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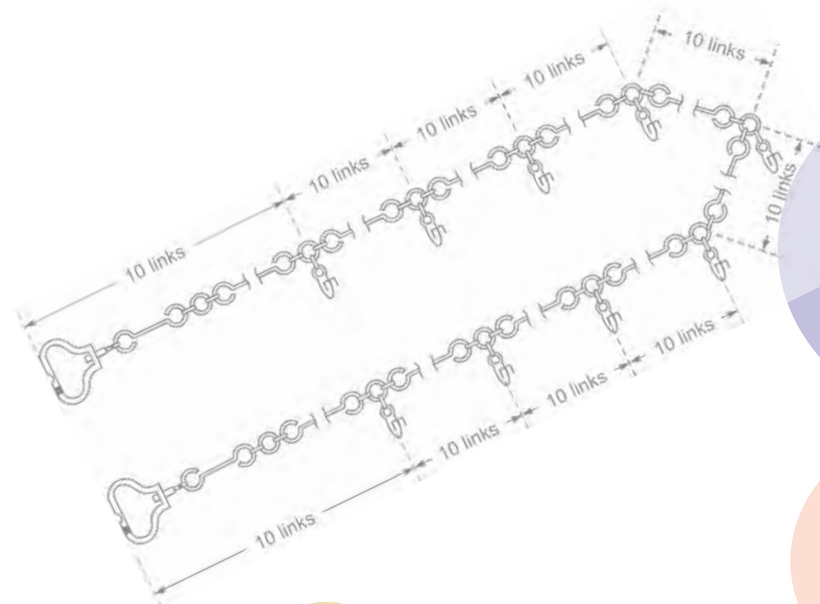
Civil Engineering

10

Engineering Surveying



Technical and Vocational Stream
Learning Resource Material

Engineering Surveying
(Grade 10)
Civil Engineering

Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

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Preface

The curriculum and curricular materials have been developed and revised on a regular basis with the aim of making education objective-oriented, practical, relevant and job oriented. It is necessary to instill the feelings of nationalism, national integrity and democratic spirit in students and equip them with morality, discipline, self-reliance, creativity and thoughtfulness. It is essential to develop linguistic and mathematical skills, knowledge of science, information and communication technology, environment, health and population and life skills in students. It is also necessary to bring the feeling of preserving and promoting arts and aesthetics, humanistic norms, values and ideals. It has become the need of the present time to make them aware of respect for ethnicity, gender, disabilities, languages, religions, cultures, regional diversity, human rights and social values to make them capable of playing the role of responsible citizens with applied technical and vocational knowledge and skills. This learning resource material for civil engineering has been developed in line with the Secondary Level civil engineering Curriculum with an aim to facilitate the students in their study and learning on the subject by incorporating the recommendations and feedback obtained from various schools, workshops, seminars and interaction programs attended by teachers, students, parents and concerned stakeholders.

In bringing out the learning resource material in this form, the contribution of the Director General of CDC Mr. Yubaraj Paudel and members of the subject committee Dr. Jagat Kumar Shrestha, Dr. Bhim Kumar Dahal, Er. Anisha Lamsal, Er. Gita Lamichhane, Mr. Durga Bahadur Pun is highly acknowledged. This learning resource material is compiled and prepared by Er. Jagadishchandra Karki, Er. Kedarnath Dahal, Er. Hemantaraj Joshi and Er. Sabin Silwal. The subject matter of this material is edited by Mr. Badrinath Timsina and Mr. Khilanath Dhamala. Similarly, the language is edited by Mr. Bijaya Kumar Ranabhat. CDC extends sincere thanks to all those who have contributed to developing this material in this form.

This learning resource material contains a wide coverage of subject matters and sample exercises which will help the learners to achieve the competencies and learning outcomes set in the curriculum. Each chapter in the material clearly and concisely deals with the subject matters required for the accomplishment of the learning outcomes. The Curriculum Development Centre always welcomes creative and constructive feedback for the further improvement of the material.

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Table of Content

Guidelines to Teachers

A. Facilitation Methods

The goal of this course is to combine the theoretical and practical aspects of the contents needed for the subject. The nature of contents included in this course demands the use of practical or learner focused facilitation processes. Therefore, the practical side of the facilitation process has been focused much. The instructor is expected to design and conduct a variety of practical methods, strategies or techniques which encourage students engage in the process of reflection, sharing, collaboration, exploration and innovation new ideas or learning. For this, the following teaching methods, strategies or techniques are suggested to adopt as per the course content nature and context.

Brainstorming

Brainstorming is a technique of teaching which is creative thinking process. In this technique, students freely speak or share their ideas on a given topic. The instructor does not judge students' ideas as being right or wrong, but rather encourages them to think and speak creatively and innovatively. In brainstorming time, the instructor expects students to generate their tentative and rough ideas on a given topic which are not judgmental. It is, therefore, brainstorming is free-wheeling, non-judgmental and unstructured in nature. Students or participants are encouraged to freely express their ideas throughout the brainstorming time. Whiteboard and other visual aids can be used to help organize the ideas as they are developed. Following the brainstorming session, concepts are examined and ranked in order of importance, opening the door for more development and execution. Brainstorming is an effective technique for problem-solving, invention, and decision-making because it taps into the group's combined knowledge and creative ideas.

Demonstration

Demonstration is a practical method of teaching in which the instructor shows or demonstrates the actions, materials, or processes. While demonstrating something the students in the class see, observe, discuss and share ideas on a given topic. Most importantly, abstract and complicated concepts can be presented into visible form through demonstration. Visualization bridges the gap between abstract ideas and concrete manifestations by utilizing the innate human ability to think visually. This enables students to make better decisions, develop their creative potential, and obtain deeper insights across a variety of subject areas.

Peer Discussion

Peer conversation is a cooperative process where students converse with their peers to exchange viewpoints, share ideas, and jointly investigate subjects that are relevant or of mutual interest. Peer discussion is an effective teaching strategy used in the classroom to encourage critical thinking, active learning, and knowledge development. Peer discussions encourage students to express their ideas clearly, listen to opposing points of view, and participate in debate or dialogue, all of which contribute to a deeper comprehension and memory of the course material. Peer discussions also help participants develop critical communication and teamwork skills by teaching them how to effectively articulate their views, persuasively defend their positions, and constructively respond to criticism.

Peer conversation is essential for professional growth and community building outside of the classroom because it allows practitioners to share best practices, work together, and solve problems as a group. In addition to expanding their knowledge horizon and deepening their understanding, peer discussions help students build lasting relationships and a feeling of community within their peer networks.

Group Work

Group work is a technique of teaching where more than two students or participants work together to complete a task, solve a problem or discuss on a given topic collaboratively. Group work is also a cooperative working process where students join and share their perspectives, abilities, and knowledge to take on challenging job or project. Group work in academic contexts promotes active learning, peer teaching, and the development of collaboration and communication skills. Group work helps individuals to do more together than they might individually do or achieve.

Gallery Walk

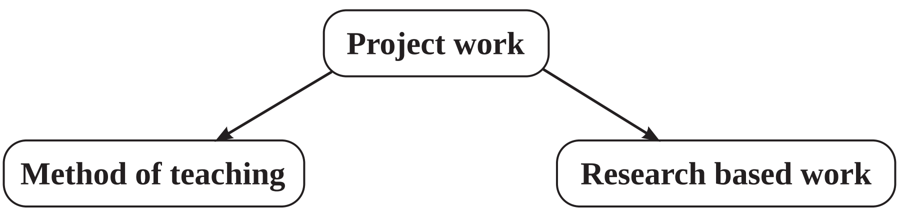
Gallery walk is a critical thinking strategy. It creates interactive learning environment in the classroom. It offers participants or students a structured way to observe exhibition or presentation and also provides opportunity to share ideas. It promotes peer-to-peer or group-to-group engagement by encouraging participants to observe, evaluate and comment on each other's work or ideas. Students who engage in this process improve their communication and critical thinking abilities in addition to their comprehension of the subject matter, which leads to a deeper and more sophisticated investigation of the subjects at hand.

Interaction

The dynamic sharing of ideas, knowledge, and experiences between people or things is referred to as interaction, and it frequently takes place in social, academic, or professional settings. It includes a broad range of activities such as dialogue, collaboration or team work, negotiation, problem solving, etc. Mutual understanding, knowledge sharing, and interpersonal relationships are all facilitated by effective interaction. Interaction is essential for building relationships, encouraging learning, and stimulating creativity in both in-person and virtual contexts. Students can broaden their viewpoints, hone their abilities, and jointly achieve solutions to difficult problems by actively interacting with others.

Project Work

Project work is a special kind of work that consists of a problematic situation which requires systematic investigation to explore innovative ideas and solutions. Project work can be used in two senses. First, it is a method of teaching in regular class. The next is: it is a research work that requires planned investigation to explore something new. This concept can be presented in the following figure.



Project work entails individuals or teams working together to achieve particular educational objectives. It consists of a number of organized tasks, activities, and deliverables. The end product is important for project work. Generally, project work will be carried out in three stages. They are:

- Planning
- Investigation
- Reporting

B. Instructional Materials

Instructional materials are the tools and resources that teachers use to help students. These resources/materials engage students, strengthen learning, and improve conceptual comprehension while supporting the educational goals of a course or program. Different learning styles and preferences can be accommodated by the variety of instructional resources available. Here are a few examples of typical educational resource types:

- Daily used materials
- Related Pictures
- Reference books
- **Slides and Presentation:** PowerPoint slides, keynote presentations, or other visual aids that help convey information in a visually appealing and organized manner.
- **Audiovisual Materials:** Videos, animations, podcasts, and other multimedia resources that bring concepts to life and cater to auditory and visual learners.
- **Online Resources:** Websites, online articles, e-books, and other web-based materials that can be accessed for further reading and research.

Maps, Charts, and Graphs: Visual representations that help learners understand relationships, patterns, and trends in different subjects.

Real-life Examples and Case Studies: Stories, examples, or case studies that illustrate the practical application of theoretical concepts and principles.

C. Assessment

Formative Test

Classroom discussions: Engage students in discussions to assess their understanding of concepts.
Quizzes and polls: Use short quizzes or polls to check comprehension during or after a lesson.
Homework exercises: Assign tasks that provide ongoing feedback on individual progress.
Peer review: Have students review and provide feedback on each other's work.

Summative Test

Exams: Conduct comprehensive exams at the end of a unit or semester.
Final projects: Assign projects that demonstrate overall understanding of the subject.

Peer Assessment

Group projects: Evaluate individual contributions within a group project.
Peer feedback forms: Provide structured forms for students to assess their peers.
Classroom presentations: Have students assess each other's presentations.

Objective Test

Multiple-choice tests: Use multiple-choice questions to assess knowledge.
True/False questions: Assess factual understanding with true/false questions.
Matching exercises: Evaluate associations between concepts or terms.

Portfolio Assessment

Compilation of work: Collect and assess a variety of student work samples.
Reflection statements: Ask students to write reflective statements about their work.
Showcase events: Organize events where students present their portfolios to peers or instructors.

Observational Assessment

Classroom observations: Observe students' behavior and engagement during class.
Performance observations: Assess practical skills through direct observation.
Field trips: Evaluate students' ability to apply knowledge in real-world settings.

Unit 1 : Introduction

1.1 Definition of Surveying

The art of determining the relative position of features on, above or beneath the surface of the earth surface by means of direct or indirect measurement of distance, direction and elevation is called surveying.

1.2 Objective of Surveying

The main objective of surveying is to prepare a map of a given area showing various natural as well as man made features. Further, objectives of surveying can be listed as:

- To determine the relative position of any objects or points on the earth.
- To determine the distance and angles between various objects.
- To define control points and boundaries of an area, for example, a cadastral survey.

1.3 Uses of Surveying

The uses of surveying are:

- Topographical maps showing hills, rivers, towns, villages, forests etc. are prepared by surveying.
- For planning and estimating new engineering projects like water supply and irrigation schemes, mines, railroads, bridges, transmission lines, buildings etc. surveying is required.
- Cadastral map showing the boundaries a field houses and other properties are prepared by surveying.
- Engineering map showing the position of engineering works like roads, railways, buildings, dams, canals etc. are prepared through surveying.
- To set out a work and transfer details from map to ground knowledge of surveying is used.
- For planning navigation routes and harbors, marine and hydro-graphic surveying are used.

- To help military strategic planning, military maps are prepared by surveying.
- For exploring mineral wealth, mine survey is necessary.
- For determining different strata in the earth crust, geological surveys are required.

1.4 Classification of Surveying

Engineering surveying can be classified into several categories as following:

A. Primary Classification **B. Secondary Classification**

A. Primary Classification

This classification is based on whether or not the curvature of the Earth's surface is taken into account. Based on curvature of the earth surface, surveying is divided into:

1. **Plane Surveying**
2. **Geodetic Surveying**

1. Plane Surveying

Plane surveying is a small extent of survey in which the earth's surface is assumed to be plane and the curvature of the earth is ignored. It involves areas up to 260 square km. Knowledge of plane geometry and trigonometry are necessary for plane surveying.

2. Geodetic Surveying

Geodetic surveying takes place in a national scale where earth's curvature is considered. It involves areas greater than 260 square km. Knowledge of spherical trigonometry is necessary for geodetic surveying.

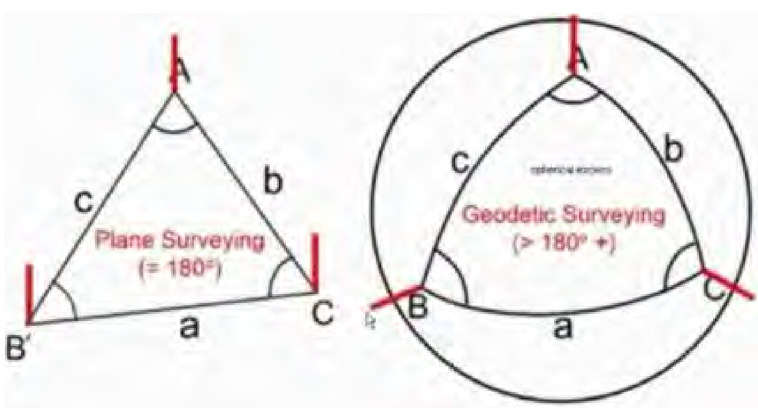


Fig 1: Plane and Geodetic Survey

B. Secondary Classification

i) Based on Instruments Used

a. Chain Surveying
b. Compass Surveying
c. Plane Table Surveying
d. Theodolite Surveying
e. Tachometric Surveying
f. Photographic Surveying
g. Aerial Surveying

ii) Based on Methods

a. Triangulation Surveying
b. Traverse Surveying

iii) Based on Object of Survey

a. Geological Surveying
b. Mine Surveying
c. Archaeological Surveying
d. Military Surveying
e. Engineering Surveying

iv) Based on Nature of Field

a. Land Survey
    - Topographical Survey
    - Cadastral Survey
    - City Survey

b. Marine or Hydrographic Survey
c. Astronomical Survey

1.5 Basic Principles of Surveying

The general basic principles of surveying are:

1. Working from Whole to Part

According to the first principle, the whole area is first enclosed by main (major) stations and main survey lines. That area thus enclosed is then divided into a number of parts by forming a well-conditioned triangle. The object of this method is to prevent accumulation of error and to control the localized minor errors.

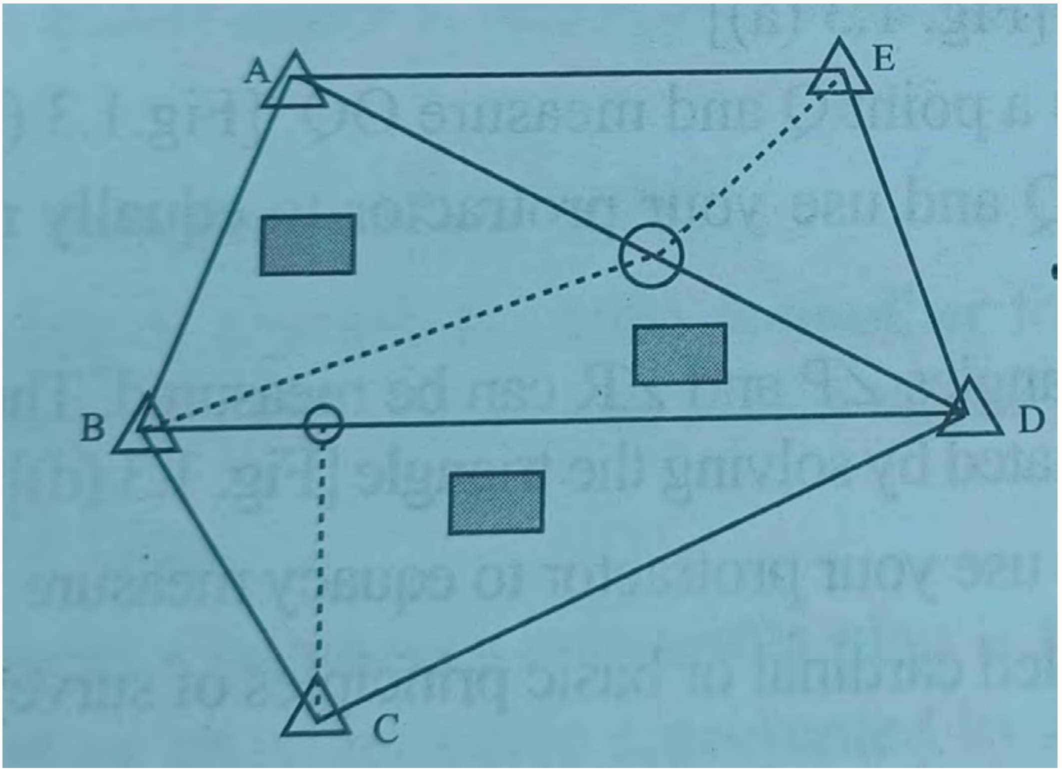


Fig 2: Working from whole to part

2. Location of point by measurement from two control points

According to this principle, the new station should always be fixed by at least two measurement (linear or angular) from fixed reference points.

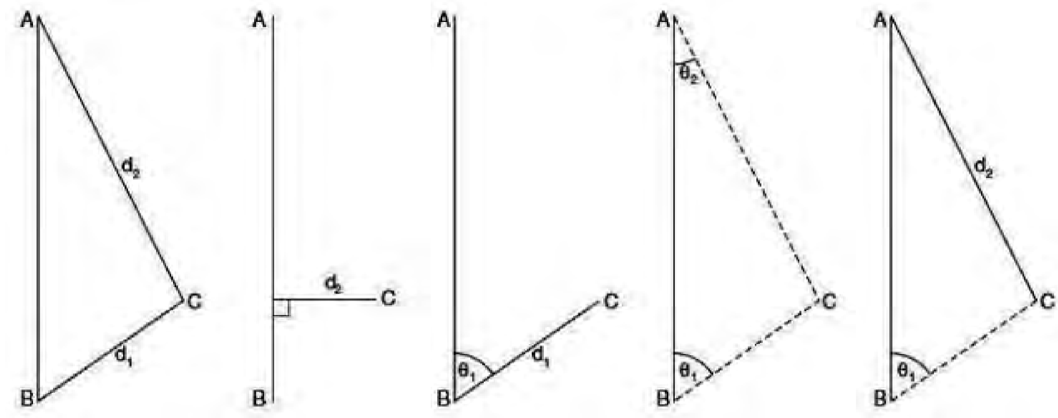


Fig 3: Location of a point

1.6 Definition of Scale

The actual length of an object is not always possible to represent in a drawing sheet so, it is required to enlarge or reduce the object in order to accommodate it on the drawing sheet in some proportion. The ratio by which the actual length of the object is reduced or enlarged is known as scale. A scale is defined as the ratio of the linear dimensions of the object as represented in drawing to the actual dimensions on the ground.

Full Size Scale

If the actual length of the object is shown on the drawing, the scale used is said to be a full-size scale i.e. 1:1.

Reducing Scale

If the actual length of the object is reduced in order to accommodate it in the drawing sheet, the scale used is said to be a reducing scale. For example: 1:2, 1:10, 1:10, 1:100, 1:200, 1:500, 1:1000, etc. in which the initial value represents the actual size in drawing sheet and the latter value represents the size in actual field.

Enlarging Scale

If the actual length of the object is enlarged in order to bring out its detail more clearly in the drawing sheet, the scale used is said to be an enlarging scale. For example: 2:1, 5:1, 10:1, 100:1, 200:1, 500:1, 1000:1, etc. in which the initial value represents the actual size in drawing sheet and the latter value represents the size in actual field.

1.7 Representative Fraction

The ratio of distance of the object on the drawing to the corresponding actual length of that object on the ground is known as representative fraction. It is denoted by RF.

$$\text{Representative Fraction (RF)} = \frac{\textit{Distance of object on drawing}}{\textit{Actual distance of object}}$$

For example:

If a scale drawn on a drawing sheet is 1 cm = 10 m then,

$$\text{Representative Fraction (RF)} = \frac{1}{10\times100} = \frac{1}{1000}$$

1.8 Types of Scale

1. Plain Scale

The scale in which it is possible to measure only two dimensions is called plain scale. This scale is used to represent two successive units such as kilometers, hectometers, decimeters, meters and so on.

