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Surveying

Civil Engineering

Comprehensive Theory *with* Solved Examples

Civil Services Examination

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Surveying

01
CHAPTER

Basic Concepts of Surveying

1.1 INTRODUCTION

- Surveying is the science of determining the relative position of natural and man-made features on earth's surface, along with their elevations and the presentation of this information either graphically or numerically.
- The results of survey when drawn on paper forms a **plan or a map**.
- 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 for this, sufficient number of points and lines have to be located on the plan.

1.2 CLASSIFICATION OF SURVEY

1.2.1 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.
- 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.
- Almost all surveys for various engineering projects like construction of dams, highways, railway lines, canals etc. use plane survey.
- In plane surveying, measurements plotted will represent the projection on the horizontal plane of the actual field measurement.

For example: PQ is plotted as PQ'.

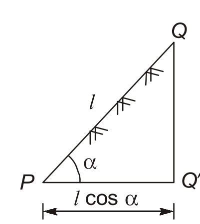


Fig.

(b) Geodetic Survey:

- In this 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 and measurements are required to be made with the highest possible order. Here, a line connecting the two points is an arc and not the straight line.

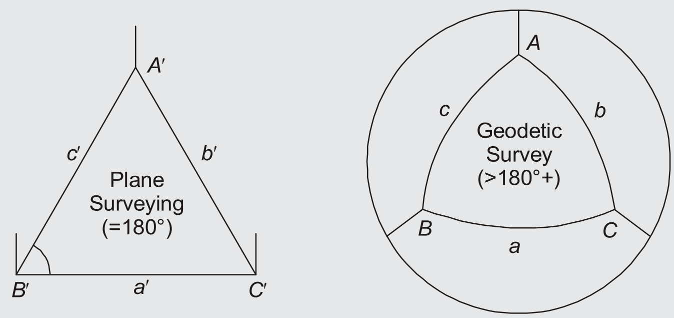
Geodetic survey is needed to fix the widely spaced **control points** that are later on used as necessary control points for fixing the minor control points.

NOTE

1. Geodetic survey is carried out by department of National survey of India.
2. Control points are the points of known co-ordinates. It is used as a reference for taking other measurements during surveying.

DO YOU KNOW?

1. For surveying up to 195.5 km^2 in area, plane surveying will be adequate.
2. If any arc (AB) is equal to 18.5 km, then the corresponding chord ($A'B'$) will be 1.52 cm shorter than the arc.



1.2.2 Classification of Survey Based on Instrument Used

(a) Chain Survey

For making plan of very small open fields, only linear measurements may be required in field work which are taken with a chain and tape. This type of survey is called chain survey.

It cannot be used in densely built-up areas and places with trees and shrubs providing obstacles to chain.

It is useful for laying of sewer lines, water supply lines, construction of roads etc.

(b) Traverse Survey

The survey in which linear measurements are made with chain and directions or angles are measured with compass or transit respectively is known as traversing.

This survey is useful for large projects like dams and reservoirs. It is not very accurate method. In traversing, speed and accuracy of field work is increased.

(c) Levelling

Here, the relative vertical heights of different points are determined. A graduated staff and a level are used for this purpose.

(d) Tacheometry

In this type of survey, both horizontal and vertical distances are measured by sighting a graduated staff with a transit telescope fitted with an anallatic lens.

They are not that much accurate in plane areas but are extremely useful when direct measurements of horizontal distances are inaccessible.

(e) Plane Table Survey

It is a graphical method of surveying in which 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 and accuracy is low.

(f) **Triangulation survey:** 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 length of sides of all triangles are then computed from the measured length of base line and observed angles using sine formula.

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

(g) EDM Survey

- EDM is a electronic distance measurement device that can measure horizontal distances very accurately using propagation, reflection and subsequent reception of other light or radio waves.
- Trilateration is a type of triangulation in which all the three sides of each triangle are measured accurately with the help of EDM instruments.
- Angles are then computed directly from the known sides of triangles.

