accurately. But numerical scale may not give accurate results in case of shrinkage of may.

Example 1.1 A plan represents a rectangular area of 61965 m^2 and measures 8.5 cm by 10 cm. What is the scale of map?

Solution:

Area of plan = $8.5 \times 10\text{ cm}^2 = 85\text{ cm}^2$

But actual area = Plan area × (scale)^2

$$\Rightarrow \quad \text{Scale} = \sqrt{\frac{61965}{85}} = 27$$

∴ Time scale is 1 cm = 27 m.

1.7.2 Representation of Scale

(a) **Engineer's scale:** This scale is represented by a statement like 1 cm = 50 m or 1 cm = 180 m etc. A scale of 1 cm = 80 m implies 80 m on ground is represented by 1 cm on map.

(b) **Representative fraction (RF):** This scale is expressed as fractions in same units. For example, 1 cm = 50 m is represented in RF as 1 : 5000 or 1/5000. Here 50 m is converted as 5000 cm.

(c) **Graphical scale:** It is the line drawn on map such that its map distance corresponds to a convenient unit of length on ground.

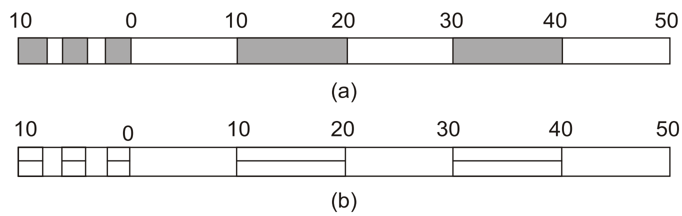


Fig: Graphical scale

1.7.3 Types of Scales

Scales may be classified as follows:

1. Plain scale
2. Diagonal scale
3. Vernier scale
4. Scale of chords

1. **Plain scale:** It is the scale on which it is possible to measure two dimensions only such as units and lengths, meters and decimeters, cm and mm etc.
2. **Diagonal scale:** On a diagonal scale, it is possible to measure there dimensions such as meters, decimeters and centimeter.
3. **Vernier Scale:** A vernier is a device for measuring accurately to fractional part of the smallest division on a graduated scale i.e. main scale. It consists of a small auxiliary scale which slides along side the main scale. It is known as vernier scale. It consists of an index mark which point out zero of the vernier scale. The divisions of vernier scale are made either slightly shorter or slightly longer than that of the main scale.

   The vernier can be divided into following classes:

   (a) **Direct vernier:** The vernier which extends in the same direction as that of the main scale and in which the smallest division on the vernier is shorter than the smallest division on the main scale, is known as direct vernier. Let n divisions of vernier scale are equal in length to $(n-1)$ divisions on main scale.

   Thus, $n.v = (n-1)S$

   $$v = \frac{n-1}{n}\cdot S$$

   Where v = Length of one division on vernier scale

   and S = Length of one division on the main scale

   The least count (L.C.) is, given by

   $$\text{L.C.} = s - v$$

   or $$\text{L.C.} = s - \frac{(n-1)}{n}s$$

   or $$\text{L.C.} = \frac{s}{n}$$

- The least count (L.C.) of the vernier is thus equal to the value of the smallest division on the main scale(s) divided by the total number (n) of divisions on the vernier.

(b) Retrograde Vernier: A retrograde vernier has divisions which are slightly longer than those of the main scale. If n divisions of the vernier scale are equal to $(n + 1)$ divisions on the main scale,

$$nv = (n+1)s$$

or
$$v = \frac{(n+1)}{n}s$$

Therefore, least count (L.C.) $= v - s$

$$= \frac{(n+1)}{n}s - s$$

or
$$\text{L.C.} = \frac{s}{n}$$

As in the case of a direct vernier, the least count is equal to the smallest division on the main scale (s) divided by the number (n) of divisions on the vernier.

It may be noted that the readings in the case of a retrograde vernier increase in a direction opposite to that of the main scale, whereas in the case of a direct vernier both increase in the same direction.

(c) Double Vernier: A double vernier is a vernier scale with its zero at the centre and extending in both directions from the centre. It is used where there are two main scales running in opposite direction. The vernier to be used will run in the same direction as the main scale.

(d) Extended vernier: Extended verniers are used when the main scale divisions are very close and it is difficult to judge the coincidence. In this case (2n – 1) divisions of main scale are divided into n divisions of the vernier scale. The least count is m/n.

$$\text{Vernier division, } v = (2n - 1)\ \text{m/n}$$

4. Scale of chords: Scale of chords is sued to measure an angle and is marked either rectangular protractor or an ordinary box wood scale.

1.8 ERRORS INCURRING DUE TO SHRINKAGE OF MAP

- Drawing sheets or map shrink due to temperature, humidity etc.
- Obviously, the lines present on map will shrink.
- The lengths measured from the shrunk map do not represent the correct distances.
- Graphical scale has the advantage that the amount of shrinkage of map and the graphical scale is the same.
- But in the absence of graphical scale, correct lengths has to be worked out. Here, we define **shrinkage ratios** (or **shrinkage factor**) as

$$\text{Shrinkage ratio (or shrinkage factor)} = \frac{\text{Shrunk length}}{\text{Actual length}} = \frac{\text{Shrunk scale}}{\text{Original scale}} = \frac{\text{Shrunk R.F.}}{\text{Original R.F.}}$$

This shrinkage ratio is always less than one (or unity)

$$\text{Thus, correct length} = \frac{\text{Measured length}}{\text{Shrinkage ratio}}$$

Similarly,
$$\text{Correct area} = \frac{\text{Measured area}}{(\text{Shrinkage ratio})^2}$$

Example 1.2 The plan area of an old survey plotted to a scale of 10 m to 1 cm presently measures 80.5 cm^2. It is believed that plan has shunk so that the original line of 10 cm now measures 9.2 cm. A note on the plan states that chain used was of 20 m and was 8 cm too short. What is the true area of the survey ?