- IS standard IS: 1491-1959 has recommended the scale sizes for plain scale as:

Full size	1:1
50cm to a meter	1:2
20cm to a meter	1:5
5mm to a meter	1:200

2. Diagonal Scale

The scale in which it is possible to measure three dimensions is called diagonal scale. This scale is used to represent three successive units or one unit and its fraction up to the second place of decimals such as kilometers, hectometers, decameters, meters and so on.

The principle of diagonal scale is based on the principles of similar triangles in which corresponding sides are proportional.

Distance

1’-1 = (1/10) x AB

2’-2 = (2/10) x AB

3’-3 = (3/10) x AB

…………………

9’-9 = (9/10) x AB

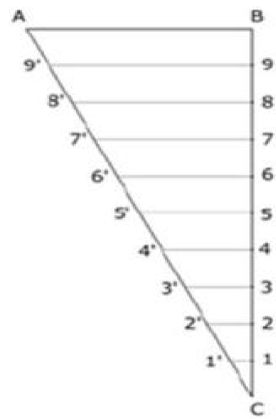


Fig 4: Principle of Diagonal Scale

3. Scale of Chords

These scales are used to measure and set out angles without using protractor. It is rectangular in shape just like a plain scale but it is marked with letters C or CHO and has graduation from 0° to 90°.

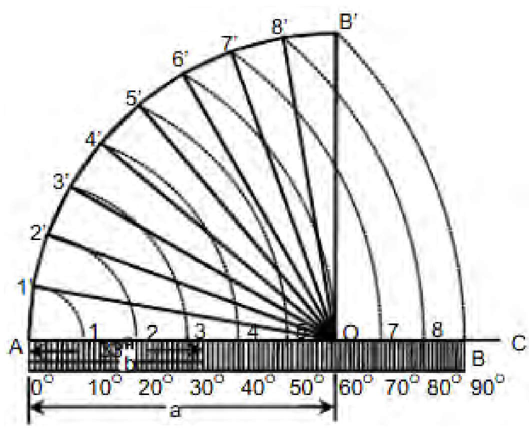


Fig 5: Scale of Chords

4. Vernier Scale

Vernier scale consists of two approximating scales. One of them is fixed and is called primary scales whereas the other is movable and is called vernier. The least count of the vernier scale is equal to the difference between the smallest divisions in the main scale and the smallest divisions of the vernier scale.

Single Vernier

If the graduations of the main scale are numbered in one direction only, the vernier which extends also in one direction is called a single vernier.

Double Vernier

If the graduations of the main scale are numbered in both directions and vernier also extends in both directions having its index mark in the middle then, the vernier is called double vernier.

Vernier Scale are classified into:

a. Direct Vernier

The vernier which extends or increases in the same direction on which the graduations of their main scales increases and in which the smallest division is shorter than the smallest division of their main scales are called as direct vernier. In such vernier, n divisions of the main scale equal in length to (n+1) divisions of the vernier scales.

b. Retrograde Vernier

The vernier which extends or increases in opposite direction of their main scales and also in which the smallest division of the vernier is longer than the smallest divisions of their main scale is called retrograde vernier. In such vernier, (n+1) divisions of the main scale are equal in length to n divisions of the vernier scale.

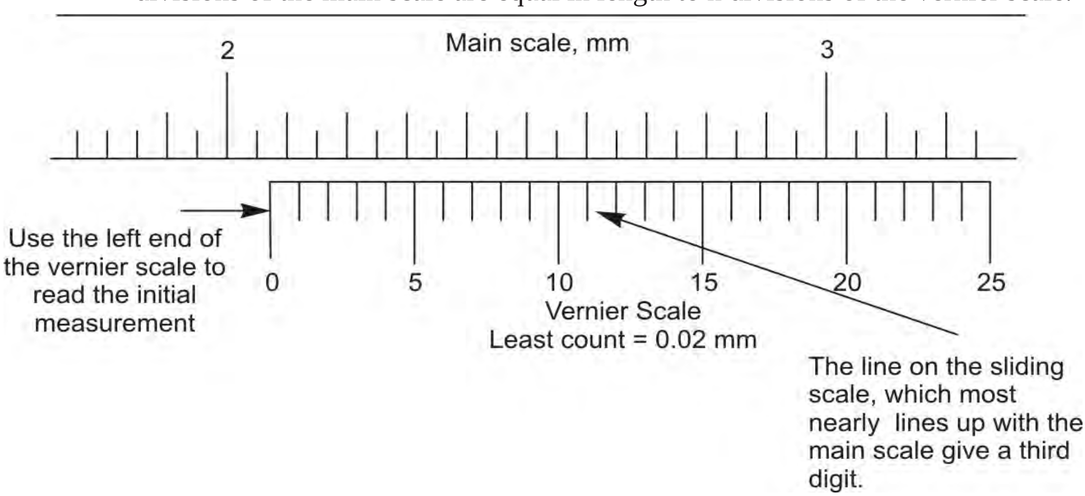


Fig 6: Vernier Scale

1.9 Numerical Practice

1. If the scale of a particular map is 2 cm: 1 km, what is the representative fraction or RF?

Solution:

Representative Fraction = distance on the map ÷ distance on the ground

But,

1km = 1000m

and 1m = 100cm

Thus,

1km = 1,00,000 cm

RF= 2cm: 1km,

can also be written as,

RF= 1cm = 0.5km.

Or 1cm = 0.5 * 1, 00,000 cm

Or 1cm = 50,000cm

Therefore,

RF here is 1: 50,000.

2. The actual length is 1m. The length of the drawing is 5cm. Find the representative factor.

Solution:

Here,

given

actual length is 1 m =100cm

and

length of drawing is 5 cm.

R.F. = 5 cm/100 cm

= 0.05 (or) = 1/20.

Exercises

Choose the correct answer from the given alternatives.

1. The objective of surveying is to prepare a ....

   a. Drawing   b. Map   c. Cross section   d. None of these

2. Representative Fraction of 1m = 500 cm is ....

   a. 1:5   b. 1:10   c. 1:100   d. None of these

3. If the graduations of the main scale are numbered in one direction only, the Vernier which extends also in one direction is called ....

   a. Single Vernier   b. Double Vernier

   c. Retrograde Vernier   d. None of these

4. The survey conducted for the observation and study of marine features and large water bodies is called ...

   a. Hydrological survey   b.Marine survey

   c. Hydrogeological survey   d. Cadastral survey

5. The curvature of earth is ignored in .....

   a. Plane Surveying   b. Geodetic Surveying

   c.Cadastral Surveying   d. Topographical Surveying

Write short answer to the following questions.

1. Describe the primary divisions of surveying.
2. List out the objectives of surveying.
3. List out the uses of surveying.

Write long answer to the following questions.

1. Differentiate between plane surveying and geodetic surveying.
2. A rectangular plot of land of area 0.65 hectare is represented on a map of similar rectangle area of 7.11 cm2. Calculate the representative factor of the scale of the map. Draw a scale to read up to a meter from the map. The scale should be long enough to measure up to 500m.

Project Work

1. Practice Representative Fraction
2. Practice Scale Conversion

Unit 2: Measurement of Distance

One of the fundamentals of surveying is to measure the distance. Distances are not necessarily linear, especially if they occur on the spherical earth. The distance is used to define the dimensions of an object. Various direct and indirect methods are introduced for measurement of distance. The accessories that are extensively used in distance measurement are as follows:

2.1 Accessories for Distance Measurements

The accessories that are extensively used in distance measurement are as:

- **Chain and Tape**
  - Chains are used to measure the distances on the field. A chain is made up of connected steel segments or links measuring usually 20 meters and a special joint or tally marker is attached at every 5 meters and two brass handles are provided at two ends. A chain is prepared with 100 or 150 pieces of galvanized mild steel wire of diameter of 4 mm.

Fig 7: Chain

  - Tapes are also used to measure the distances on the field. A tape is made up of cloth, linen, metal, steel and invar materials. In general, 3m, 5m, 30m and 50m tapes are available in the market.

Fig 8: Tape

- **Arrow and Peg**
  - Arrows are called as marking or chaining pins and are used to mark the end of chain during chaining process. Arrows are made of stout steel wire of diameter 4mm. One end of the arrow is bended into a ring of diameter 50mm and another end is pointed.
  - Pegs are used to mark the positions. They are made of hard timber and tapered at one end. They are usually 2.5cm square and 15cm long. They are driven into the ground with about 4cm lengths projecting above the ground.

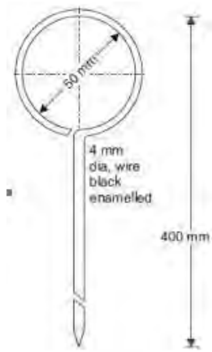


Fig 9: Arrow

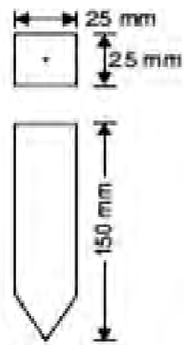


Fig 10: Peg

- **Ranging Rods**
  - Ranging rods are used for ranging a line. These are made of seasoned timber or bamboo or iron but nowadays steel ranging rods are used. They are available in length of 2m or 3m having 3cm nominal diameter. They are painted alternatively black and white or red and white throughout their length.

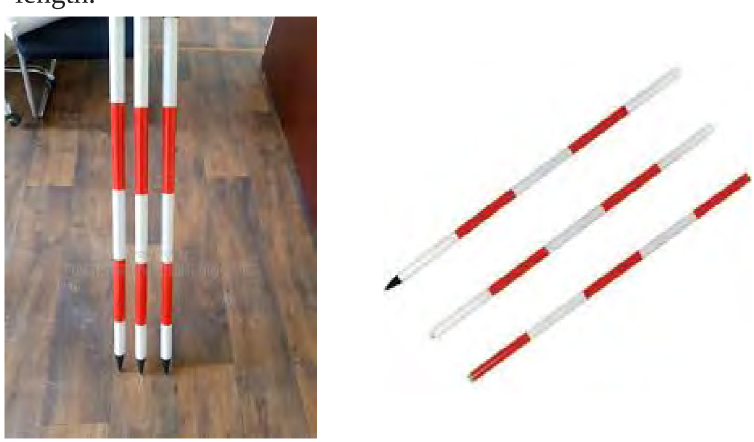


Fig 11: Ranging Rods

- **Plumb Bob**
  - A plumb bob is required when measuring distance along slopes in order to transfer points to ground. It is also used for testing the verticality of ranging rods. It is also used for centering in theodolite, compass, plane table and other surveying instruments.

Fig 12: Plumb Bob

- **Abney Level**
  - An abney level is one of the types of clinometer, which is commonly used for rapid work. It is a device that couples a protractor to a sighting tube. Abney level consists of a square sighting tube having a pin hole or an eye piece at one end and cross wire at the other end. Two objective end mirrors are placed at an angle of 45^o to the axis of the tube. The scale plate (protractor) has both percent and degree scale graduations while the indicator or scale pointing arm is provided with a vernier scale. Abney level is typically useful for following works:

    a) Measuring vertical angles

    b) Measuring slopes of ground surface

    c) Tracing grade contours

    d) Taking cross section in hilly ground.

Fig 13: Abney Level

2.2 Types of Chains

- **Gunter's Chain**
  - Gunter's chain comes in standard 66ft. These chains consist of 100links, each link being 0.66ft or 7.92inches. The length 66ft is selected because it is convenient in land measurements. 10 square Gunter's chains = 1 Acre 10 Gunter chains = 1 Furlong 80 Gunter chains = 1 mile

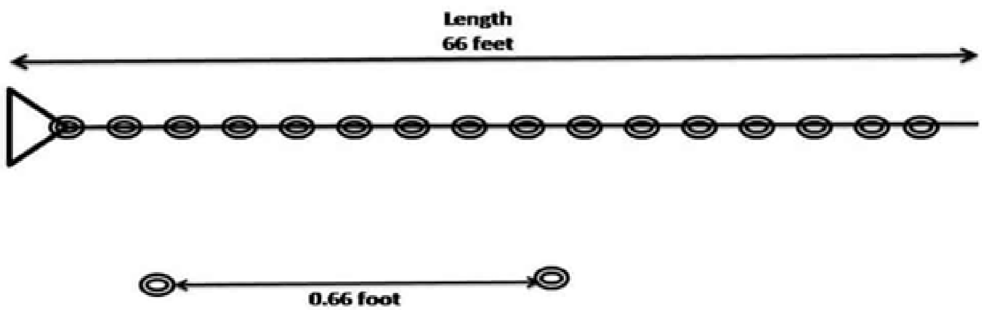


Fig 14: Gunter's Chain

- **Engineer's Chain**
  - This chain comes in 100ft length. It consists of 100 links each link being 1ft long. At every 10 links a brass ring or tags are provided for indication of 10 links.

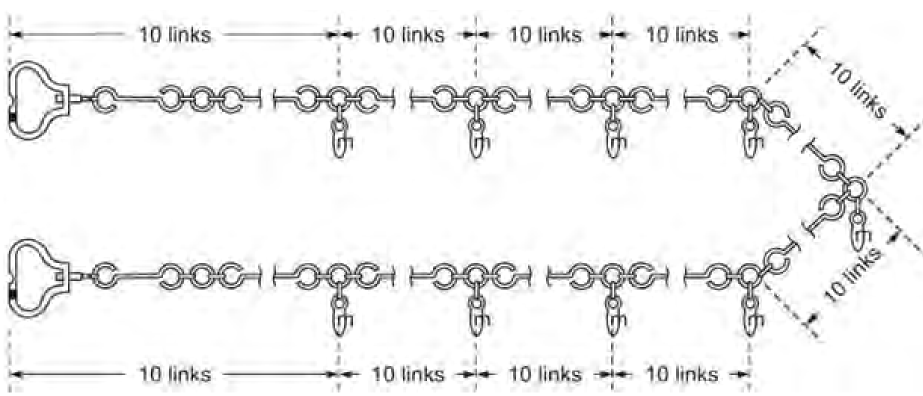


Fig 15: Engineer's Chain

- **Metric Chain**
  - Metric chains are the most commonly used chain. These types of chains come in many lengths such as 5, 10, 20 and 30 meters. Most commonly used is 20m chain. Tallies are provided at every 2m of the chain for quick reading. Every link of this type of chain is 0.2m. The total length of the chain

is marked on the brass handle at the ends.

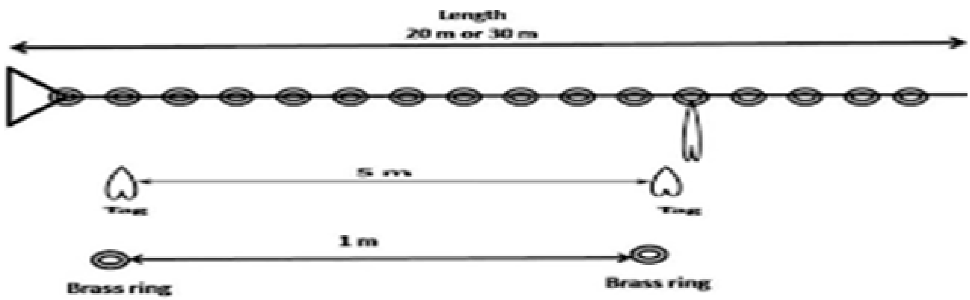


Fig 16: Metric Chain

2.3 Types of Tapes

- **Cloth or Linen Tape**
  - Linen tape, also known as cloth tape is a varnished strip made of closely woven linen. The width of the strip is about 12 to 16 mm. It is available in different lengths such as 10m, 20m, 30m, and 50m. Both ends of the linen tape are provided with metallic handles and the whole tape is wounded in leather or metal case.

Fig 17: Cloth or Linen Tape

- **Metallic Tape**
  - The metallic woven tape is an improved version of linen tape. Brass or copper made wires are used as reinforcement for the linen material. Hence, it is more durable than normal linen tape. A brass ring is provided at the end of the tape which is included in the length of the tape. These tapes are available in different lengths of 2m, 10m, 15m, 20m, 30m, and 50m. These are used for survey works such as topographical survey works where minor errors are not taken into consideration.

Fig 18: Metallic Tape

- **Steel Tape**
  - A steel tape is made of steel or stainless steel. It consists of a steel strip of 6mm to 16mm wide. It is available in lengths of 1m, 5m, 8m, 10m, 20m, 30m and 50m. Meters, decimeters, and centimeters are graduated in the steel strip. Steel tapes generally came up with the metal case with automatic winding device. The tape is withdrawn from the case by using a hand during measuring and it is rewound into the case by just pressing button provided on the case. Steel tapes are not flexible and are suitable for measuring leveled surfaces only. They may corrode easily when exposed to moisture and to prevent this tape, it should be cleaned and oiled after every use. These tapes are generally used for standardizing chains, measurements of construction work, etc.

Fig 19: Steel Tape

- **Invar Tape**
  - Invar tapes are made of an alloy which consists of 36% of nickel and 64% of steel. Invar tape contains a 6mm wide strip and is available in different lengths of 30m, 50m, 100m. The coefficient of thermal expansion of invar alloy is

very low. It is not affected by changes in temperature. Hence, these tapes are used for high precision works in surveying such as baseline measurement, triangulation surveys, etc. Invar tapes are expensive than all the other types of tapes. These tapes should be handled with care otherwise bends or links may be formed.

Fig 20: Invar Tape

2.4 Ranging

The process of fixing or establishing intermediate points to facilitate measurement of the survey lines are called as Ranging. The intermediate points are located by means of ranging rods, offset rods and ranging poles. While measuring the survey lines, the chain or the tape has to be stretched along the survey line along that joins two terminal stations. When the line to be measured has a smaller length compared to the chain then, the measurement goes smooth. If the length of the line is greater, the survey lines have to be divided by certain intermediate points, before conducting the chaining process. This process is called ranging.

2.5 Classification of Ranging

The process of ranging can be done by two methods:

a) Direct Ranging

Direct ranging is the ranging conducted when the intermediate points are intervisible. Direct ranging can be performed by eye or with the help of an eye instrument.

Fig 21: Ranging by eye

b) Indirect Ranging

Indirect ranging is employed when the two points are not intervisible or the two points are at a long distance. This may be due to some kind of intervention between the two points. In this case, the following procedure is followed.

As shown in figure-3, two intermediate points are located M1 and N1 very near to chain line by judgment such that from M1, both N1 and B are visible and from N1 both M1 and A are visible.

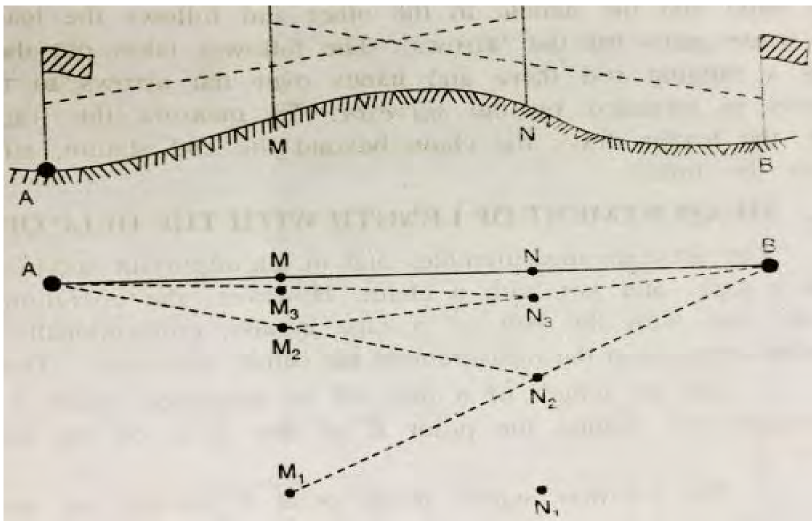


Fig 22: Indirect Ranging

At M1 and N1 two surveyors stay with ranging rods. The person standing at M1 directs the person at N1 to move to a new position N2 as shown in the figure. N2 must be in line with M1B.

Next, a person at N2 directs the person at M1 to move to a position M2 such that it is in line with N2A.

Hence, the two persons are in points are M2 and N2. The process is repeated until the points M and N are in the survey line AB. Finally, it reaches a situation where the person standing at M finds the person standing at N in line with NA and vice versa. Once M and N are fixed, other points are fixed by direct ranging.

2.6 Horizontal Distance Measurement on Plain Ground

When the ground is fairly smooth and the ground cover vegetation is light and low, the effort required to measure the distance between two points or to set a point ahead of some required distance is very minimal. There is a definite procedure to be followed in measuring the distance between two points. The person moving ahead or away from the instrument is called the head chainman. The head chainman takes the zero end of the tape or the end of the tape with the graduated foot, and moves on the line toward the distance point. The person remaining behind to hold the end of the tape on the last established point of beginning is called the rear chainman. The rear chainman does not handle the tape as the head chainman moves ahead. During this time, the rear chainman is responsible for keeping the head chainman on line. The next step requires a general lining-in procedure. Both chainmen check to make sure that the tape is straight, not twisted, and is more or less on line. Again, the major responsibility of the rear chainman is to observe that the tape is not twisted and there is a continuous reflection of light off the surface. If the reflection is broken, there is a twist in the tape. Obviously, the graduations on the face of the tape should be up at both ends. When the tape is straight and on line the rear chainman holds the 100 ft mark on the established point. The head chainman repositions himself so that he is perpendicular to the line, facing the instrument. The tape is pulled tight with a tension of 10 to 15 pounds. The stake or pin are held upright with the zero mark of the tape centered and low on the stake or pin. The instrument operator tells the head chainman to move the stake left or right to come precisely on line. As the stake is moved on line, the instrument operator continues to check that the tape is straight, tight, and at the proper distance. The rear chainman continues to hold steady his mark with the end of the tape. When the instrument operator indicates the stake is exactly on line and the rear chainman continues to call that all is good, the head chainman sets his pin or begins to drive his stake. The rear chainman releases the 100 ft end of the tape, and the head chainman takes the zero end of the tape, moves forward as before, and repeats the process. The head chainman then pulls the tape with the proper tension and reads the fine division of the extra foot on the tape. The graduation held by the rear chainman on the new point added to the graduation read by the head chainman on the forward point gives the measurement between the two points in hundredths of a foot.