NOTE: Trilateration is used for fixing the position of control points like triangulation. With the help of EDM, it is more convenient in comparison to triangulation.

(h) 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.

(i) 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.

1.2.3 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.

(b) **Geographical survey:** This survey is done for preparation of geographical maps depicting the land use efficiency, irrigation intensity, surface drainage, slope profile, contours 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) **Mine survey:** In this both surface and underground surveys are required. It involves making the surface map and doing the underground survey for locating the reserve of minerals.

(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 enemy area are prepared which gives crucial information about the existing roads, airports, ordnance depots etc.

(f) **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, incandescent floods etc.

(g) **Astronomic Survey:** These surveys are conducted for determination of latitudes, longitudes, azimuthe, local time, etc. at various places on the earth by observing heavenly bodies (the sun or stars).

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

1.2.4 Classification based on Place of Survey

(a) **Land survey:** It involves re-running of old land survey lines to determine their lengths and directions thereby subdividing the area into definite shapes and sizes and calculating their areas etc. in order to set up a structure. Following are the examples of land surveying:

(i) **Topographical survey:** It gathers data about the elevation of points on a piece of land and present them as contour line on a plot. The purpose of this survey is to collect survey data about the natural and man-made features of land, as well as its elevations.

(ii) **Cadastral survey:** These are done to establish boundary of properties for legal purposes. These are also known as public land surveys.

(iii) **City survey:** An extensive survey of the area in and around the city for fixing reference monuments, locating and improving property lines and to determine the features of land is known as a city survey.

(b) **Hydrographic Survey:** It involves survey of water bodies like the streams, sea, ponds etc. The basic purpose of this survey is to establish the shore line. Apart from this, this survey is done to determine the amount of water stored by a water body, navigation possibilities, 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, underground plans, transfer of surface line coordinates to the underground line etc. are drown.

(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.

NOTE

- **Horizontal and vertical controls** in land surveying are developed to create a framework around which other survey can be adjusted. These are used for accurate mapping projects in land surveying and many other high precision projects.
- Field surveying activities begin with the establishment of horizontal and vertical control points.
- This process includes research of the public records to identify survey monuments in the vicinity of the project area that are identified on recorded maps.
- In addition, research of local agency benchmark database to identify local benchmarks is done.
- Field surveys are then conducted to search for and locate existing survey monuments and to transfer the deviation from a known benchmark to the project site.

1.3 PRINCIPLES OF SURVEYING

(a) Work from whole to part
(b) Locate a point by atleast two measurements.

1.3.1 Work from Whole to Part

- It is the very first principle of surveying.
- The basic idea behind this principle is to localise the errors and prevent their accumulation.
- 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 expansion of errors in small frame work.

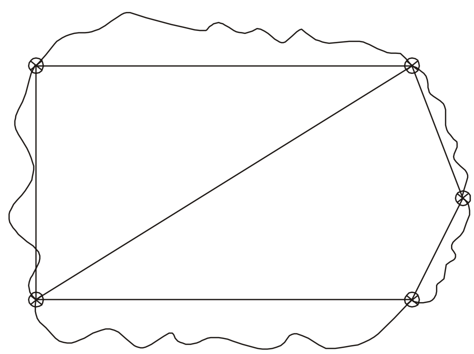


Fig.

- Major Control points are decided and measured accurately with high degree of precision. Minor details can be collected later to avoid the error to be accumulated.

1.3.2 Location of Point is Measured w.r.t two Reference Points

- Two control point A and B are selected in the area and the distance between them is measured accurately.
- If *A* and *B* are the control points, the point *C* can be plotted by any of the following methods.