Solution:

$$\text{Original plan area (A)} = \left(\frac{10}{9.2}\right)^2 \times 80.5 = 95.11 \text{ cm}^2$$

Scale of plan is 10 m = 1 cm

$\therefore$ Area on ground = $95.11 \times 10^2 = 9511 \text{ m}^2$

Now the chain was 8 cm too short and chain length used was of length 20 m

$\therefore$ $l' = 20 - 0.08 = 19.92$ m

$$\therefore \quad \text{True area of field/survey} = \left(\frac{19.92}{20}\right)^2 \times 9511 = 9435.06 \text{ m}^2$$

1.9 DISTINCTION BETWEEN PRECISION AND ACCURACY

- Precision is referred to as the degree of fineness and care with which any physical measurement is made whereas accuracy is the degree of perfection obtained in the measurement.
- Measurements may be accurate without being precise and Vice Versa.
- In surveying, to produce a plan, the accuracy required is defined by the scale of the plot.
- A good draughts person can plot a length to within 0.25 mm and so at a scale of 1 : 1000 i.e. 1 mm on the plan representing 1 m on the ground, the smallest plotable distance is 0.25 m. Thus for a survey at 1 : 1000 scale all the measurements must be taken such that the relative positions of any point with respect to any other must be determined to 0.25 m or better.

1.10 ERRORS INCURRING DUE TO WRONG MEASURING SCALE

The measured length of a line on a map (or a plan) will not be correct if a wrong measuring scale is used. To understand this, let a map is prepared with a scale of 1 : 100, but later on the length is taken with a scale of 1 : 150. Thus the measured distance of 20 cm. On map will actually represent 20 m on ground, but would be taken as 30 m due to wrong scale.

$$\therefore \quad \text{Correct length} = \frac{\text{Wrong scale}}{\text{Correct scale}} \times \text{Measured length}$$

Similarly,
$$\text{Correct area} = \left(\frac{\text{Wrong scale}}{\text{Correct scale}}\right)^2 \times \text{Measured area}$$

OBJECTIVE BRAIN TEASERS

Q.1 Which of the following scale in the longest?
(a) 1 : 50000 (b) 1 cm = 50 m
(c) 1 cm = 500 km (d) R.F. = 1/500000

Q.2 The R.F. of scale 1 cm = 5 km is
(a) 1/5 (b) 1/50
(c) 1/500000 (d) 1/50000

Q.3 The main principal of survey is
(a) to work from left to right
(b) to work from top to bottom
(c) to work from to left to bottom right
(d) to work from whole to part

Q.4 Shrinkage ratio is expressed as
(a) shrunk length/original length
(b) shrunk length + original length
(c) shrunk length × original length
(d) None of these

Q.5 The type of surveying wherein curvature of earth is also accounted for is known as
(a) plain surveying
(b) hydrographic surveying
(c) aerial surveying
(d) geodetic surveying

Q.6 A survey plan was plotted to a scale of 20 m to 1 cm. This scale was reduced in such a way that originally 20 cm line now measures 19 cm. If area of reduced plan is 100 cm^2, then actual area of survey was
(a) 44320 m^2 (b) 110.8 cm^2
(c) 36100 m^2 (d) Data insufficient

Q.7 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I
A. Stream gauging
B. Station pointer
C. Tide gauge
D. Sounding

List-II
1. Solving three point problem
2. To determine water level and its variation
3. The process of determining the river bed depth
4. To measure turbidity
5. Measuring the discharge of a stream

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	1	2
(c)	5	1	2	3
(d)	3	1	2	5

Q.8 The map projection in which the angle between any pair of short lines represented correctly is called
(a) conformal projection
(b) equidistant projection
(c) azimuthal projection
(d) equal area projection

Q.9 The type of surveying in which the curvature of the earth is taken into account is called
(a) Geodetic surveying
(b) Plane surveying
(c) Preliminary surveying
(d) Topographical surveying

Q.10 **Assertion (A) :** Nautical sextant is used in hydrographic surveying.
Reason (R) : This instrument helps in determining the depth of water.
(a) Both Assertion (A) and Reason (R) are individually true and Reason (R) is the correct explanation of Assertion (A).
(b) Both Assertion (A) and Reason (R) are individually true but Reason (R) is NOT the correct explanation of Assertion (A).
(c) Assertion (A) is true but Reason (R) is false.
(d) Assertion (A) is false but Reason (R) is true.

Q.11 A rectangular plot of 50 km^2 in area is shown on a map by a similar rectangular area of 2 cm^2. RF of the scale to measure a distance of 50 km will be
(a) $\frac{1}{1600}$ (b) $\frac{1}{500000}$
(c) $\frac{1}{400}$ (d) $\frac{1}{16000}$