Example

1) The distance between two stakes is less than 100 ft.
2) The tape is pulled so that the head chainman is holding zero very close to the forward point, and the rear chainman pulls the tape and finds that the point is between the 63 and 64 graduations on the tape.

3) The rear chainman then pulls the tape and holds the 63 mark on the rear point.

4) The rear chainman then calls to the head chainman saying HOLDING 63.

5) Both chainmen check to make sure the tape is straight, not twisted, and pulled taut.

6) The head chainman reads 0.58 on the extra foot.

7) The distance between the two points is 63.58 ft.

2.7 Horizontal Distance Measurement on Sloping Ground

Horizontal distances are required in surveying. Because in plotting we need horizontal distances. As far as possible all measurements should be done in a horizontal plane. So, in chaining along sloping ground, the horizontal distances between two stations are carefully measured by applying some convenient methods. The following are the different methods that are generally used for this purpose:

1. Direct Method

- This method is also known as **"Stepping Method"**.
- The horizontal distances are directly measured by the process of stepping.

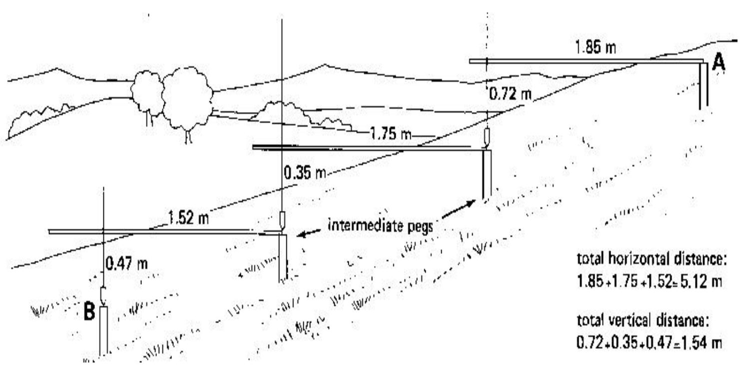


Fig 23: Direct Method

Procedure

- A path of chain or tape is stretched out from 'A'.
- The path length of chain or tape depends on the steepness of the ground.
- The follower holds the zero end of the chain at 'A' and directs the leader at A1 to be in the line of AB and stretch the chain or tape above the ground in horizontal line.
- The leader then transfers the point 'A1' to A2 on the ground by means of plumb

bob or dropping a pebble or an arrow,

- Now, the followers take the new position 'A2' and directs the leader to move forward and stretch the tape or chain in a line of AB.
- Now, the followers take the new position 'A2' and directs the leader to move forward and stretch the tape or chain in a line of AB.
- This process is repeated till the point B is reached.

Horizontal distance AB = 1.85 + 1.75 + 1.52 = 5.12m

2. Indirect Method

In this method, the sloping side is measured on the ground and later it is converted into the horizontal equivalent using geometrical condition.

The following methods are adopted for calculating horizontal distance indirectly:

- **By measuring angle of inclination with clinometer**

  A clinometer is a graduated semicircular protractor. It consists of two pins P1 and P2 for sighting the object. A plum bob is suspended from point O with a thread. When the straight edge is just horizontal, the thread passes through 0^o. When the straight edge is tilted, the thread remains vertical, but passes through a graduation on the arc which shows the angle of slope.

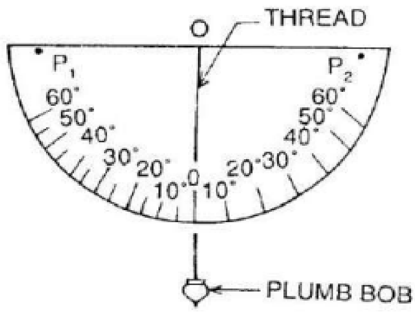


Fig 24: Clinometer

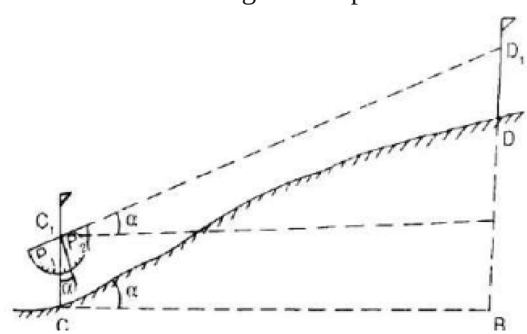


Fig 25: Angle measurement using Clinometer

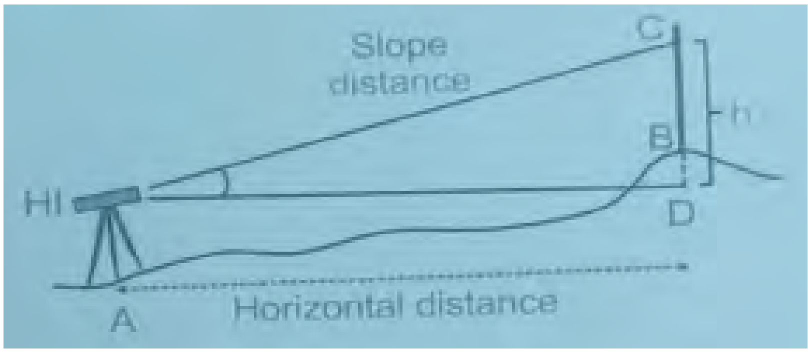
Suppose C and D are two points on sloping ground. Two ranging rods are fixed at these points. Then, two other points C1 and D1 are marked on the ranging rods so that CC1 = DD1.The clinometer is placed in such a way that its center just touches the mark C1. The clinometer is then inclined gradually until the points P1, P2, and D1 are in the same straight line. At this position, the thread of the clinometer will show an angle which is the angle of slope of the ground.

Suppose this angle is α. The sloping distance CD is also measured.

The required horizontal distance = CB = lcosα

- **By measuring difference of levels**

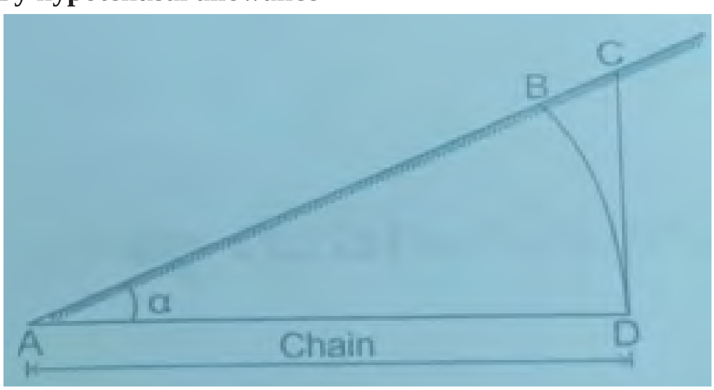
  The distance along the slope is measured with chain and the difference in elevation between the first and the end stations is found with the help of any levelling instrument.



Knowing the sloping distance l, and the difference in elevation h, the horizontal distance, can be found out by the relation:

$$D = \sqrt{l^2 - h^2}$$

- **By hypotenusal allowance**



Let α = the angle of slope of the ground. AD = AB = 1 Chain = 100 links.

Then, AC = 100 sec α links and BC = AC – AB = 100 (Sec α- 1) links.

The amount 100 (sec α – 1) is known as hypotenusal allowance. While chaining along the slope, one chain would be actually located at B. But the arrow should be placed at C after making hypotenusal allowance. The next chain length will start from C. The same principle is followed until the end of the line is reached.

2.8 Unit of Measurement

In the field of surveying, accurate measurements are crucial for precise mapping, construction, and land management. Surveyors use various units of measurement, primarily falling into two categories: linear measures and angular measures. Understanding these units and their conversions is essential for professionals and students a like.

Historically, two main systems of measurement have been used in surveying:

1. **Metric System**

   Introduced in India in 1956 through the Standards of Weight and Measure Act, this system is now widely used globally. It is based on units of 10 and includes measures for length, area, and volume.

2. **Foot-Pound-Second (FPS) System**

   Also known as the British Imperial System, this was commonly used before 1956 and is still prevalent in some countries. It includes units like feet, yards, and acres.

   Surveyors often need to convert between these systems, especially when working with historical data or in regions that use different measurement standards. The following tables provide comprehensive information on various units of measurement and conversion factors used in surveying.

These tables cover

- Basic units of length, area, and volume in both metric and FPS systems
- Conversion factors for lengths, areas, and volumes
- Specialized units used in land surveying and nautical measurements

  Understanding these units and their relationships is fundamental for accurate surveying work and effective communication in the field.

Basic Units of Length in Metric System

Unit	Equivalent
10 millimetres	1 centimetre
10 centimetres	1 decimetre
10 decimetres	1 metre

Unit	Equivalent
10 metres	1 dekametre
10 dekametres	1 hectametre
10 hectametres	1 kilometre
1.852 kilometres	1 nautical mile

Basic units of area in metric system

Unit	Equivalent
100 sq. metres	1 are
10 ares	1 deka-are
10 deka ares	1 hecta-are

Basic Units of Volume in Metric System

Unit	Equivalent
1000 cub. millimetres	1 cub. centimetre
1000 cub. centimetres	1 cub. decimetre
1000 cub. decimetres	1 cub. metre

Basic Units of Length in F.P.S. System

Unit	Equivalent
12 inches	1 foot
3 feet	1 yard
5.5 yards	1 rod, pole or 1 sq. perch
4 poles	1 chain (66 feet)
10 chains	1 furlong
8 furlongs	1 mile
6 feet	1 fathom
120 fathoms	1 cable length
6080 feet	1 nautical mile

Basic Units of Area in F.P.S. System

Unit	Equivalent
144 sq. inch	1 sq. foot
9 sq. feet	1 sq. yard
30.25 sq. yard	1 sq. rod or pole
40 sq. rods	1 rood
4 roods	1 acre
640 acres	1 sq. mile
484 sq. yards	1 sq. chain
10 sq. chains	1 acre

Basic units of volume in F.P.S. System

Unit	Equivalent
1728 cu. inches	1 cu. foot
27 cu. feet	1 cu. yard

Angular measurements are fundamental in surveying for determining directions, orientations, and the relative positions of points on Earth's surface. An angle is defined as the amount of rotation between two intersecting lines around their common point of intersection.

The basic unit of angular measurement is the radian, which is the angle subtended at the center of a circle by an arc equal to the radius of the circle. However, in practical surveying, two primary systems are used for angular measurements:

1. Sexagesimal System

The sexagesimal system, also known as the degree-minute-second (DMS) system, is the most widely used method for angular measurements in surveying. In this system:

- A full circle is divided into 360 degrees (360°)
- Each degree is subdivided into 60 minutes (60')
- Each minute is further divided into 60 seconds (60")

This system has been used since ancient times and is deeply ingrained in surveying practices. Most surveying instruments, such as theodolites and total stations, are graduated according to this system.

2. Centesimal System

The centesimal system, also known as the grad system, is an alternative method of angular measurement that's gaining popularity, especially in some European countries. In this system:

- A full circle is divided into 400 grads (400g)
- Each grad is divided into 100 centigrads
- Each centigrad is divided into 100 centicentigrads

The centesimal system offers advantages in computation and interpolation due to its decimal nature, making it easier to use with modern digital equipment.

Importance in Surveying

Angular measurements are crucial in various surveying applications, including:

- Triangulation and trilateration for establishing control networks
- Traversing for determining the positions of points
- Setting out curves in road and railway construction
- Calculating areas and volumes
- Astronomical observations for precise positioning

Surveyors must be proficient in both systems and understand how to convert between them, as different regions or projects may require the use of one system over the other. The choice between sexagesimal and centesimal systems often depends on local practices, the equipment available, and the specific requirements of the survey project.

Accuracy in angular measurements is paramount in surveying. Even small errors in angular measurements can lead to significant discrepancies over large distances. Therefore, surveyors use precise instruments and techniques to ensure the highest possible accuracy in their angular measurements.

Angular Measurement Systems

System	Full Circle	Subdivision 1	Subdivision 2
Sexagesimal	360 degrees (360°)	1 degree = 60 minutes (60’)	1 minute = 60 seconds (60”)

System	Full Circle	Subdivision 1	Subdivision 2
Centesimal	400 grads (400g)	1 grad = 100 centigrads	1 centigrad = 100 centicentigrads

Conversion Factors between Sexagesimal and Centesimal Systems

Sexagesimal	**Centesimal**
1°	1.1111 grads
0.9°	1 grad
1’	0.0185 grads
0.54’	0.01 grads (1 centigrad)
1”	0.0003086 grads
0.324”	0.0001 grads (1 centicentigrad)

Radian Measure

Measure	Equivalent
1 radian	57.2958 degrees
1 radian	63.6620 grads
π radians	180 degrees
2π radians	360 degrees (full circle)

2.9 Conversion Table for Important Units

Conversion Factors for Lengths

Metres	**Yards**	**Feet**	**Inches**
1	1.0936	3.2808	39.37
0.9144	1	3	36
0.3048	0.3333	1	12
0.0254	0.0278	0.0833	1

Conversion Factors for Areas

Sq. metres	Sq. yards	Sq. feet	Sq. inches
1	1.196	10.7639	1550
0.8361	1	9	1296
0.0929	0.1111	1	144
0.00065	0.00077	0.0069	1

Conversion Factors for Areas (Ares, acres and sq. yards)

Ares	Acres	Sq. metres	Sq. yards
1	0.0247	100	119.6
40.469	1	4046.9	4840
0.01	0.000247	1	1.196
0.0084	0.00021	0.8361	1

Conversion Factors for Volumes

Cub. metres	Cub. yards	Gallons (Imps)
1	1.308	219.969
0.7645	1	168.178
0.00455	0.00595	1

2.10 Chain and Tape Corrections

A) Tape Correction

1) Temperature correction (C_t)

The correction for temperature Ct is given by the formula:

$$C_t = \alpha(T_m - T_\alpha)\ L$$

Where, α = Coefficient of Thermal Expansion;

ZTm is the mean temperature in the field during measurement; To is the temperature during the standardization of the tape; L = Measured length;

1) There are Two Cases Possible

1. The temperature of the field is greater than the temperature at which the tape is standardised; Tm > To. This results in an increase in the tape length, making the measured length shorter. Hence the correction is additive.
2. The temperature of the field is lesser than the standardised temperature, i.e. Tm<To, then the tape length decreases. This results in an increase the measured length than the original. Hence the correction is subtractive.

2) Pull Correction (Cp)

The correction for pull or tension is given by the formula: $Cp = \frac{(P-Po)L}{AE}$

Where, P = Pull applied during the measurement; Po= Standard Pull; Both P and Po are measured in Newtons;L = measured length;A =Area of cross-section in cm2; E = Young's modulus in N/cm2.

Two cases are Possible

1. Pull applied during the measurement is greater than pull at which the tape is standardized i.e. P > Po. This results in an increase in the length of tape which makes the measured length shorter. Hence the correction is additive.
2. Pull applied during the measurement is lesser than pull at which the tape is standardized i.e. P < Po. This results in a decrease in length of tape which makes the measured length longer. Hence the correction is subtractive.

   The pull applied in the field must be less than 20 times the weight of the tape used for measurement.

3) Sag Correction

Stretching the tape between two supports make the tape to form a horizontal catenary. Hence, the horizontal distance becomes greater than the distance along the curve. Hence,

Sag Correction = Horizontal distance – length along the horizontal catenary

As shown in the figure below, the curve is assumed as a parabola to facilitate the calculation of correction for sag.

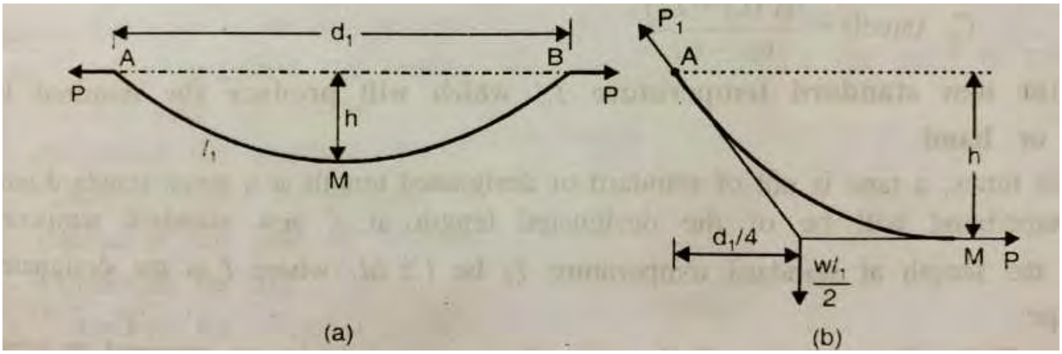


Fig 26: Sag Correction for Tape

Tape correction per length is given by, $Cs = lW^2 /24n^2P^2$

Where, Cs = Tape Correction per Tape length; l=Total length of the tape; W= total weight of the tape; n= number of equal spans; P= Pull applied;

4) Slope correction

The slope correction or correction due to vertical alignment is given by the relation $Cv = 2L \sin^2(x/2)$

Or

$$\textbf{Total Slope Correction} = \sum \frac{h^2}{2L}$$

Where, h = The difference in elevation between the ends; x = slope measured;

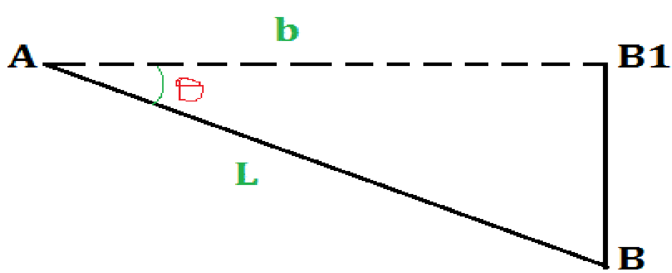


Fig 27: Correction for Slope

The distance that is measured along the slope is always greater than the horizontal distance. This makes the correction to be subtractive.

B) Chain Correction

1) Correction to Measured Length

If 'l' is the actual or true length of the line and l' is the measured length of the line then,

True length of the line = Measured length x [L'/L]

l = l' x (L'/L)

Different cases are:

- Absolute length > Designated length means, measured distance is short, hence the correction is additive.
- Absolute length < Designated length means, measured distance is long, hence the correction is subtractive.

2.11 Numerical practice

1) **The distance between two points, measured with a 20 m chain, was recorded as 327 m. It was afterwards found that the chain was 3 cm too long. what was the true distance between the points?**

Solution

Given,

True length of chain, L = 20 m

Error in chain, e = 3 cm = 0.03 m

L'= L+e (too long)

= 20 +0.03

= 20.03 m

Measured length = 327 m

True length of line = (L'/L) X 327

= 327.49 m

2) **The distance between two points, measured with a 30 m chain, was recorded as 202 m. It was afterwards found that the chain was 5 cm too short. What was the true distance between the points?**

Solution

Given,

True length of chain, L = 30 m

Error in chain, e = 5 cm = 0.05 m

L’ = L – e = 30 -0.05 (too short)

= 29.95 m

Measured length = 202 m

true length of the line = (L’/L) x 202

= 201.663 m

= True length of line = 201.663 m

3) **The length of a survey line was measured with a 20 m chain and was found to be equal to 1200 m. As a check, the length was again measured with a 25 m chain and was found to be 1212 m. On comparing the 20 m chain with test gauge length, it was found to be 1 decimeter too long. The 25 m chain was ……………. cm too short.**

Solution:-

For 20 m chain

True length of 20 m chain L′=20+0.1=20.1m

∴ Actual length of survey line,

l= 1200×20.120=1206 m

For 25 m chain,

Actual length of survey line,

l=Measured length × Wrong length of chain

True length of chain

1206=1212×L′25\

L′=24.876 m

∴ (25−24.876) ×100=12.4 cm

∴ The 25 m chain was 12.4 cm too short.

4) **A 30-m steel tape is of standard length at 20°C. If the coefficient of the thermal expansion of steel is 0.0000116/1°C, determine the distance to be laid out using this tape to establish two points exactly 1250.55-m apart when the temperature is 32°C.**

Given:

NL = 30 m, L = 1250.55 m

α = 0.000116/1°C, T = 32°C, To = 20°C

L' =?

Solution :-

CT = (1250.55m) (0.000016/1°C) (32°C - 20°C)

CT = 0.1740 m L'

= L-CT L'

= 1250.55m- 0.1740m

L' = 1250.376 m

Exercises

Choose the correct answer from the given alternatives.