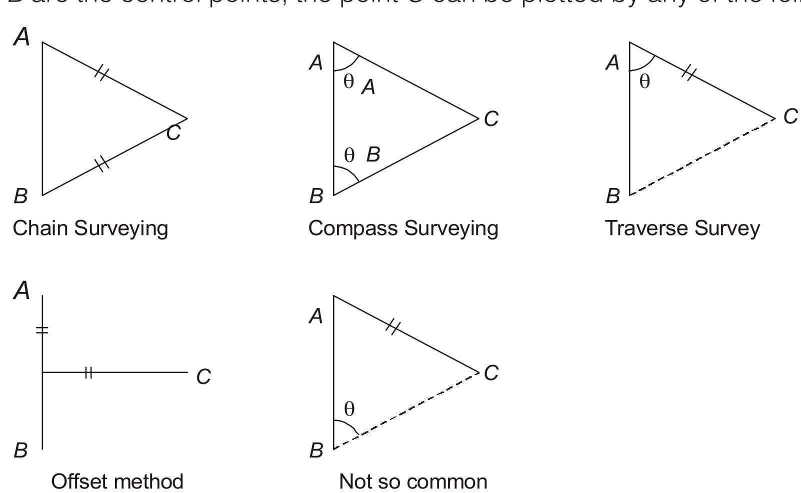


Fig.

1.4 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

1.5 PLAN AND MAP

Plan	Map
1. If the scale is large, the representation is called plan.	1. If the scale is small, then the representation is called Map.
2. Plans are used for technical purposes such as architecture, engineering or planning.	2. Map may represent any space, real or imagined.
3. Plan is a true scale representation.	3. Map is drawn such that some features on it cannot be drawn to scale.
4. On a plan-Horizontal distances and direction are shown.	4. On a topographic map, vertical distances are shown by contour lines.
5. Drawn for small area — House, bridge.	6. Drawn for large area — Punjab, Haryana.

1.5.1 Scale of Map

- The 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

1.5.2 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 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.

Scale can also be graphically represented by drawing a line on map and marking the ground distance directly on it.

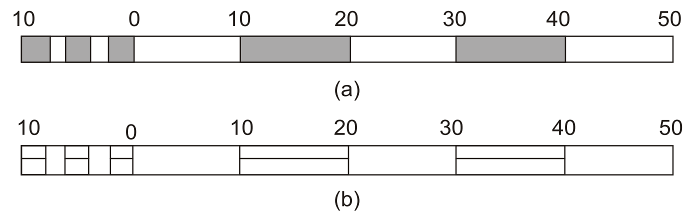


Fig. *Graphical scale*

1.6 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 shrinked map do not represent the correct distances.
- Graphical scale has the advantage over the numerical scale that the amount of shrinkage of map and the graphical scale is the same.
- In case of shrinking of map, the graphical scale also changes with the map, and therefore, the ratio is unaffected.
- But in the absence of graphical scale, correct lengths have to be worked out. Here, we define **shrinkage ratios** (or **shrinkage factor**) as

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

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

$$\text{Thus correct length on map in terms of original scale} = \frac{\text{Measured length on Map}}{\text{Shrinkage ratio}}$$

Similarly,
$$\text{Correct area on map in terms of original scale} = \frac{\text{Measured area on map using planimeter}}{(\text{Shrinkage ratio})^2}$$

1.7 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 be prepared with a scale of 1 : 100, but later it is detected that surveyor wrongly used 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, $$\text{Correct area} = \left(\frac{\text{Wrong scale}}{\text{Correct scale}}\right)^2 \times \text{Measured area}$$

EXAMPLE - 1.1

The length of a line originally 100 mm long on a map plotted to a scale of 1/1000, was found to be 96 mm due to shrinkage of the map. The map prepared using a tape of length 20 m was later found to be actually 20.03 m. If a certain area on the map, measured using a planimeter is 282 mm^2, determine the correct area on the ground.

Solution:

Due to shrinkage in the map, the scale of the map will change from 1/1000 to 1/S where

$$S = 1000 \times \frac{100}{96}$$

Further, since the 20 m tape was actually 20.3 m, a correction factor c of $\frac{20.03}{20}$ has to be applied to all the linear measurements.

The correct area on the ground due to change in scale.

$$A = \text{Measured area} \times (\text{new scale})^2$$
$$= \text{Measured area} \times S^2$$

Now the corrected area due to incorrect length of the tape

$$A = A'c^2$$
$$= 282 \times \left(1000 \times \frac{100}{96}\right)^2 \times \left(\frac{20.03}{20}\right) \text{mm}^2$$
$$= 282 \times \left(1000 \times \frac{100}{96}\right)^2 \times \left(\frac{20.03}{20}\right)^3 \times \frac{1}{1000^2} \text{m}^2 = 307 \text{ m}^2$$

1.8 USE OF VERNIERS IN SCALES

- It is a device used for measuring the fractional part of one of the smallest division of a graduated scale.
- The principle of vernier is based on the fact that eye can perceive without strain and with considerable precision when two graduation coincide to form one continuous straight line.
- The vernier carries an index mark which forms the zero of the vernier.
- If the graduations of the main scale are numbered in one direction only, the vernier used is called a single vernier, extending in one direction. If the graduations of the main scale are numbered in both directions, the vernier is called double vernier, extending in both directions, having its index mark in the middle.
- The least count of the vernier is equal to the difference in length of one division of the main scale and one division of the vernier scale.

A vernier can primarily be divided into following two classes:

(a) Direct Vernier

(b) Retrograde Vernier

(a) **Direct Vernier:** A direct vernier is the one which extends or increase 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. It is constructed such that $(n-1)$ divisions of the main scale are equal in length of n division of the vernier.

Let S = Value of one smallest division on main scale.

v = Value of one smallest division on the vernier

n = no. of division on vernier

Since a length of $(n-1)$ divisions of main scale is equal to n divisions of vernier.

$$nv = (n-1)S$$

$$\boxed{v = \frac{(n-1)S}{n}}$$

$$\text{Least count} = S - v = S - \left(\frac{n-1}{n}\right)S = \frac{S}{n}$$

Thus, the least count (L.C.) can be found by dividing the value of one main scale division by the total number of division on the vernier.

(b) **Retrograde Vernier:** A retrograde vernier is the one which extends or increase in opposite direction as that of main scale and in which smallest division of the vernier is longer than the smallest division on the main scale.

It is so constructed that $(n+1)$ divisions of the main scale are equal in length of n division of the vernier.

$$nv = (n+1)S \quad : \quad \text{or} \quad v = \frac{(n+1)}{n}S$$

$$\text{The least count, } v - S = \frac{(n+1)}{n}S - S = \frac{S}{n}$$

which is same as before.

EXAMPLE - 1.2

The value of the smallest division of circle of a repeating theodolite is 10′. Design a suitable vernier to read upto 10″.

Solution:

$$\text{L.C.} = \frac{S}{n}; \quad S = 10$$

$$\text{L.C.} = 10'' = \frac{10}{60}\text{minutes}$$

$$\frac{10}{60} = \frac{10}{n} \quad \Rightarrow \quad n = 60$$

Take 59 such primary divisions from the main scale and divide if into 60 parts.

EXAMPLE - 1.3

Design a vernier for a theodolite circle divided into degrees and half degrees to read upto 30″.

Solution:

$$\text{Least Count} = \frac{S}{n}, \quad S = 30$$

$$\text{L.C.} = 30'' = \frac{30}{60}\text{minutes}$$

$$\frac{30}{60} = \frac{30}{n} \Rightarrow \text{ or } n = 60$$

Take 59 such primary divisions should be taken for the length of the vernier scale and then divided into 60 parts for a direct vernier.

1.9 ERRORS

No measurement in surveying is exact. Every measurement contains errors of unknown magnitude due to several reasons which should be understood.

1.9.1 Sources of Error

The sources of error in surveying are:

(a) **Natural errors:** These errors result from the sources which are beyond the control of the surveyor such as temperature, refraction, magnetic declination, etc. They can be contained within permissible limits by taking precautionary measures.

(b) **Instrumental errors:** These errors result from the imperfect construction and adjustment of the instrument. For example, incorrect graduations on a tape. They can be contained within permissible limits by applying proper corrections.