1. A 20 m chain is divided into ...

   a. 150 links b.100 links c. 200 links d. 250 links

2. One link means the distance from ....

   a.Centre to centre of middle rings b.Centre to centre of inner rings

   c. Centre to centre of outer rings d. None of these

3. For ranging, no. of ranging rods required is ....

   a. At least 2 b. At least 3 c. At least 4 d.None of these

4. The length of Gunter's chain is ....

   a.50ft b. 100 ft c. 66 ft d. 180ft

Write short answer to the following questions.

1. What is chain?
2. List out the various tape corrections with their respective formulae.
3. Explain different methods of chaining on a sloping ground.
4. A measurement was recorded as 171.278 m with a 30-m tape that was only 29.996 m under standard conditions. What is the corrected measurement?
5. Line is measured as 876.42 m. The field temperature is 24° C.A 30-m tape with correct length at 20° C was used. Find the corrected length of the line.
6. A 100' steel tape weights 0.02 lbs/ft and supported at the ends only with a tension of 12 lbs. A distance of 350.00' was measured. What is the correction for sag?

Write long answer to the following questions.

1. Describe the types of chain and tape used in surveying.
2. Describe about the horizontal distance measurement in plain ground.
3. Explain horizontal distance measurement in sloping ground.
4. Explain different accessories used in surveying.

Project works

1. Perform Ranging to Measure Distance

2. Measure Horizontal Distance on Plain Ground

4. Measure Horizontal Distance on Sloping Ground

5. Practice Conversion Table for Important Units

6. Perform and Compute Chain and Tape corrections – Temperature Correction, Pull Correction, Sag Correction

Unit 3 : Reliability of Survey

3.1 Accuracy Required

Measurement is essential for us to understand the external world, and through millions of years of life, we have developed a sense of measurement. Measurements require tools that provide scientists with a quantity. The problem here is that the result of every measurement by any measuring instrument contains some uncertainty. This uncertainty is referred to as an error. Accuracy and precision are two important factors to consider while taking measurements. Both these terms reflect how close a measurement is to a known or accepted value.

Accuracy

The ability of an instrument to measure the accurate value is known as accuracy. In other words, it is the the closeness of the measured value to a standard or true value. Accuracy is obtained by taking small readings. The small reading reduces the error of the calculation. It implies the closeness between related measurements and their expectations.

3.2 Error

A discrepancy is defined as the difference between two or more measured values of the same quantity. However, measurements are never exact and there will always be a degree of variance regardless of the survey instrument or method used. These variances are known as errors and will need to be reduced or eliminated to maintain specific survey standards.

3.3 Types of Error

- **Mistakes**

  Mistakes are blunders or gross errors that result from carelessness, poor judgment, or misunderstanding. Mistakes do not follow any mathematical or physical law. Mistakes can significantly distort survey results and are often larger in magnitude than other types of errors.

- **Compensating error / Accidental error**

  Compensating error or accidental errors remain after the exclusion of mistakes and systematic errors, and they arise for several causes beyond the observer's control.

Compensating mistakes occur in one or both directions and are hence referred to as compensating errors. These errors are subject to the rule of probability, and the theory of error only applies to unintentional errors. Because they are random, these mistakes are also known as random errors.

- **Systematic Error/Cumulative Error**

  Systematic errors are always of the same magnitude and sign under specified similar conditions of measurement and can be classified as positive or negative depending on whether they make the result too large or too little. Because systematic errors have the effect of piling up in just one direction, they are also known as cumulative errors. They become dangerous if they do not come in observation. Systematic mistakes are discovered to obey a particular statistical or physical law.

3.4 Precision

The closeness of two or more measurements to each other is known as the precision of a substance. If you weigh a given substance five times and get 3.2 kg each time, then, your measurement is very precise but not necessarily accurate. Precision is independent of accuracy. A common way to define precision in surveying is as a 1/X dimensionless ratio. The ratio is 1 unit variation across a magnitude of X. For example, 1/1000 means 1 ft variation in 1000 ft of measurement. Because it is dimensionless, it could also mean 1 meter per 1000 meters, 1 mile per 1000 miles, etc. 1/1000 is better than 1/500; both have a 1 unit variation but the former occurs over 1000 while the latter 500.

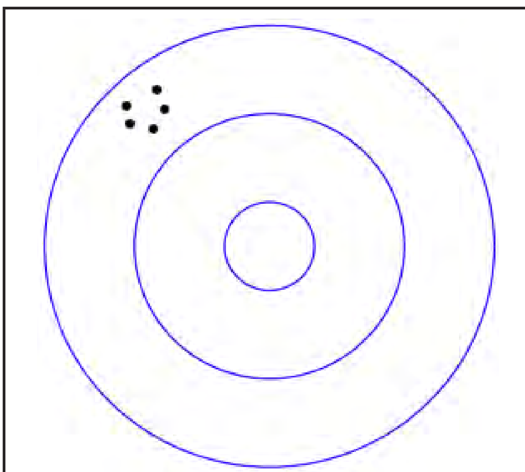


Fig 28: Precision without accuracy

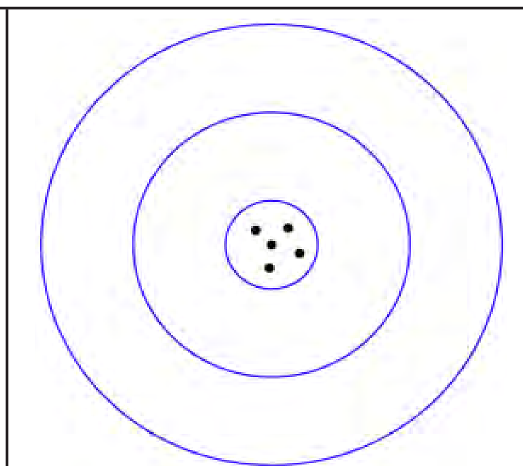


Fig 29: Precision with accuracy

3.5 Correction

Absolute Error

The difference between the measured value of a quantity and its actual value gives the absolute error. It is the variation between the actual values and measured values. It is given by

Absolute error = |VA-VE|

Percent Error

It is another way of expressing the error in measurement. This calculation allows us to gauge how accurate a measured value is with respect to the true value. Percent error is given by the formula

Percentage error (%) = (VA-VE) / VE) x 100

Relative Error

The ratio of the absolute error to the accepted measurement gives the relative error. The relative error is given by the formula:

Relative Error = Absolute error / Actual value

❖ How to Reduce Errors in Measurement

Keeping an eye on the procedure and following the below listed points can help to reduce the error.

- Make sure the formulas used for measurement are correct.
- Cross check the measured value of a quantity for improved accuracy.
- Use the instrument that has the highest precision.
- It is suggested to pilot test measuring instruments for better accuracy.
- Use multiple measures for the same construct.
- Note the measurements under controlled conditions.

Exercises

Choose the correct answer from the given alternatives.

1. Compensating errors ...

    a. Can't be corrected | b. Can be corrected
    c. Both a and b | d. None of these

2. Cumulative errors ......

    a. Can't be corrected | b. Can be corrected
    c. Both a and b | d. None of these

3. Systematic errors are those errors that ....

    a. Can't be corrected | b.Can be corrected
    c. Both a and b | d.None of these

Write short answer to the following questions.

1. Describe about the types of error.
2. Describe about accuracy and precision with examples.

Write long answer to the following questions.

1. Define error. Describe how errors be reduced.
2. Describe about the types of errors in brief. Describe how they can be reduced.

Project Work

1. Determine Degree of Accuracy in Chaining
2. Determine Degree of Accuracy in Taping
3. Compute Error in Chaining and Taping
4. Determine Precision
5. Compute Correction

Unit 4 : Chain Survey

Site Visit (live site)

The chain survey is the simplest method of surveying. In the chain survey, only measurements are taken in the field, and the rest work, such as plotting calculation, etc. are done in the office. Here only linear measurements are made i.e. no angular measurements are made. This is most suitably adapted to small plain areas with very few details.

4.1 Principles of Chain Surveying

Chain surveying in civil engineering is a simple and practical technique that relies on fundamental principles to ensure accurate measurement. Understanding the principle of chain surveying is essential to its application and accuracy.

1. **Establishing a Framework of Triangles**

   One core principle in chain surveying uses the principle of dividing the survey area into a series of connected triangles. Triangles are a preferred shape in surveying because they are stable and accurate for measurement. If the length of all three sides are known, a triangle's shape is fixed. This method of dividing the survey area allows surveyors to cover large areas through smaller, manageable triangles, which minimises errors and simplifies calculations.

2. **Locating Points Using Reference Lines**

   Chain surveying in civil engineering also relies on baseline measurements. A baseline is the primary line measured and is typically the longest line in the survey. From this line, other lines or chains are measured to form triangles and establish secondary points across the survey area. By measuring additional lines from this baseline, surveyors ensure each point is accurately located in relation to other points, enabling precise mapping of the area.

3. **Direct Linear Measurement**

   The second principle of chain surveying is the reliance on direct measurement. All measurements in chain surveying are taken in a straight line from point to point, making it suitable for flat and relatively simple landscapes. The surveyor uses a chain or tape to measure distances between designated survey points, marking them with pegs or markers. Since only linear distances are measured, chain surveying is a simple and efficient way to gather data without requiring complex instruments.

4. **Avoiding Obstructions and Accounting for Errors**

   Although chain surveying uses the principle of direct measurement, obstacles may sometimes be in the way. Surveyors use methods to bypass obstacles, such as shifting the chain to measure indirectly or offsetting the measurement line to avoid the obstruction. Additionally, by carefully maintaining the chain, calibrating equipment, and measuring on stable ground, surveyors can reduce inaccuracies and maintain consistent results across multiple measurements.

5. **Checking and Verifying Measurements**

   Finally, another principle of chain surveying is the consistent checking of measurements. Surveyors often re-measure lines or check triangular formations to confirm accuracy. By re-measuring a line from both directions or double-checking points, surveyors can verify their data and correct any errors, which is essential for reliable mapping and planning. This principle is especially important in chain surveying in civil engineering, where precision is critical for project success.

4.2 Suitability of Chain Surveying

Chain survey is suitable when:

i. Area to be surveyed is comparatively small.

ii. Ground is fairly level.

iii. Area is open and

iv. Details to be filled up are simple and less.

4.3 Unsuitability of Chain Surveying

Chain surveying is unsuitable when:

i. The area is crowded with many details.

ii. The area consists of too many undulations.

iii. The area is very large and

iv. The formation of well -conditioned triangles becomes difficult due to obstacles.

4.4 Well - conditioned Triangles and Ill – conditioned Triangles

A triangle is said to be well-conditioned when no angle in it is less than 30° or greater than 120°.

An equilateral is considered to be the best-condition or ideal triangle (Figs 2.1(a) and (b)).

Well-conditioned triangles are preferred because their apex points are very sharp and can be located by a single dot. In such a case, there is no possibility of relative displacement of the plotted point.

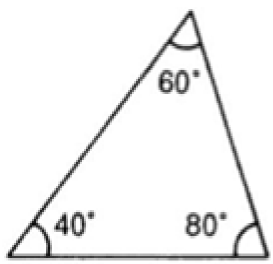


Fig 30: Well Conditioned Triangle

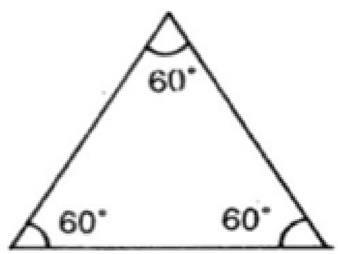


Fig 31: Ideal Triangle

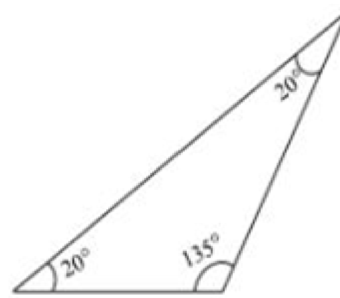


Fig 32: Ill Conditioned Triangle

4.5 Survey Stations

Survey stations are the points at the beginning and the end of a chain line. They may also occur at any convenient points on the chain line. Such stations may be:

1. Main stations
2. Subsidiary stations and
3. Tie stations

1) Main stations

Stations taken along the boundary of an area as controlling points are known as "main stations". The lines joining the main stations are called „ main surveyed. The main survey lines should cover the whole area to be surveyed. The main stations are denoted by with letters A, B, C, D, etc. The chain lines are denoted by "---…---….---…---".

2) Subsidiary stations

Stations which are on the main survey lines or any other survey lines are known as "subsidiary stations". These stations are taken to run subsidiary lines for dividing the area into triangles, for checking the accuracy of triangles and for locating interior details. These stations are denoted by with letters $S1$, $S2$, $S3$etc.

3) Tie stations

These are also subsidiary stations taken on the main survey lines. Lines joining the tie stations are known as tie lines. Tie lines are mainly taken to fix the directions of adjacent side of the chain survey map. These are also taken (chain angles are described in chapter 3). Sometimes tie lines are taken to locate interior details. Tie stations are denoted by letters $T1$,$T2$,$T3$. etc.

4.6 Reconnaissance Survey

A reconnaissance survey, often referred to as a "recce survey" or "preliminary survey," is an essential initial step in various fields, particularly in civil engineering, urban planning, and environmental science. This survey serves as a preliminary assessment to gather vital information about a site before any detailed planning or development work begins. It is designed to provide a broad overview of the existing conditions and potential challenges associated with the site, ensuring that subsequent detailed surveys and designs are informed and efficient.

Preparation of Index Sketch

The neat hand sketch of the area which is prepared during reconnaissance survey is known as the 'index sketch' or 'key plan'. The index sketch shows the skeleton of the survey work.

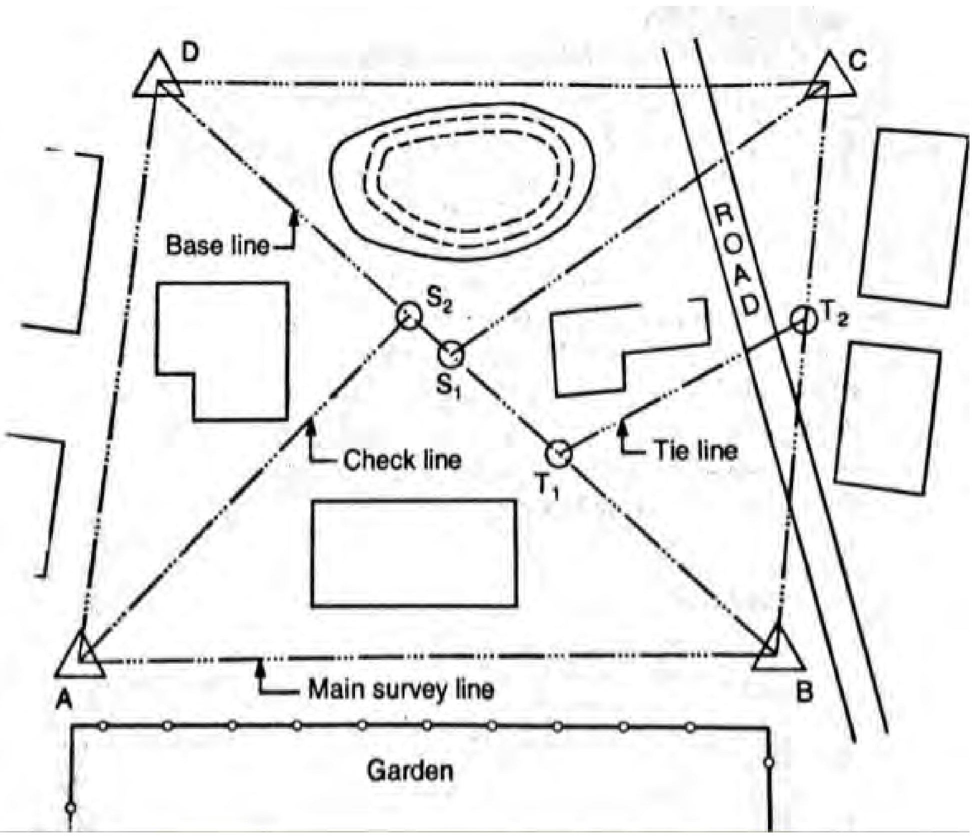
Selection of Survey Stations

The following points should be remembered during the selection of survey stations:

1. The stations should be so selected that the general principle of surveying may be strictly followed.
2. The stations should be intervisible.
3. The stations should be selected in such a way that well-conditioned triangles may be formed.
4. The base line should be the longest of the main survey lines.
5. The survey lines should be taken through fairly level ground, as far as practicable.
6. The main survey lines should pass close to the boundary line of the area to be

surveyed.

7. The survey lines should be taken close to the objects so that they can be located by short offsets.
8. The tie stations should be suitably selected to fix the directions of adjacent sides.
9. The subsidiary stations should be suitably selected for taking check lines.
10. Stations should be so selected that obstacles to chaining are avoided as far as possible.
11. The survey lines should not be very close to main roads, as survey work may then be interrupted by traffic.



Location Sketch of Survey Stations

4.7 Survey Lines

Main Survey Lines

The main lines are the chain lines joining the two main survey stations.

Base Line

The baseline is the main and longest line, which passes approximately through the center of the field. All the other measurements to show the details of the work are taken with respect of this line.

Check Line

A check line also termed as a proof line is a line joining the apex of a triangle to some fixed points on any two sides of a triangle. A check line is measured to check the accuracy of the framework. The length of a check line, as measured on the ground should agree with its length on the plan.

Tie Line

A tie line joints two fixed points on the main survey lines. It helps to check the accuracy of surveying and to locate the interior details. The position of each tie line should be close to some features, such as paths, buildings, etc.

4.8 Offsets

These are the lateral measurements from the base line to fix the positions of the different objects of the work with respect to base line. These are generally set at right-angle offsets. It can also be drawn with the help of tape. There are two kinds of offsets:

a) Perpendicular offsets

b) Oblique offsets

b) Perpendicular Offsets

When the lateral measurements are taken perpendicular to the chain line.

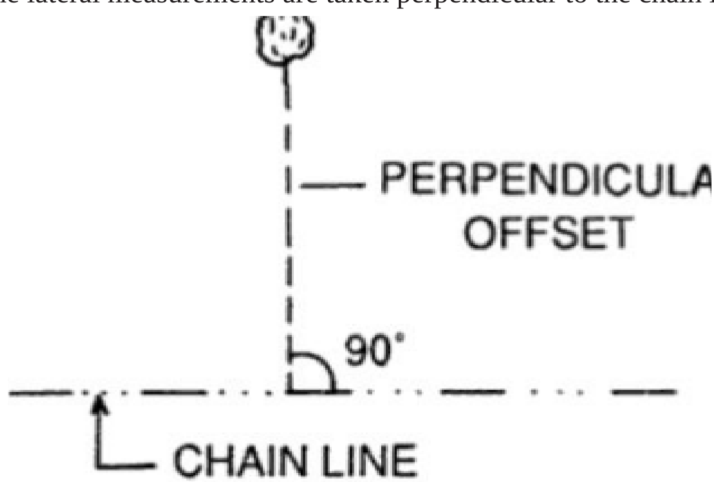


Fig 34: Perpendicular Offset

c) **Oblique Offsets**

Any offset not perpendicular to the chain line is said to be oblique offset.

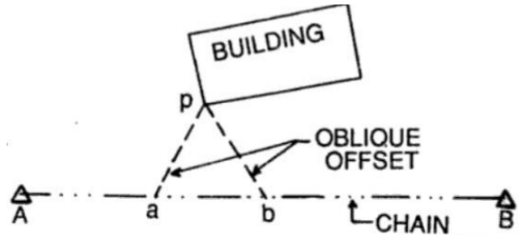


Fig 35: Oblique Offset

4.9 Procedure of Chain Survey

1. **Reconnaissance**

   Before the commencement of any survey work, the area to be surveyed is thoroughly examined by the surveyor, who then thinks about the possible arrangement of the framework of survey. The surveyor inspects the area to be surveyed, surveyor prepares index sketch or key plan.

2. **Selection of Survey station and Survey Lnes**

   The surveyor fixes up the required no stations at places from where maximum possible stations are possible.

3. **Referencing and Marking of Stations**

   Then the surveyor selects the way for passing the mainline, which should be horizontal and clean as possible and should pass approximately through the center of work.

   Then ranging roads are fixed on the stations. After fixing the stations, chaining could be started. Make ranging wherever necessary.

4. **Detailing**

   Measure the chainage and offset. Enter in the field book.

4.10 Field Book

The notebook in which field measurements are noted is known as the 'field book'. The size of the field book is 20 cm x 12 cm and it opens lengthwise. Field books are of two types:

a) **Single Line Field Book**

Single line book has a red line along the length of the paper in the middle of the width.It indicates chain line. The space on either side of the line is used for sketching the objects and entering offset distances.

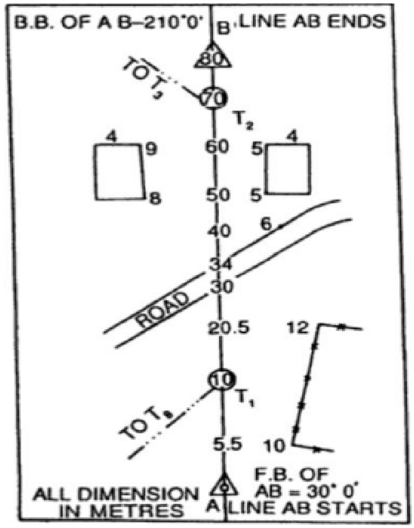


Fig 36: Single Line Field Book

b) Double Line Field Book

In double line book, there are two blue lines in the space of 15 – 20 mm in the middle each page of the book. The space between the two line is utilized for noting the chainages.

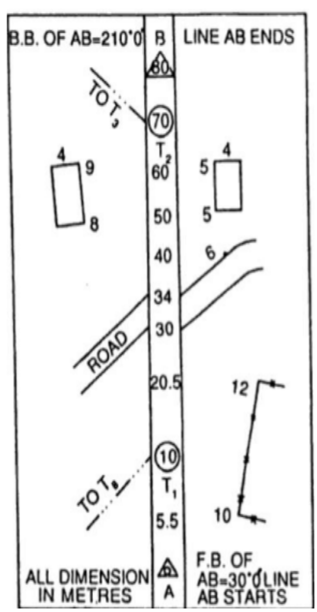


Fig 37: Double Line Field Book

4.11 Conventional Symbols

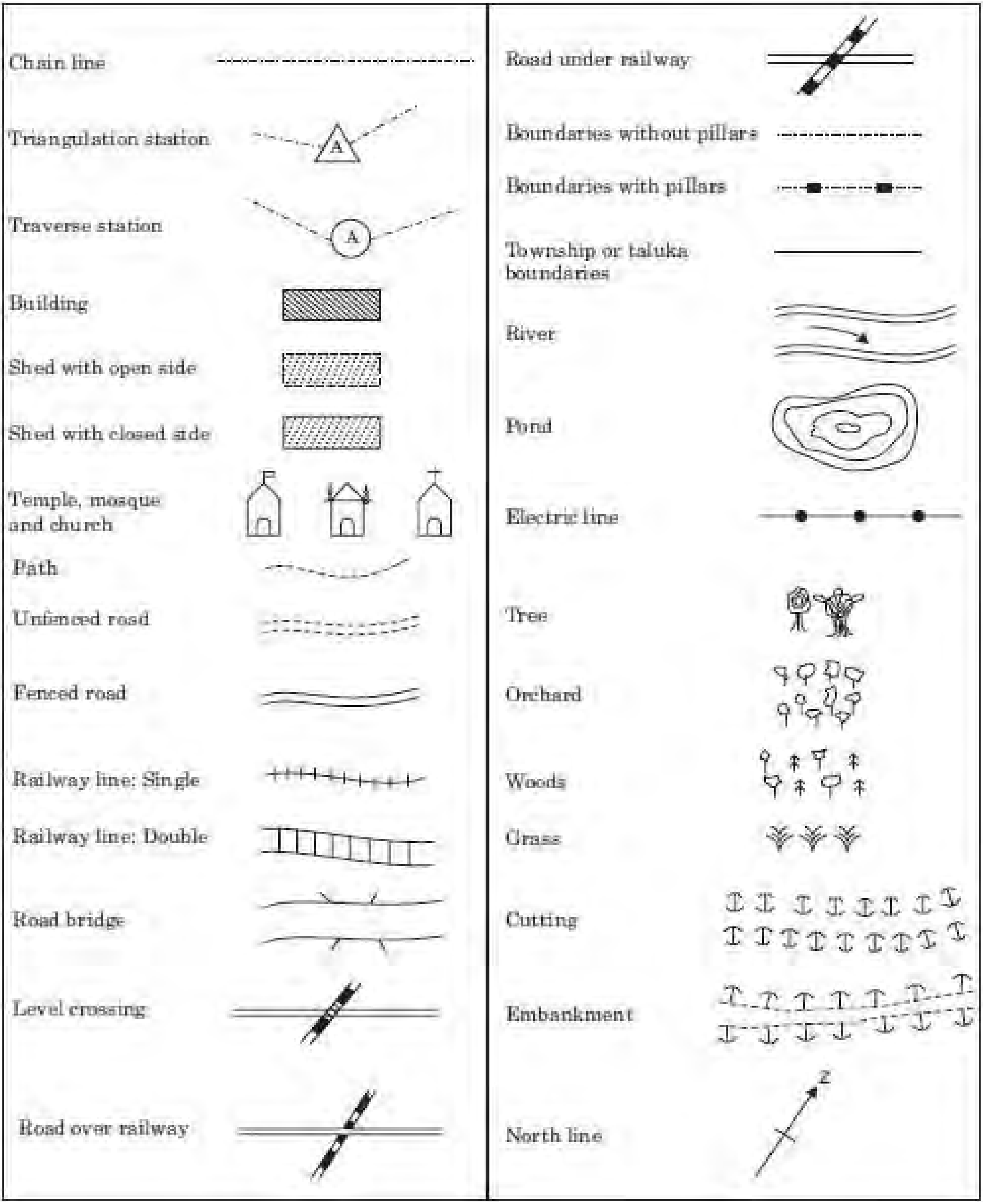


Fig 38: Conventional Symbols in Chain Survey

4.12 Procedure of Plotting a Chain Survey

Plotting means to represent on paper, to a suitable scale, the previously surveyed objects in accordance with their shape and size. Plotting is commenced after the field-work is over.

The plotting of a chain survey is done in the following steps:

(i) A suitable scale is chosen before starting the plotting work. The scale depends upon the importance of the work and extent of survey.

(ii) Leave a suitable margin (2 cm to 4 cm) all round the paper.

(iii) Select a suitable position of the base line so that the map or plan is shown to the best advantages. The base line should be plotted as accurately as possible because the entire accuracy of the frame-work depends upon it.

(iv) Mark the intermediate stations on the base line and complete the frame-work of triangles.

(v) Check the accuracy of the plotted frame work by means of check and tie lines. If the error is within the permissible value then, adjust the lengths of the sides of the wrong triangles. But if the error exceeds the permissible limits then, resurvey the wrong lines.

(vi) For plotting the offsets, mark the changes of the points along the chain line from where offsets were measured and then draw the perpendicular lines with set squares and scale off lengths of the offsets.

The method of plotting the offset is much simplified if offset-scale (Fig. 3.19) is used for plotting them. In this method, the long scale is placed along the chain line with its zero exactly at start of the line. The offset scale is then placed at right angles to the long scale and is then moved along it to the required changes and the offset lengths are marked with a pricked.

(vii) While plotting keep the field-book side by side in the same direction as the work proceeded in the field parallel to the chain line to be plotted and then plot the various offsets. After plotting one line completely, transfer the offset scale along the second line and open the filed-book page for that line, keep it in the same direction and plot the off-sets. Similarly, plot all the lines and details and complete the plan.

Exercises

Choose the correct answer from the given alternatives.

1. Chain survey is recommended when the area is ...
   a. Crowded b. Undulating
   c. Simple and fairly plain d. All of the above

2. In chain survey, whole area is divided into ...
   a. Rectangles b. Squares c.Circles d. Triangles

3. Well - conditioned triangle has angles lying between ...
   a. 30^{o} and 120^{o} b.20^{o} and 150^{o} c. 15^{o} and 135^{o} d. 60^{o} and 90^{o}

4. Perpendicular offsets can be taken by setting right angle in the ratio ...
   a. 3:6:9 b. 2:4:6 c.1:2:4 d. 3:4:5

5. The obstacle which obstructs vision but not chaining is ...
   a. River b. Hill c. Building d. All of these

Write short answer to the following questions.

1. Describe the types of field book.
2. Why it is necessary to use well - conditioned triangle in chain surveying?

Write long answer to the following questions.

1. Describe the principle of chain surveying.
2. Define chain surveying. Describe the suitabilities and unsuitabilities of chain surveying.

Project Work

1. Perform Field Procedure of Chain Survey – Reconnaissance (Preparation of Index Sketch, Selection of Survey Stations, Location Sketch of Survey Stations), Taking offsets of ground points
2. Establish Survey Lines – Main Survey Lines, Base line, Check Line, and Tie line
3. Perform Offsets – Perpendicular Offsets, Oblique Offsets
4. Record Field Book – Single Line Field Book and Double Line Field Book

Unit 5 : Compass Survey

5.1 Principles of Compass Surveying

In compass traversing the directions of survey lines are fixed by angular measurements and not by forming a network of triangles. A compass survey is one in which the traverse work consists of series of lines the lengths and directions of which are measured with a chain or a tape, and with a compass respectively.

Compass surveying is suitable in the following situations:

- When the survey work is to be completed quickly.
- When the area is hilly and chaining is difficult.
- When the area to be surveyed is relatively large.
- When the details are too many.
- When the area cannot be divided into network of triangles.
- When the area to be surveyed is long and narrow e.g. road, stream etc.
- When the survey is to be done through dense forest.

5.2 Traversing

A traverse is a series of connected lines whose lengths and directions are to be measured and the process of surveying to find such measurements is known as traversing. In general, chains are used to measure length and compass or theodolite are used to measure the direction of traverse lines. The traversing is performed by four different methods and these methods are classified according to the survey instrument used. The methods are as follows:

1. Chain Traversing
2. Compass Traversing
3. Theodolite Traversing
4. Plane Table Traversing

1. Chain Traversing

Chain traversing is done by taking linear measurements only. Hence, chain or tape is enough for chain traversing. The angle between the adjacent traverse lines is measured using the chain angles concept. Chain traversing is performed in areas such as ponds etc. where it is difficult to adopt triangulation.

The chain angles concept is nothing but finding the angle between two adjacent sides by establishing the third side using tie stations. This angle between the sides can also be fixed by establishing a chord of known length between the sides.

Fig 39: Survey Chain

2. **Compass Traversing**

   In the case of compass traversing, both linear and angular measurements of traverse lines are taken by using chain and prismatic compass respectively. Both fore bearing and back bearings are measured and required corrections for local attraction are applied. If any closing error is obtained while plotting of traverse, then Bowditch rule is applied for the adjustment of error.

Fig 40: Survey Compass

3. **Theodolite Traversing**

In the case of theodolite traversing, the linear measurements are done by using chain or stadia method and angular measurements are done by theodolite. Using theodolite, the magnetic bearing of the first traverse line is measured and from that magnetic bearing of other sides are calculated. This method is very accurate compared to other methods.

Fig 41: Theodolite Traversing

4. **Plane Table Traversing**

In the case of plane table traversing, the measuring and plotting of the traverse on the paper are done simultaneously. The plane table equipment is set up at every traverse station one by one in a clockwise or anti-clockwise direction. The sides of each traverse station are drawn on paper to a suitable scale. If there is any closing error, graphical methods are used for its adjustment.

Fig 42: Plane Table Traversing

5.3 Types of Traverse–Closed Traverse, and Open or Unclosed Traverse

The types of traverse are discussed below as:

1. **Open Traverse**
2. **Closed Traverse**

1. Open Traverse

An open traverse is a traverse in which the sides of traverse do not form a closed polygon. A traverse is said to be open traverse when the traverse starts at one point and terminates at another point as shown in the figure. Open traverse is also called as unclosed traverse. It is suitable for surveying of roads, coastal lines, etc.

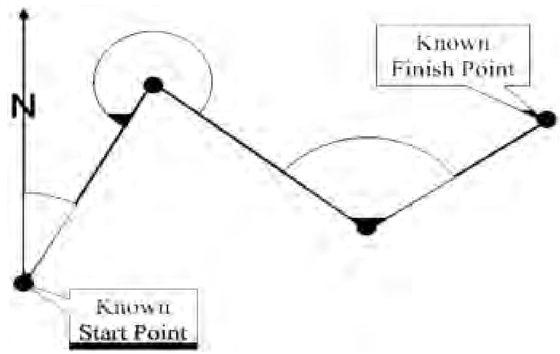


Fig 43: Open Traverse

2. Closed Traverse

A closed traverse is a traverse in which the sides of a traverse form a closed polygon. A traverse is said to be closed traverse when the traverse formed a closed circuit as shown in the figure. In this case, both starting and terminating points of the traverse coincide with each other. It is suitable for the survey of boundaries of ponds, sports grounds, forests, etc.

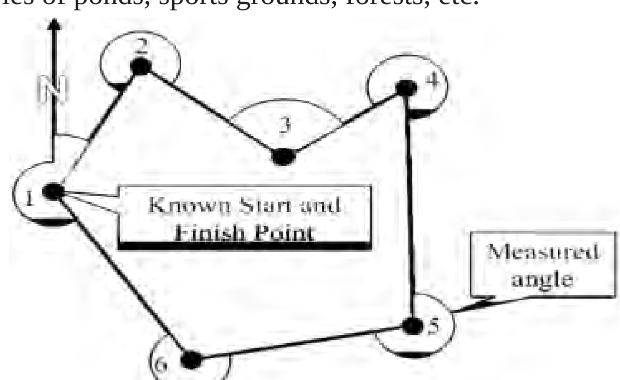


Fig 44: Closed Traverse

5.4 Types of Compass

The types of compass that are used commonly are:

(i) Prismatic compass

(ii) Surveyor's compass

i) Prismatic Compass

Figure below shows the cross-section of a typical prismatic compass.

A magnetic needle of broad form (1) is balanced on a hard and pointed steel pivot (2). The top of the pointed pivot is protected with agate cap (3). An aluminium graduated disk (4) is fixed to the top of the needle. The graduations are from zero to 360° in clockwise direction when read from top. The direction of north is treated as zero degrees, east as 90°, south as 180° and west as 270°. However, while taking the readings observations are at the other end of line of sight. Hence, the readings are shifted by 180° and graduations are marked as shown in Fig. 13.2. The graduations are marked inverted because they are read through a prism. The line of sight consists of object unit and the reading unit. Object unit consists of a slit metal frame (5) hinged to the box. In the centre the slit is provided with a horse hair or a fine wire or thread (6). The metal frame is provided with a hinged mirror (7), which can be placed upward or downward on the frame. It can be slided along the frame. The mirror can be adjusted to view objects too high or too low from the position of compass. Reading unit is provided at diametrically opposite edge. It consists of a prism (8) with a sighting eye vane (9). The prism magnifies the readings on the graduation disk just below it. For focussing, the prism is lowered or raised on the frame carrying it and then fixed with the stud (10). Dark sunglasses (11) provided near the line of sight can be interposed if the object to be sighted is bright (e.g., sun). The bottom of the box (12) which is about 85 mm to 110 mm supports the pivot of needle firmly at its centre. The object vane and the prism are supported on the sides of the box. The box is provided with a glass (13) lid which protects the graduation disc at the same time permit the direct reading from the top. When the object vane is folded on the glass top it presses a lifting pin (14) which activates lifting lever (15) lifts the needle off the pivot. Thus, it prevents undue wear of pivot point. While taking reading, if graduation disc vibrates, it can be dampened with a spring (16). For pressing spring, a knob or brake pin (17) is provided on the box. When not in use prism can be folded over the edge of the box. The box is provided with a lid to close it when the compass is not in use. The box is provided with a socket to fit it on the top of a tripod.

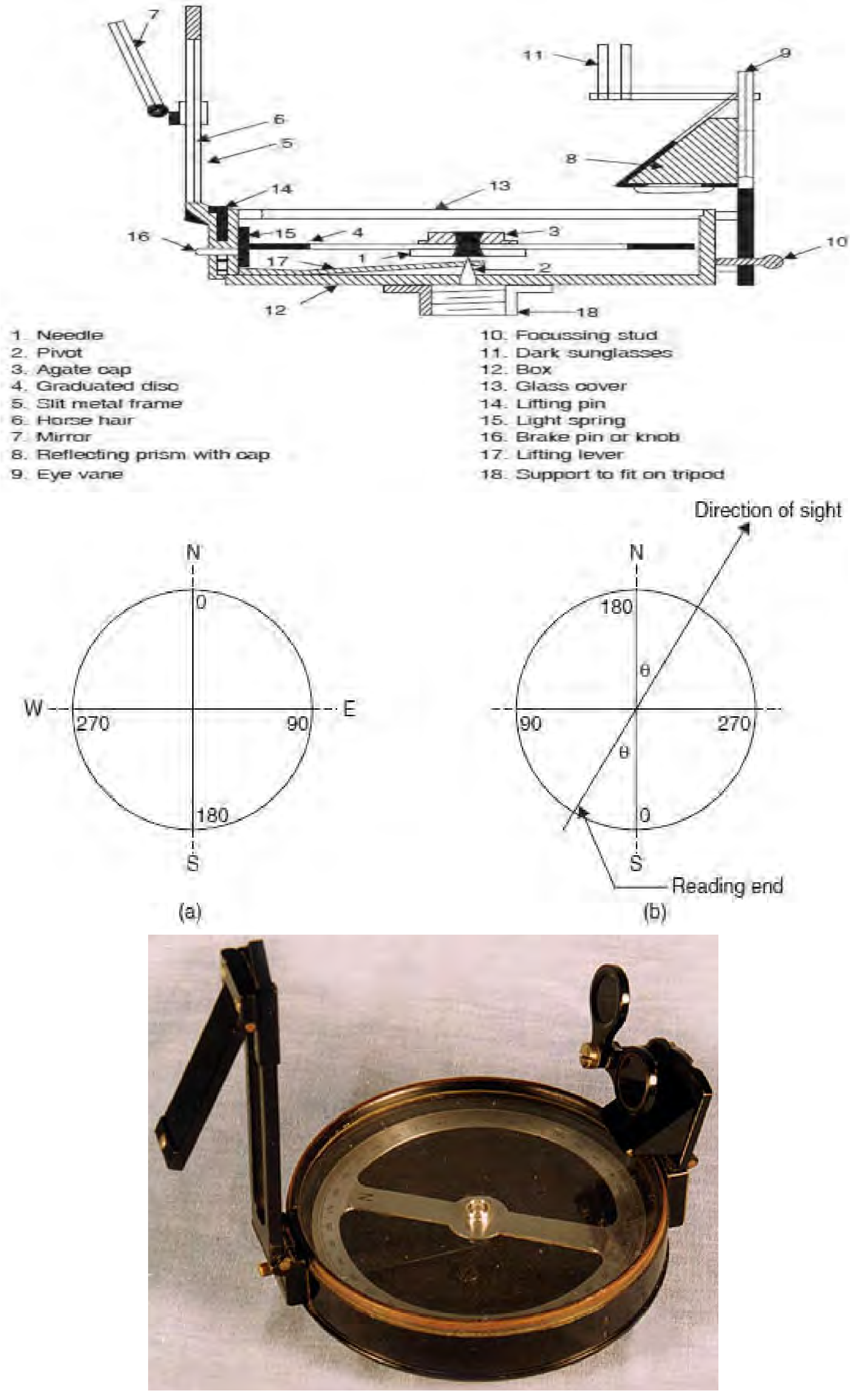


Fig 45: Prismatic Compass

The parts of a Prismatic Compass are:

1. Compass Box

- This is the main body of the compass, shaped like a round container.
- It is about 100 mm wide (about 4 inches), making it easy to hold.
- The box protects all the important parts inside.

2. Magnetic Needle

- This is like a thin, flat magnet that can spin freely.
- It is attached to a light, round ring made of aluminum.
- The needle always points to magnetic north, like a regular compass.

3. Graduated Ring

- This is a circular scale attached to the magnetic needle.
- It has numbers and marks going all the way around.
- The numbers go from 0 to 360 degrees, showing all directions.
- Interestingly, the numbers are written backwards.

4. Pivot

- This is a sharp point in the center of the compass box.
- The magnetic needle and ring balance on this point, allowing them to spin easily.

5. Object Vane

- This is like a sight on one side of the compass.
- It has a thin vertical line (or hair) that you line up with what you're looking at.
- Some compasses have a little mirror here that can tilt, helping you see things that are very high up or low down.

6. Eye Vane (or Sight Vane)

- This is on the opposite side from the object vane.
- It has a small slit you look through, like aiming a gun.
- There's a special prism attached to this part (more on that next).

7. Prism

- This is a piece of glass shaped like a triangle.
- When you look through it, it bends light in a special way.

- It lets you see the numbers on the graduated ring while you're looking at your target.
- The prism also makes the backward numbers look normal and bigger, so they're easier to read.

8. Glass Cover

- This is a clear lid that goes over the top of the compass box.
- It keeps dust and dirt away from the delicate parts inside.

9. Lifting Mechanism

- When you close the object vane, it pushes on a small lever.
- This lever lifts the magnetic needle off the sharp pivot point.
- This protects the needle and pivot from damage when you are not using the compass.

10. Brake Pin

- This is a small pin you can push to stop the needle from swinging around too much.
- It helps you get a steady reading when the needle keeps moving.

11. Sun Glass (or Dark Glass)

- This is a special tinted glass you can use when it is very bright outside.
- It cuts down on glare, making it easier to see what you are aiming at.

ii) Surveyor's Compass

In this type of compass graduation disc is fixed to the box and magnetic needle is free to rotate above it. There is no prism provided at viewing end, but has a narrow slit. After fixing the line of sight, the reading is directly taken from the top of the glass cover. Hence, graduations are written directly (not inverted). In this compass graduation are from zero to 90°, zero being to north or south and 90° being to east and west. An angle of 20° to north direction to the east is written as N 20° E, and an angle of 40° to east from south is written as S 40° E. Always first direction indicated is north or south and the last letter indicates east or west direction. In this system graduated circle rotates with line of sight and magnetic needle is always towards north. The reading is taken at the tip of needle. Hence, on the compass east and west are marked interchanged and marked. Fig. below shows the photograph of a surveyor's compass.