(c) **Personal errors:** These result due to the limitations of human senses of sight, touch and hearing. For example, improper bisecting while measuring an angle.

1.9.2 Types of Error

Errors and classified as systematic errors and accidental errors.

(a) **Systematic errors:** These errors occur from well-understood causes and can be reduced by suitable methods. For example, error due to sag of tape can be measured and substracted from each measurement. Systematic errors can either be constant or variable depending upon whether the conditions remains the same or changes. These are also called cumulative errors.

(b) **Accidental errors:** These errors are caused due to factors beyond the control of surveyor. For example, inaccurate calibration of chain.

1.10 MISTAKE AND ERROR

Mistake:

- Mistake is caused by misunderstanding of the problem, poor judgement or carelessness.
- They can be corrected if discovered and can be avoided by being careful.

Errors:

- Error is the difference of measured and true value.
- They can be minimised but not avoided.

1.11 PRECISION AND ACCURACY

Precision:

It is referred to as the degree of fineness and care with which any physical measurement is made.

Accuracy:

- It is the degree of perfection obtained.
- For a set of measurements to be considered accurate value, when it has value close the true values.
- Precision represents a set of observation that are closely grouped together and have small deviations from the true value.

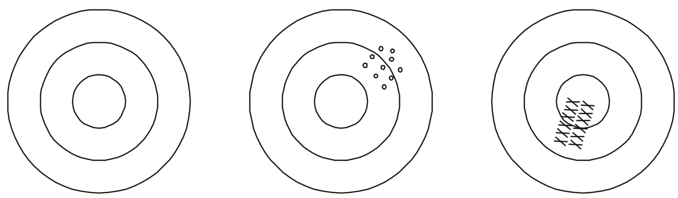


Fig.

Accuracy required:

- In surveying, to produce a plan, the accuracy required is defined by the scale of 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 possible distance is 0.25 m.

  Thus, for a survey at 1 : 1000, all the measurements must be taken such that the relative position of any point wrt any other must be determined to 0.25 m.

PRACTICE QUESTIONS

Question : 1

A rectangular plot was measured with a 20 m chain and its size was established as 450 m × 250 m. Later on, it was found that the chain used for measuring the sides of plot was 15 cm too long. What is the true area of the plot?

Solution:

Measured area of rectangular plot = 450 × 250 = 1,12,500 m^2

Actual length of chain = 20.15 m

$$\text{True area of plot} = \left(\frac{20.15}{20}\right)^2 112500 = 1,14,193.83\ m^2$$

Alternatively

Measured length (L) = 450 m; Measured breadth (B) = 250 m

Actual chain length = 20.15 m

$$\therefore \quad \text{True length} = \left(\frac{l'}{l}\right)L = \left(\frac{20.15}{20}\right)450 = 453.375\ m$$

$$\text{True breadth} = \left(\frac{20.15}{20}\right)250 = 257.875 \text{ m}$$

$$\therefore \quad \text{True area} = 453.375 \times 251.875 = 1,14,193.83 \text{ m}^2$$

Question : 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 shrunk 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

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

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

$$\therefore \quad l' = 20 - 0.08 = 19.92 \text{ m}$$

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

Question : 3

The dimensions i.e. length, breadth and height of an embankment were measured with a 20 m chain and volume of embankment came out to be 550.77 cu.m. Later on, it was found that the chain used for measurement was 15 cm too short. What is the actual volume of embankment?

Solution:

$$\text{True volume} = \left(\frac{l'}{l}\right)^3 \times \text{measured volume}$$

$$= \left(\frac{20 - 0.15}{20}\right)^3 \times 550.77 = 538.47 \text{ m}^3$$

Question : 4

The length of a line measured from a chain was found to be 280 m. Calculate the true length of the line if:

(a) The length was measured with a 30 m chain and chain was found to be 12 cm too long.

(b) The length was measured with a 30 m chain in the beginning and 30.2 m at the end of the work.