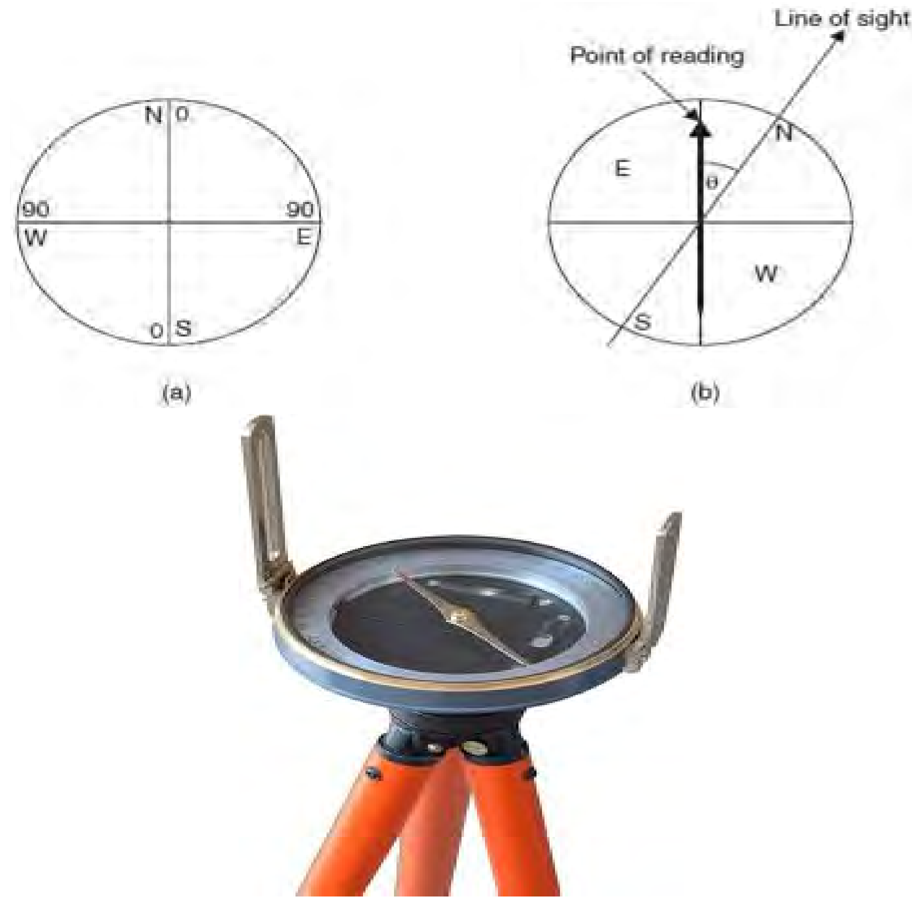


Fig 46: Surveyor's Compass

5.5 Comparison between Prismatic Compass and Surveyor's Compass

Feature	**Surveyor's Compass**	**Prismatic Compass**
Magnetic Needle	Edge bar type, acts as index	Broad needle type, not an index
Graduated Ring	- Attached to box, rotates with line of sight - Quadrant Bearing (Q.B.) system - 0° at N and S, 90° at E and W - E and W interchanged - Erect graduations	- Attached to needle, doesn't rotate with line of sight - Whole Circle Bearing (W.C.B.) system - 0° at S, 90° at W, 180° at N, 270° at E - Inverted graduations

Feature	Surveyor's Compass	Prismatic Compass
Sighting Vanes	- Object vane: Metal with vertical hair - Eye vane: Small with fine slit	- Object vane: Metal with vertical hair - Eye vane: Metal with larger slit and prism
Reading System	- Direct reading through top glass - No simultaneous sighting and reading	- Reading through prism - Simultaneous sighting and reading possible
Tripod Use	Required	Optional (can be handheld)
Versatility	Less versatile due to tripod requirement	More versatile, suitable for various field conditions
Accuracy and Ease of Use	Stable but less convenient for reading	Quicker readings, easier field operation

5.6 Meridian

Meridian is a reference direction with respect to which the direction of lines are mentioned. There are three types of meridian. They are:

- True Meridian
- Magnetic Meridian
- Arbitrary Meridian

True Meridian

The line or plane passing through the geographical North Pole, geographical South Pole and any point on the surface of the earth, is known as the 'true meridian' or 'geographical meridian'. The true meridian at a station is constant. The true meridians passing through different points on the earth's surface are not parallel, but converge towards the poles. But for surveys in small areas, the true meridians passing through different points are assumed parallel. The angle between the true meridian and a line is known as 'true bearing' of the line. It is also known as the 'azimuth'.

Magnetic Meridian

When a magnetic needle is suspended freely and balanced properly, unaffected by magnetic substances, it indicates a direction. This direction is known as the 'magnetic meridian'. The angle between the magnetic meridian and a line is known as the 'magnetic bearing' or simply the ‘bearing’ of the line.

Arbitrary Meridian

Sometimes for the survey of small area, a convenient direction is assumed as a meridian, known as the ‘arbitrary meridian’. Sometimes the starting line of a survey is taken as the arbitrary meridian. The angle between the arbitrary meridian and a line is known as the ‘arbitrary bearing’ of the line.

Grid meridian

Sometimes, for preparing a map some state agencies assume several lines parallel to the true meridian for a particular zone. These lines are termed as ‘grid lines’ and the central line the ‘grid meridian’. The bearing of a line with respect to the grid meridian is known as the ‘grid bearing’ of the line.

5.7 Magnetic Declination

Magnetic declination (sometimes called magnetic variation) is the angle between magnetic north and true north. Declination is positive when this angle is east of true north and negative when it is west. Magnetic declination changes over time, and with location. Declination value is needed to determine true north, because compasses point toward magnetic north.

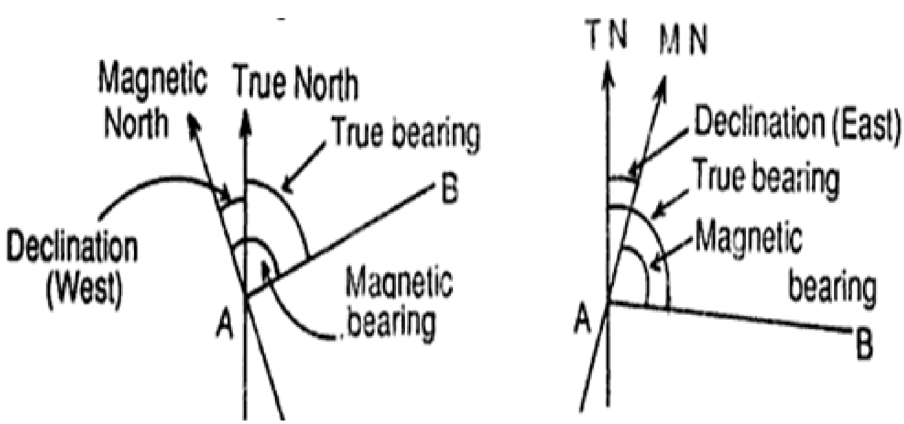


Fig 47: Magnetic Declination

5.8 Bearing- True Bearing, Magnetic Bearing, and Arbitrary Bearing

A bearing in surveying is a clockwise or anticlockwise angle formed by the directions north and south. Bearing in surveying can be based on true north, magnetic north, grid north (the Y-axis of a map projection), or a previous map, which is often a historical magnetic north.

Bearing, in land surveying, refers to the acute angle measurement relative to a given meridian, such as true, magnetic, or arbitrary meridian, and is taken from either north or south towards east or west. The angle, less than 360 degrees, indicates the direction of a line in relation to the reference meridian, and can be measured clockwise or counterclockwise (e.g. N57°E, S51°E, S21°W, N87°W, or N15°W). Bearings provide crucial information for understanding the horizontal angle between the reference line and the surveyed direction, which can be referenced to true north, magnetic north, grid north (the Y-axis of a map projection), or a previous map, often a historical magnetic north.

The types of Bearing in surveying work with respect to different meridians are as follows:

- **True Bearing**

  A line's true bearing is the horizontal angle it forms with the true meridian through one of its extremities. Because the true meridian through a point remains constant, the true bearing of a line is a constant quantity.

- **Magnetic Bearing**

  The magnetic bearing of a line is the horizontal angle formed by the magnetic meridian passing through one of the line's extremities. To measure it, a magnetic compass is used.

- **Arbitrary Bearing**

  The horizontal angle is formed by a line with any arbitrary meridian at one of its extremities. A theodolite or sextant is used to measure it.

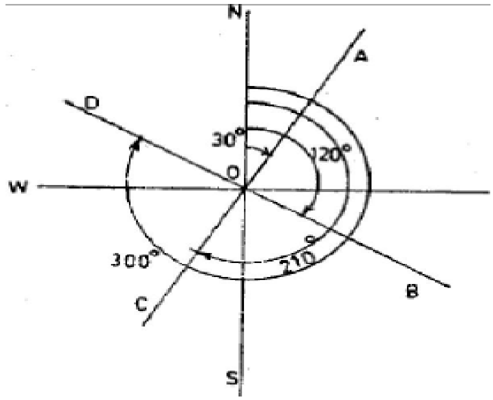
5.9 Bearing system- Whole Circle Bearing System, and Quadrantal Bearing System

The following are the common designations of bearing in surveying works:

- **Whole Circle Bearing System**

  The bearing of a line is measured clockwise from magnetic north in this system. As a result, the value of the bearing ranges from 0 to 360 degrees in this system of bearing in surveying works. The prismatic compass is graduated in this method.

  For instance, if a line forms part of the circumference of a circle, its bearing is the angle it makes with the circle's centre. This method is used to calculate the bearing of a line in relation to another fixed point or object.



For example:

WCB of OA = 30^0

WCB of OB = 120^0

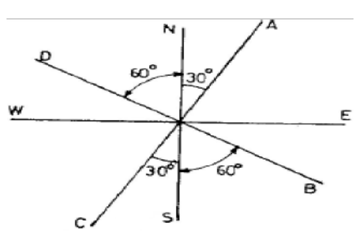
WCB of OC = 210^0

WCB of OD = 300^0

- **Quadrantal Bearing System**

  The bearing of a line is measured eastward or westward from north or south, depending on which is closest, in this system of bearing in surveying works. As a result, both north and south are used as reference meridians, with the direction varying either clockwise or anticlockwise depending on where the line is located. The quadrant in which lines are located must be specified in a quadrantal bearing system. These bearings are observed using a surveyor's compass.

  When a line's bearing is measured to one of four points on the circle's periphery, the quadrantal bearing system is used. For instance, if a line forms part of the circumference of a circle, its bearing is the angle it forms with the circle's centre. Four arbitrary meridians with equal distances between them are chosen for the quadrantal method of bearing in surveying works. The true bearings of these meridians are recorded by using chains of specified size.



For example:

QB of OA = N 30^0 E

QB of OB = S 60^0 W

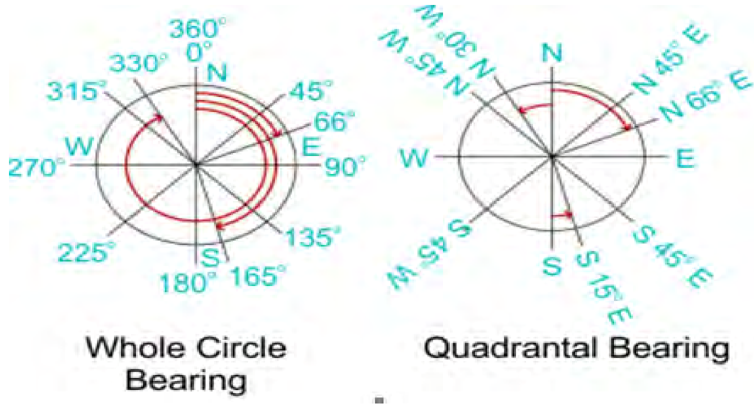


Fig 48: WCB and QB

5.10 Fore Bearing and Back Bearing

Bearings measured while surveying, i.e. in the forward direction of survey lines, are referred to as fore bearings or forward bearings

A surveyor, for example, places his stake some distance away from a line he is surveying. He can calculate the angle between the two by sighting the stake against the celestial body. He points his instrument in the right direction of a survey by measuring that angle and calculating its bearing.

Back Bearing

Backward bearing angle in surveying refers to bearings measured in the opposite direction of surveying progress, i.e., in the survey line's backward direction. A backward bearing is the position of a line in relation to a point, a reference point, or an object.

The theoretical difference between fore and back bearings should be ±180^o.

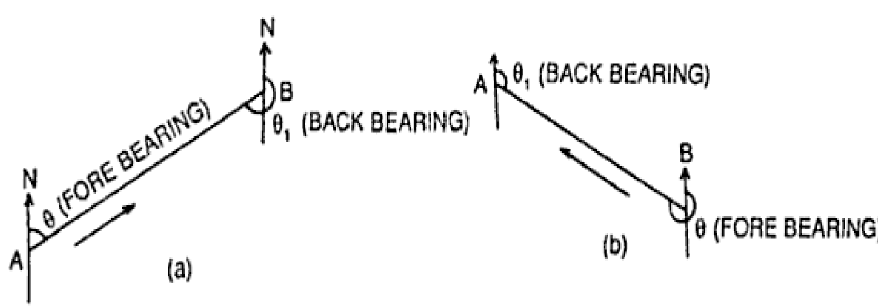


Fig 49: Fore Bearing and Back Bearing

5.11 Local Attraction

Local attraction is the phenomenon due to which the direction of the magnetic needle deviates from the true magnetic north due to the various magnetic objects in the vicinity. These magnetic objects include electric wires, steel, rails, iron buildings, steel tapes, including other magnetic materials. The presence of local attraction can be determined by checking the difference between the fore and back bearing of the line. If the difference is deviating from 180 degrees, it signifies Local Attraction.

Local attraction in compass surveying may exist due to the:

- wires or cables carrying electricity.
- buried Metallic materials and water pipes and conduits.
- train tracks located in the vicinity.
- natural iron ores like magnetite, pyrite, hematite, etc. can also cause local attraction.
- steel and metallic buildings located in the area may incite local attraction.
- survey equipment like chains, rods, steel tapes, etc.
- magnetic materials like key chains, coins, and metal buttons made of steel can lead to local attraction.

5.12 Method of Elimination of Local Attraction

Due to local attraction, compass surveying observations can show significant deviation from the original values. As such, the bearing so obtained need to be necessarily corrected so as to nullify the effect of local attraction.

Method 1: Using the Station Free from Local Attraction

- It is based on the difference between fore bearing and back bearing.
- In normal cases, the difference between the fore bearing and the back bearing of the line should be 180˚.
- If no deviation is observed, then the station is free from the local attraction.
- However, if some error is observed, then the bearings of the line need to be corrected.
- If some station is free from local attraction, bearings of other lines are determined from that station.
- However, in case no stations have a difference of bearings equal to 180˚, in that case, the bearing having the least difference from 180˚ is considered. Subsequently, bearings

of other lines are obtained from this station.

Method 2: From the Included Angles

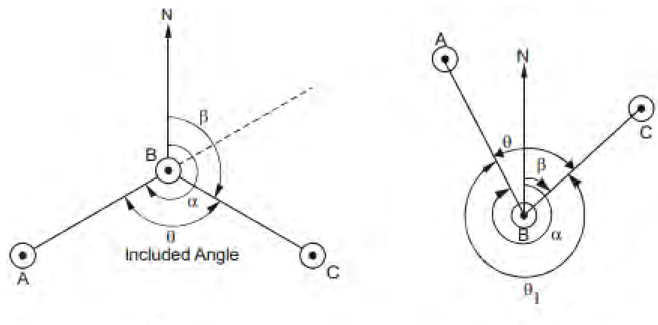
- In this method, the process of annihilating the effect of local attraction is faster.
- Notably, local attraction shows no effect on the interior angles of the traverse. As such, this method is based on the interior angles of the closed traverse.
- The sum of interior angles of the closed traverse should necessarily be equal to (2n-4) 90˚.
- In case the actual sum shows deviation from the theoretical sum, then the error is equally distributed among all angles, and corrections are made for all angles.
- The angles so obtained are used for determining the correct bearings.
- As a check, the difference in the fore bearing and the back bearing should be 180˚.

5.13 Calculation of Angles from Bearings

There are mainly two cases:

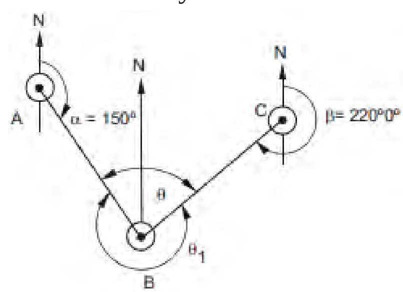
(a) If the whole circle bearings of two lines at a station where these lines intersect are recorded then, the included angle between these lines would be equal to the difference between the whole circle bearings of two lines. If the difference is less than 180o the included angle would be interior angle and if it is more that 180o it will be the exterior angle between the two lines forming the traverse.

In Figure (a), it is given that back bearing (BB) of line AB, i.e. (α) = 240^o and fore bearing (FB) of line BC, (β) = 120^o. Then the included angle ABC, $\theta = \alpha - \beta = 240^o - 120^o = 120^o$. Therefore, it can be said that if both the bearings are measured from a common point (B) then included angle can be obtained by subtracting FB of next line (BC) from the BB of previous line (AB). In Figure (b), if α is given as 330^o and β as 40^o then $\theta 1 = 330^o - 40^o = 290^o$ is the exterior angle. In this case, included angle θ would be 360^o – (difference between WCB of lines BA and BC). Hence, included angle $\theta = 360^o - \theta 1 = 360^o - 290^o = 70^o$.



(a) (b)

(b) If the WCB at point of intersection of survey lines AB and BC (i.e. at station B) are not given but rather fore bearing of line AB (i.e. WCB of line AB at A) and back bearing of line BC (i.e. WCB of line BC at C) are known, then the included angle at station B between survey lines AB and BC can be obtained as follows:



WCB of AB at B = Back bearing of line AB at B = $150^o + 180^o = 330^o$.

Back bearing of line BC at C = 220^o .

WCB of BC at B = Fore bearing of line BC at B = $220^o - 180^o = 40^o$

Included angle $\theta 1 = 340^o - 40^o = 290^o$ = Exterior angle.

Hence, Interior angle $\theta = 360^o - \theta 1 = 360^o - 290^o = 70^o$

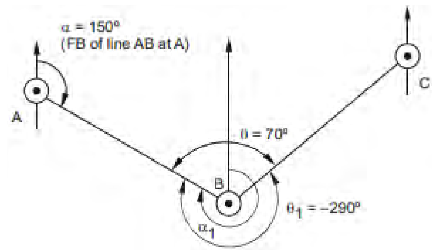
5.14 Calculation of Bearings from Angles

If included angles measured clockwise between survey lines at stations and bearing of any one line are known, bearings of all other lines can be calculated as follows:

Bearing of a line = given bearing of adjacent line + Included angle (measured clockwise) between the lines.

If the sum is more than 360^0, then deduct 360^0 to obtain the bearing of the line. The process is explained with the help of following examples.

(a) Let fore bearing of line AB, α and included angle θ between AB and BC are given.



Then back bearing of line AB at B would be $\alpha 1$ = 150° + 180° = 330° Included angle θ = 70° Then fore bearing of line BC = 330° + 70° = 400° > 360°

∴ Fore bearing of line BC = 400° – 360° = 40°

(b) Let fore bearing of line BC and included angle θ is given.

Included angle θ measured from BC to BA = 70° measured counterclockwise or will be 360° – 70° = 290° measured clockwise.

Hence the back bearing of line AB, i.e. WCB of line AB at B would be 40° + 290° = 330° measured clock wise.

5.15 Sources of Error in Compass Survey

Various errors observed during a compass survey can be broadly classified as Instrumental errors, Personal errors and Natural errors.

Instrumental Errors

Instrumental errors could be due to defective manufacture or due to damage to instrument during rough handling, transportation and use. For example:

(a) The needle may not be perfectly straight or balanced.

(b) Needle losing its magnetic property.

(c) The pivot may become blunt or bent.

(d) The plane of sight losing its verticality and/or twisted so that it is not passing through the centre of compass.

(e) The graduated circle may lose its shape or horizontality.

Personal Errors

Even when the instrument is in perfect order, some errors may occur during bearing measurements. These can be due to:

(a) Setting and levelling inaccuracies, i.e. the compass center may not coincide the center point of survey station, or it may not be levelled accurately so that it does not lie in a horizontal plane.

(b) Ranging inaccuracies, i.e. the ranging rods at other object stations may not be fixed in vertical position or these may not be perfectly bisected by line of sight.

(c) Reading and recording inaccuracies, i.e. due to carelessness, the position of line of sight may either be not read properly or accurately or wrongly recorded in field notebook.

Natural Errors

Perfect instruments and their perfect use may not make the measurements error free because of the following reasons:

(a) Magnetic storms, sunspots, lunar perturbations or minor tremors in earth may cause irregular variations in bearing measurements.

(b) Secular, annual and/or diurnal variations in declination affect the bearing accuracy due to variation in magnetic meridian.

(c) The local attraction due to presence of iron ore in ground, or steel structures, electric lines etc. in the vicinity of survey stations.

5.16 Numerical Practice

1. Convert the following whole circle bearings to reduced bearings

(a) $42^{o}\ 58'$ (b) $156^{o}\ 12'$ (c) $219^{o}\ 47'$ (d) $327^{o}\ 34'$

Solution

(a) WCB = $42^{o}\ 58'$

The survey line lies in 1st quadrant

Hence RB = WCB, i.e. RB = N $42^{o}\ 58'$ E

(b) WCB = $156^{o}\ 12'$

In second quadrant RB = 180^{o} - WCB = 180^{o} - $156^{o}\ 12'$ = S $33^{o}\ 48'$ E

(c) WCB = $219^{o}\ 47'$

In third quadrant

RB = WCB - 180^{o} = $219^{o}\ 47'$ - 180^{o} = S $39^{o}\ 47'$ W

(d) WCB = $327^{o}\ 34'$

In fourth quadrant

RB = 360^{o} - WCB = 360^{o} – $327^{o}\ 34'$ = N $32^{o}\ 26'$ W

2. Following are the observed fore bearings of the lines. Find their back bearings:

   AB 42^o 34′, BC 163^o 46′

   CD 204^o 29′, DE 337^o 52′

Solution

(a) FB of AB = 42^o 34′

Back bearing of line AB

= Fore bearing of AB + 180^o

= 42^o 34′ + 180o = 222^o 34′

(b) FB of BC = 163^o 46′

Back bearing of line BC

= Fore bearing of BC + 180^o

= 163^o 46′ + 180^o = 343^o 46′

(c) FB of CD = 204^o 29′

Back bearing of line CD

= Fore bearing of BC – 180^o

= 204^o 29′ - 180^o = 24^o 29′

(d) FB of DE = 337o 52′

Back bearing of line DE

= Fore bearing of DE – 180^o

= 337^o 52′ - 180^o = 157^o 52′

3. Find the angle between lines OA and OB in following cases where the respective bearings are :

(a) 37^o 10′ and 316^o 28′

(b) 16^o 34′ and 139^o 43′

(c) 118^o 12′ and 287^o 54′

Solution

[**Rule:** When bearing of two lines as measured from point of intersection of lines, i.e. from O, and lines OA and OB are given, subtract smaller from greater. The difference will be interior angle if it is less than 180o and exterior angle if it is more. Interior angle will then be (360^o – exterior angle).]

(a) OA = 37^o 10′, OB = 316^o 28′ Included angle = 316^o 28′ - 37^o 10′ = 279^o 18′ > 180^o ⇒

Exterior angle Interior angle AOB = 360o - 279o 18′ = 80o 42′

(b) OA = 16^{o} 34′, OB = 139^{o} 43′ Included angle = 139^{o} 43′ - 16^{o} 34′ = 123^{o} 09′ < 180^{o} ⇒ Interior angle Interior angle = 123^{o} 09′

(c) OA = 118^{o} 12′, OB = 280^{o} 54′ Included angle = 280^{o} 54′ - 118^{o} 12′ = 162^{o} 42′< 180^{o} ⇒ Interior angle. Interior angle = 162^{o} 42′.

4. The fore bearing of line AB is $155^{0}25'20''$. Identify the back bearing of the line AB in quadrantal system.

The fore bearing of line AB = $155^{0}25'20''$.

The back bearing of line AB ,

BB = FB + 180^{0}

= $155^{0}25'20''$ + 180^{0}

= $335^{0}25'20''$ (WCB)

= N (360^{0} - $335^{0}25'20''$) W

= N $24^{0}34'40''$ W

Exercises

Choose the correct answer from the given alternatives.

1. The direction of a line relative to a given meridian is called ....
   a. Bearing b. Declination c. Angle d. Dip

2. In a reduced bearing system, bearing is measured from ....
   a. Nearest One (North or South) b. North
   c. South d. East

3. The bearing observed with prismatic compass is ....
   a. WCB b. QB c. both a and b d. None of these

Write short answer to the following questions.

1. The magnetic bearing of a line is S 28030’ E. Calculate the true bearing if the magnetic declinations are 5038’ East and 50 38’ West.
2. Distinguish between closed traverse and open traverse.
3. Describe Fore and Back bearing with sketches.

Write long answer to the following questions.

1. Define Compass surveying. What are the objects of compass surveying? Describe about the principles used in compass survey.
2. Differentiate between Prismatic compass and Surveyor’s compass.

Project Work

1. Introduce Principle of Operation of Compass – Prismatic Compass, and Surveyor’s Compass
2. Practice Comparison between Prismatic Compass and Surveyor’s Compass
3. Practice Bearing System - Whole Circle Bearing System, and Quadrantal Bearing System
4. Practice Fore Bearing and Back Bearing
5. Determine and Compute Local Attraction
6. Perform Compass Traversing and detailing
7. Perform Reconnaissance Survey – Preparation of Index Sketch, Selection of Survey Stations, Location Sketch of Survey Stations
8. Practice Calculation of Angles
9. Practice Calculation of Bearings
10. Perform Procedure of Plotting a Compass Survey

Unit 6 : Levelling

6.1 Definitions of the Terms Used in Leveling

Leveling

Levelling is defined as the art of determining the relative heights or elevations of points or objects on the surface of the earth. Therefore, it deals with measurements in vertical plane. It is used to establish the elevation of a point relative to a datum, or to establish a point at a given elevation relative to a datum. This can be important when laying out or measuring buildings, other built assets and landscape. For land levelling work, levelling is the first job to be taken up.

Datum

Datum is also called datum plane or only datum. A datum surface is usually an imaginary level surface or arbitrarily assumed level surface, from which vertical distances are measured. Its elevation is zero.

Bench Mark (Permanent, Temporary, Arbitrary)

Bench mark is a fixed point of reference of known or assumed elevation with respect to which other elevations are calculated. It is a starting point for leveling. The types of bench marks are:

1) **Great Trigonometrical Survey (G.T.S.) Bench Mark**

   These bench marks are established with very high precision at intervals all over the country by Department of survey, Nepal. These points are used as foundational references for geodetic surveys and large infrastructure projects due to their high precision. Their position and elevation above the standard datum are given in the catalogue published by the department.

2) **Permanent Bench Mark**

   These are the fixed points of reference established between the GTS bench marks by Government agencies such as PWD. These marks are set on clearly defined and enduring natural or man-made features, ensuring long-term availability. On clearly defined and permanent points such as top of the parapet wall of a bridge or culvert, corner of a plinth of a building, gate pillars etc., The primary purpose of these marks is to serve as intermediate reference points between the highly precise G.T.S. Bench Marks.

3) **Arbitrary Bench Mark**

These are the reference points whose elevations are arbitrarily assumed. They are used in small levelling operations. These are reference points used for smaller, localized leveling tasks where high precision is not necessary.

4) **Temporary Bench Mark**

These are the reference points established at the end of day’s work or when there is a break in the work. The work, when resumed, is continued with reference to these bench marks. These are short-term reference points used in leveling operations when a permanent bench mark is unavailable.

Reduced Level

Reduced level is the vertical distance above or below the datum. The elevation of a point is considered positive when the point lies above the datum and negative when it lies below the datum. In short, it is termed as R.L.

Line of Collimation

Line of collimation is the line joining the intersection of the cross hairs to the optical centre of the object glass and its continuation. It is called the line of sight.

Back Sight

Back sight is a staff reading taken on a point of known elevation, as on a bench mark or a change point. It is also called a plus sight. It is the first staff reading taken after the level is set up and levelled.

Fore Sight

Fore sight is the last staff reading denoting the shifting of the level. It is the staff reading taken on a point whose elevation is to be determined. It is also termed as a minus sight. It is the last staff reading, denoting the shifting of the instrument.

Intermediate Sight

All readings taken between back sight and fore sight. These are the points whose RL is determined by the method already mentioned above in FS. Also called inter-sight readings.

Change Point or Turning Point

Change point or turning point is the point on which reading is taken just before and after shifting the instrument. That means both back sight and fore sight readings are taken on this point. It is also called a turning point. It should be taken on a firm, well-defined object.

Station

A station is a point whose elevation is to be determined or a point which is to be established at a given elevation.

Axis of telescope

Axis of telescope is a line joining the optical centre of the object glass to the center of the eye piece.

Height of the Instrument

It is the reduced level (R.L.) of the plane of sight when the leveling instrument is correctly leveled. It is also called the "height of the plane of the collimation" or the collimation. The line of collimation will revolve in a horizontal plane known as plane of collimation or the plane of sight.

6.2 Principle of Leveling

The principle of leveling is based on establishing a horizontal line of sight and determining the vertical distances of points above or below this line. A leveling instrument is used to provide the horizontal line of sight, while a graduated leveling staff measures the height between the line of sight and various points on the ground. In engineering surveying, levelling is conducted by one of the following types given below:

1. **Simple Leveling**

   Simple leveling is the simplest operation in leveling when it is required to find the difference in elevation between two points, both of which are visible from a single position of the level. If the two points are so close that they can be seen from a single set up, their level difference can be determined easily.

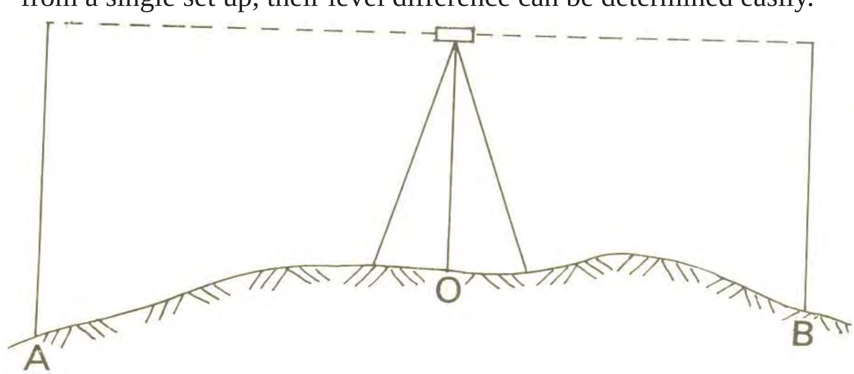


Fig 50: Simple Levelling

Procedure

If the two points are so close that they can be seen from a single set up, their level difference can be determined easily. Let A and B be two points (Fig.) located closely and it is desired to know their elevation difference. The level can be set up anywhere from where both the stations are visible i.e., at "O". But to eliminate the effect of any instrumental error, it is advisable to place the instrument at equal distance from both the stations, but not necessarily in the same line. Staff readings are taken on both the stations. The difference in reading gives the elevation difference between the points.

2. Differential Leveling

Differential leveling is the method of levelling to determine the elevation of points located at some distance apart or to determine the elevation difference between two points or to establish bench marks. The method is used in order to find the difference in elevations between two points: (i) if they are far apart, (ii) the difference in elevation between two points is too great and (iii) if there are obstacles intervening. The method of simple leveling is employed in each of the successive stages. The process is also known as compound or continuous leveling. Suppose, it is required to find the difference of level between two points A and B, which are too far apart as shown in fig.

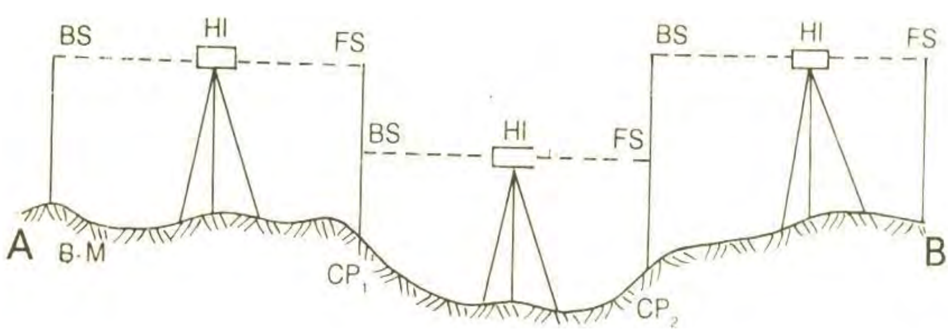


Fig 51: Differential Levelling

Procedure

When two points are located at a distance so that they cannot be viewed from a single set up of the level, then it is required to take a number of change points. Let A and B are two such points (Fig.) whose elevation is to be found out. First, the instrument is set up between A and B and the instrument is leveled and focused. Reduced level of A is assumed and is taken as bench mark. From the same set-up, the staff reading (B.S.) at A is taken. The instrument remains in its position and staff is shifted towards B and fore sight (F.S.) reading is taken on this point, which is the first change point. The distance of the change point from the level should not exceed 100m. The level is shifted towards B and set up at a convenient point to keep its distance from the first change point approximately same as before. The process of taking B.S and F.S. reading is repeated till the point B is reached. Enter last station reading in the fore sight. The readings are tabulated and the reduced levels of all stations can conveniently be calculated following the collimation or rise or fall system.

6.3 Types of Level

Following are the types of different levels used for leveling in surveying:

1) Dumpy Level

The dumpy level is simple, compact and stable. Main parts of a dumpy level are shown in figure below. A levelling instrument essentially consists of tripod or three-legged stand, levelling head mounted on the tripod, the limb, telescope and the bubble tube. The most important part is the telescope which may be either internal focusing or external focusing type. A levelling head is mounted on the tripod stand having two parallel plates and three- or four-foot screws. The limb, consists of the vertical axis and a horizontal plate, connects the levelling head with the above telescope.

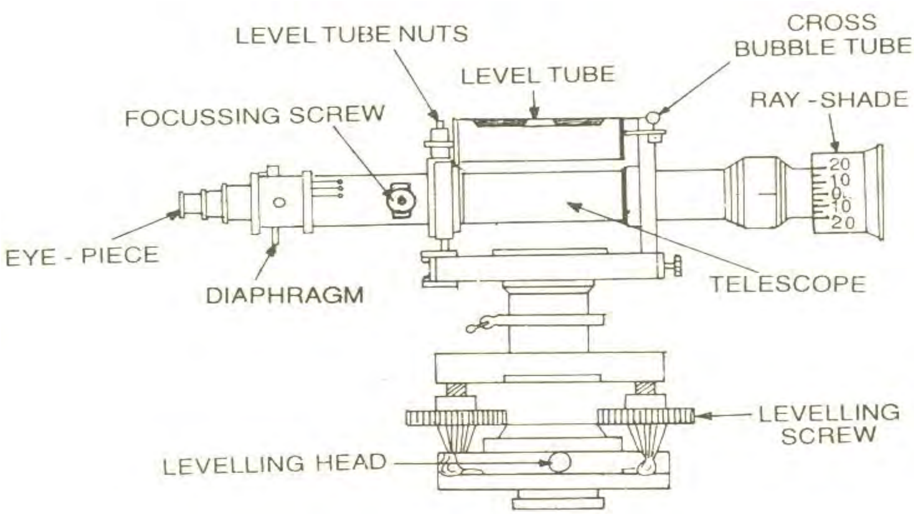


Fig 52: Dumpy Level

The telescope has an object glass at the forward end and eye piece at the rear end. The eye piece magnifies the image of the object formed by the object glass. All the parts above the levelling head are capable of rotating round the vertical axis. One or two bubble tubes are provided for leveling the instrument. The bubbles can be brought to the centre of the bubble tubes by adjusting the foot screws, which support the upper parallel plate. The diaphragm is fixed a little beyond the eye-piece inside the main tube. The diaphragm houses a brass ring which is fitted with cross hairs. There are three sets of horizontal hairs. The central cross hair gives the line of sight. The line joining the intersection of the central cross hair to the optical centre of the object glass and its continuation is the line of sight. When sighted through the eye piece, continuation of the above line meets the leveling staff at a point denotes the staff reading.

2) Tilting Level

Tilting level consist a telescope which enabled for the horizontal rotation as well as rotation about 4 degree in its vertical plane. Centering of bubble can be easily done in this type of level. But, for every setup bubble is to be centered with the help of tilting screw. The main advantage of tilting level is it is useful when the few observations are to be taken with one setup of level.

Fig 53: Tilting Level

3) Automatic Level

Automatic level is like the dumpy level. In this case the telescope is fixed to its supports. Circular spirit can be attached to the side of the telescope for approximate leveling. For more accurate leveling, compensator is attached inside the telescope. Compensator can help the instrument to level automatically. Compensator is also called as stabilizer which consists two fixed prisms and it creates an optical path between eye piece and objective. Due to the action of gravity, the compensator results the optical system to swing into exact position of line of sight automatically. But before the process of leveling, compensator should be checked. To check the compensator, just move the foot screws slightly if the leveling staff reading remains constant then compensator is perfect. If it is not constant, then tap the telescope gently to free the compensator. Automatic level is also called as self-adjusting level.

Fig 54: Auto Level

Levelling Staff

A levelling staff is a crucial instrument in surveying, consisting of a straight, rectangular rod typically made of wood or modern composite materials. It is precisely graduated into metric or imperial units, with meters or feet as the primary divisions, further subdivided into smaller increments for accurate measurements. The staff is designed to be held vertically on the point being measured, with its base representing the zero reading. When viewed through a levelling instrument, the line of sight intersects the staff at a specific point. This intersection provides a reading that represents the height of the instrument's line of collimation above the ground point where the staff is positioned.

Types of Levelling Staffs

i. Self-reading Staff

A self-reading staff is one on which the observer can directly read measurements through the telescope without any intermediate steps. This type of staff allows for straightforward and efficient observation, eliminating the need for additional tools or personnel to record readings. Self-reading staffs are commonly used in levelling and surveying tasks due to their simplicity and ease of use. They come in three primary types, as outlined below:

1. Solid Staff

Solid staffs are typically 3 meters in length and are constructed as a single, continuous piece. Due to the absence of hinges or sockets, they offer greater accuracy in reading measurements, making them ideal for precise levelling tasks. However, their rigid structure also makes them less convenient to transport and handle in the field. As a result, solid staffs are predominantly used for specialized levelling work where precision is a priority, despite their practical limitations in terms of portability.

Fig 55: Solid Staff

2. Folding or Hinged Staff

A folding or hinged staff is typically constructed from well-seasoned timber, ensuring durability and precision. It measures 4 meters in total length, composed of two 2-meter sections connected by a hinge. The staff has a width of 75 mm and a thickness of 18 mm, providing sturdiness while remaining lightweight for practical use. To protect against wear and tear, the foot of the staff is fitted with a brass cap. In some cases, a plummet is also included to help the staffman check and maintain the verticality of the staff during use.

Each meter of the staff is subdivided into decimeters, with each decimeter further divided into 20 segments, each 5 mm wide. Decimeter markings from 1 to 9 are displayed in black, while meter numerals are shown in red.

Fig 56: Folding Staff

3. Telescopic or Sopwith -Type Staff

The telescopic, or sopwith -type, staff consists of three interlocking sections. The top section is a solid piece measuring 1.25 meters, while the central and lower sections, measuring 1.25 meters and 1.5 meters respectively, are hollow. These sections fit into each other in a telescopic manner, allowing the top section to slide into the central portion. When fully extended, the staff reaches a total length of 4 meters. Brass spring catches secure the upper two sections in place when extended.

The smallest division on this levelling staff is 5 mm. Meter numerals, located on the left side, are marked in red, while decimeter numerals (1 to 9) are displayed on the right side and marked in black. The numeral 10 is replaced by the letter "M" to indicate the end of each meter length.

Fig 57: Telescopic Staff

ii. Target Staff

The target staff consists of two sections: an upper rod measuring 6 feet and a lower rod measuring 7 feet. The upper rod slides into the lower one, making the staff adjustable in length. A movable target is attached to the staff, which can be adjusted up or down along the rod.

The staff is graduated in feet, with subdivisions in tenths and hundredths for precise readings. To take a reading, the level man instructs the staff man to raise or lower the target until it is perfectly bisected by the level's line of sight. Once the target is correctly aligned, the staff man clamps it in place and records the reading. This process allows for accurate measurement in levelling tasks, with the target aiding in clear, precise readings.

6.4 Temporary Adjustment of Level

The temporary adjustments are those, which have to be done at each set-up of the level. They are necessary adjustments to take readings. They are:

Setting up the Level

- **Fixing the instrument on the tripod:** Release the clamp screw of the instrument, hold the instrument in the right hand and fix it on the tripod by turning round only the lower part with the left hand. Screw the instrument firmly.
- **Leg adjustment:** Plant the instrument at the desired point at a convenient height for sighting. Spread the tripod legs well apart and tri-brach sprang as nearly level as can be judged by the eye. Bring all foot screws in the centre of their run. Fix any two legs firmly into the ground by pressing them with the hand and move the third leg to the right or left until the main bubble is approximately in the centre. Then move it in or out until the bubble of the cross level is approximately in the centre. It is only approximate levelling.

Levelling up

Place the telescope parallel to a pair of foot screws and bring the bubble to the centre of its run by turning these screws equally either both in wards or both outwards. Turn the telescope to 900 so that it lies over the third foot screw and centre the bubble by turning this screw. Repeat the operations until the bubble remains in the centre of its run in both positions. Once this operation is complete, the bubble should remain in the centre for all directions of the telescope, provided the instrument be in correct permanent adjustment.

Elimination of Parallax

Parallax: The apparent movement of the image relatively to the crosshairs when the image formed by the objective does not fall in the plane of the diaphragm is called "parallax" and the process of precise focusing on the staff is often called "adjusting for parallax". If the image appears to move in the same direction as that of eye, it is in front of the diaphragm and the focusing screw must therefore move the objective inwards. If however, the image appears to move in the direction opposite to that of the eye, it is beyond the diaphragm towards the eye piece and the objective therefore to be moved outwards by the focusing screw. It may be noted that parallax error can be eliminated wholly by slightly turning the focusing screw backwards or forwards until such motion no longer exists.

- **Focusing the Eye-piece**

Remove the lid from the object glass and hold a white paper in front of it. Move the eye piece in and out until the cross hairs on the diaphragm are seen distinctly.

- **Focusing the Objective)**

  Direct the telescope towards the staff and on looking through the eye-piece, bring the image of the staff between two vertical hairs of the diaphragm by lightly tapping the telescope. Adjust the objective by turning the focusing screw until the parallax error is eliminated.

6.5 Booking and Reduction of Levels

The readings should be entered in the respective columns and in the order of their observation. The first reading is obviously a Back sight and should be entered in that column. A remark should be made in the remarks column describing whether Back sight (B.S.) is taken on a permanent or temporary or arbitrary Bench mark (B.M.) and its value should be noted. If more than one reading is taken from the same position of the instrument, all the subsequent readings should be recorded in the intermediate sight column. The last reading is a Change point (C.P.) and recorded in Fore sight column (F.S.). The foresight and back sight of the change point should be written in the same horizontal line. The R.L of the plane of collimation should be written in the same horizontal line opposite to B.S. If the last entry at the bottom of the page happens to be an Intermediate sight (I.S.), it should be repeated as the first entry on the next page and should be recorded both in I.S and F.S columns. The arithmetic checks should be made and written at the bottom of every page at home, the same day the levelling is done, so that if any discrepancy is found, it can be checked the next morning in the field.

Whenever any leveling is to be carried out, the first reading is taken on a point of known elevation. This is called Back sight (B.S.) reading. Before shifting the instrument one reading is taken on a firm object whose elevation is to be determined. This is known as Fore sight (F.S.) reading. Between the B.S and F.S numbers of readings known as Intermediate sights (I.S) are taken. All these readings are required to be tabulated and converted to Reduced Levels (R.L) for practical use. There are two systems of working out the reduced levels of points from the staff readings in the field:

(1) Collimation or the Ieight of Instrument (H.I.) method and

(2) Rise and fall method

1) Height of Instrument (H.I) Method

At first, the R.L. of the plane of collimation i.e., height of instrument (H.I) is calculated for every setting of the instrument and then R.L. of different stations re calculated with reference to the height of the instrument. In the first setting, the H.I. is calculated by adding the B.S. reading with the R.L. of the bench mark. By subtracting all the readings of all the intermediate sights and that of the first change point from the H.I, then their reduced levels are calculated. The new H.I is calculated by adding the B.S. reading with the R.L. of the first change point. The process is repeated till the entire area is covered.

Method to calculate RL

Height of Collimation (H of C) = Reduced Level (R.L.) + Backsight (B.S.)

Reduced Level (R.L.) = Height of Collimation (H of C) – Fore Sight (F.S.)

Reduced Level (R.L.) = Height of Collimation (H of C) – Intermediate Sight (I.S.)

Arithmetical Check

The difference between the sum of back sights and the sum of fore sights should be equal to the difference of first and last R.L.

Sum of Back Sights (ΣB.S.) − Sum of Fore Sights (ΣF.S.) = Last R.L. − First R.L.

Standard leveling field book format (HI method)

Location________ Date________ Observer________ Booker________ Temp.______

Weather________ Inst. No______

Station	BS	IS	FS	HI	RL	Remark
A	0.628			100.000+0.628	100.000	BM (top of a spike)
B		1.564			99.064	
C		1.000			99.628	
D	2.259		1.210	99.418+2.259	99.418	HI= 101.677
E			0.991		100.686	
Σ	2.887	2.564	2.201		100.686	
	- 2.201				-100.000	
	0.686				0.686	Ok!

2) Rise and Fall Method Height of Instrument (H.I) Method

The level readings taken on different stations are compared with the readings taken from the intermediate proceeding stations. The difference in the readings indicates rise or fall depending upon whether the staff reading is smaller or greater than that of the preceding reading. The rise is added and fall is subtracted from the R.L. of a station to obtain the R.L. of the next station.

Method to Calculate RL:

Fall (F) = Fore Sight (F.S.) – Back Sight (B.S.)

Fall (F) = Intermediate Sight (I.S.) – Back Sight (B.S.)

Rise (R) = Backsight (B.S.) – Fore Sight (F.S.)

Reduced Level (R.L.) = Precede Reduced Level + Rise (R)

Reduced Level (R.L.) = Precede Reduce Level – Fall (F)

Arithmetical Check

The difference between the sum of back sights and the sum of fore sights is equal to the difference between the sum of the rise and fall and should be equal to the difference of first and last R.L.

Sum of Back Sights (ΣB.S.) − Sum of Fore Sights (ΣF.S.) = Σ Rise − Σ Fall

= Last R.L. − First R.L.

Standard level field book (RF method)

Location________ Date________ Observer________ Booker________ Temp. ______
Weather________ Inst. No ______

Station	BS	IS	FS	Rise	Fall	RL	Remark
A	0.628					100.000	BM (top of a spire)
B		1.564			0.936	99.064	RL = 100-0.936
C		1.000		0.564		99.628	RL= 99.0.64+0.564
D	2.259		1.210		0.210	99.418	RL= 99.628-0.210
E			0.991	1.268		100.686	RL= 99.418+1.268
Σ	2.887		2.201	1.832	1.146	100.686	OK!
	-2.201			-1.146		-100.000	
	0.686			0.686		0.686	

Arithmatic check: ΣBS - ΣFS = ΣRise - Σ fall = Last RL - First RL

6.6 Uses of Leveling

a) Longitudinal Sections

It is the method of determining the level of ground surface along a predetermined line which may be the centre line of a road, canal, railways or pipeline. The predetermined line may be a single straight line or a series of connected straight lines. The method is also known as longitudinal leveling or sectioning. Sectioning is useful for laying out roads, canals, terrace lines, contour bunds etc.

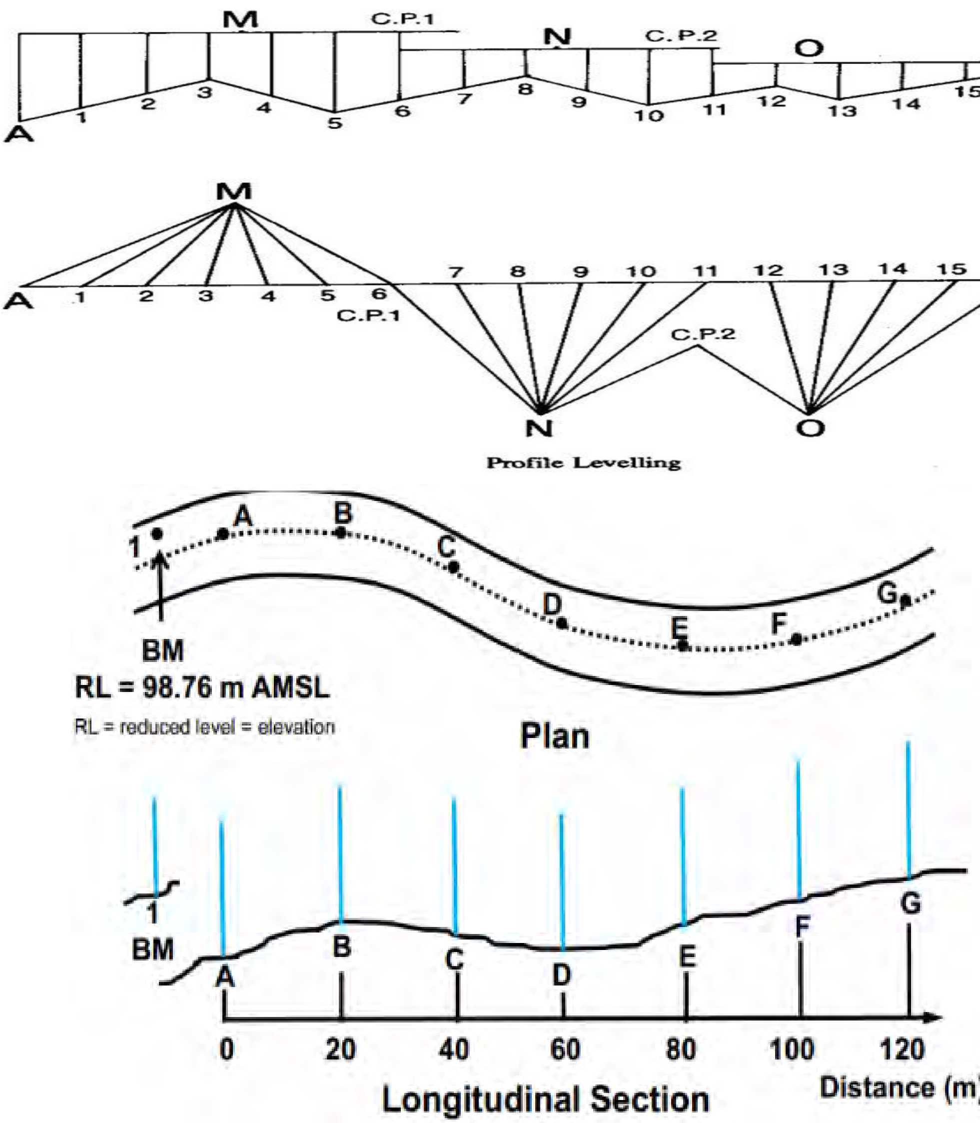


Fig 58: Longitudinal/ Profile Levelling

Procedure for Profile Leveling

The leveling operation should start from a bench mark. If no bench mark is available nearby, fly levels may be taken to establish temporary bench marks. Depending upon the precision required, the interval at which level should be taken is decided. The fixed interval may be 10, 20, 25 m etc. But apart from this fixed interval, level readings must be taken at all points where there is abrupt change of slopes. If these points are omitted, there will be serious misrepresentation of the nature of slope. The line AG (Fig.58) along which profile leveling will be carried out is located and the points are marked by pegs. Here the R.L. of the bench mark (1) is known and pt. 1 is also the first point of the line through which profile will be run. The fore bearing of the line should be measured at A by using a prismatic compass. The magnetic compass fitted with the dumpy level may also be used for measuring the bearing of the line. If there are number of connected lines, then the bearings of each line should be measured as the survey progresses. For taking levels, the instrument is set up on a firm ground located outside the line AG. Back sight reading is taken on the staff held at pt.1 (bench mark). This is a plus sight as this reading added with the R.L. of pt.1 gives the H.I. Now the staff is shifted to different points already marked and numbers of I.S. readings are taken. The reading of the last clearly visible station (station no.6) is the F.S. reading. This is used as the first change point. After taking the F.S. reading on the first change point, the instrument is shifted to a new position from where maximum number of stations can be covered. The staff-man continues to hold the staff at the same position (C.P. 1) till B.S. reading on it is taken. After this, the staff is shifted to different stations and Intermediate sights (I.S.) are taken as long as the stations are visible from this set up of the leveling instrument. At last, a Change Point (C.P.2) is selected on a firm ground and the F.S. reading is taken. The instrument is shifted and the process is continued till all the stations are completed. Whenever there is a change in the direction of the profile line, at the point of change, the back bearing of the preceding line and the fore bearing of the succeeding line must be taken. The chainage of all the staff points should be taken continuously from the starting point to the last point. As far as possible the B.S. and F.S. distances should be approximately equal. In addition to the profile readings, staff readings should also be taken on all important features. Also, the positions of the features like road, canal, river, fences etc. may be located by taking offsets or by some other means. The level readings should be checked by connecting it with a nearby permanent bench mark. If, no such bench mark is available, the work can be checked by taking fly levels to the original bench mark.

b) Cross Sections

Cross-sectioning is a levelling technique used to determine the elevation of points located perpendicular to the main line of a proposed route, typically at right angles on either side of the centerline. This method helps create a vertical profile of the ground surface. Cross-sectioning is often performed radially on curves and provides essential data for understanding the variations in elevation across the terrain.

This information is critical in engineering projects as it allows for the accurate calculation of earthwork volumes. The cross-sections are plotted similarly to longitudinal sections, with both horizontal and vertical measurements being drawn to the same scale, ensuring a precise representation of the land's contour.

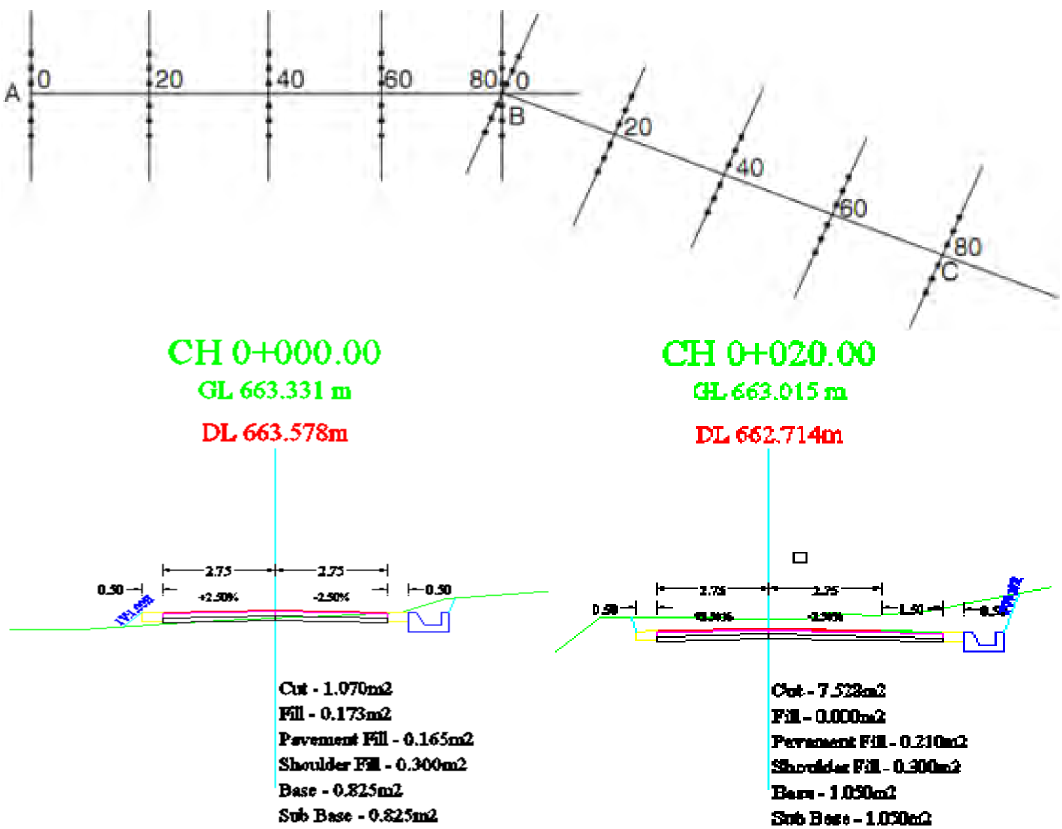


Fig 59: Cross Section Levelling

c) Contouring

Contour or contour line is defined as a line of intersection of level surface with the surface of the ground. Thus, every point on a contour line has the same elevation. Therefore, contour line may also be defined as a line joining the points of equal elevation. The shore line of a reservoir with still water represents a contour line of fixed reduced level. As the water level changes, the new shore line represents another contour of a different R.L. The contour lines of an area are presented in a map known as a contour map or topographic map. In addition to contour lines, a topographic map includes the features like streams, rivers, reservoirs, valleys, hills, bridges, culverts, roads, fences etc.

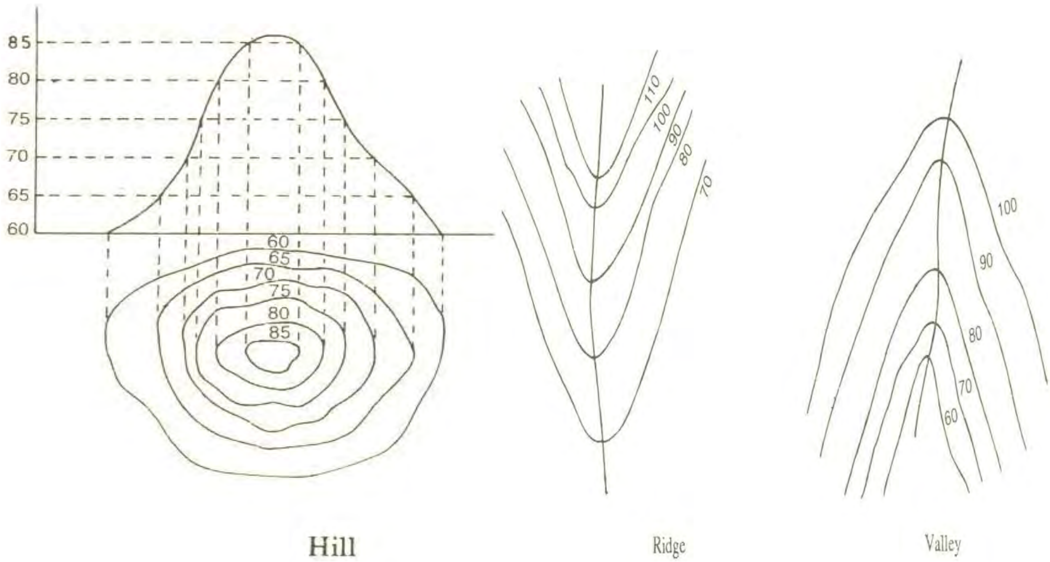


Fig 60: Contouring

d) Setting out Levels

Levelling is employed to establish vertical control on construction sites. It utilizes a leveling instrument, such as a dumpy level or an automatic level, along with a leveling staff. Surveyors measure the difference in height between reference points, known as benchmarks, using the principle of line of sight. Optical leveling is crucial for setting out structures with specific elevation requirements, such as roads, pipelines, and buildings. The method of setting out is the reverse of the surveying process. The process involves the positions and levels of building lines and road alignments shown on the construction plans to be established on the ground.

6.7 Two Peg Test

Two peg test is also known as collimation test. This test is carried out to test whether the line of collimation is parallel to the axis of bubble tube or not. It is applied for the adjustment of the line of collimation.

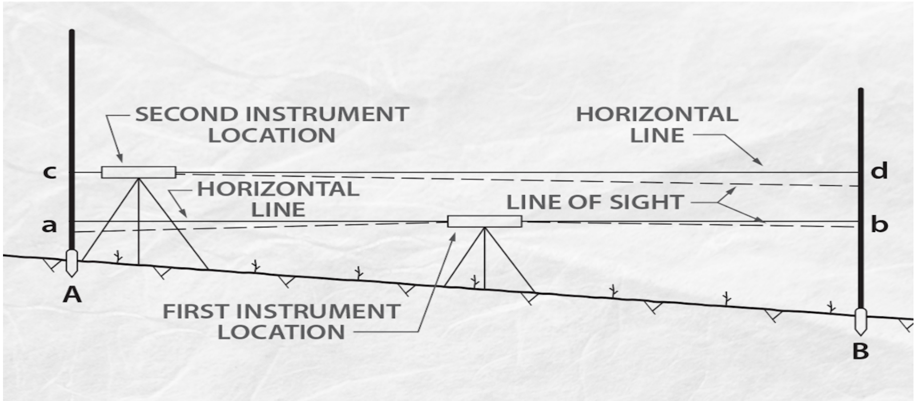


Fig 61: Two Peg Test

Procedure

1. Two points A and B were chosen on a fairly leveled ground at a distance of 30m. Instrument was set at C which was exactly at the midway of A and B.
2. Staffs were kept at points A and B and three wire readings were taken on the staff when the bubble was exactly centered.
3. Difference in elevation was calculated between two points, i.e. A & B. The difference in two staff readings give the correct difference in elevation even if the line of sight is inclined as balancing of back sight and fore sight is well carried out.
4. The level machine was shifted to point D about 5m from A and three wire readings were observed on both the staffs kept at A &B.
5. The level was shifted to another point E about 5m from B and three wire readings were observed on both the staffs kept at A &B.
6. Again the differences in elevations were carried out. If the level difference obtained previously is equal to level difference obtained, line of collimation is parallel to the axis of bubble tube. In this case, the collimation error should be less than 1:10000.
7. If collimation error is greater than 1:10000, permanent adjustment of the level instrument should be carried out.

6.8 Fly Leveling

Fly leveling is a type of differential levelling in surveying done to determine approximate elevations of different points. The fly levelling is done where rapidity, but low precision is required. Fly levelling is generally used for the reconnaissance of the area or for approximate checking of the levels. When differential levelling is done in order to connect a benchmark to the starting point of the alignment of any project. Only BS & FS readings are taken at every set up. No distances are measured.

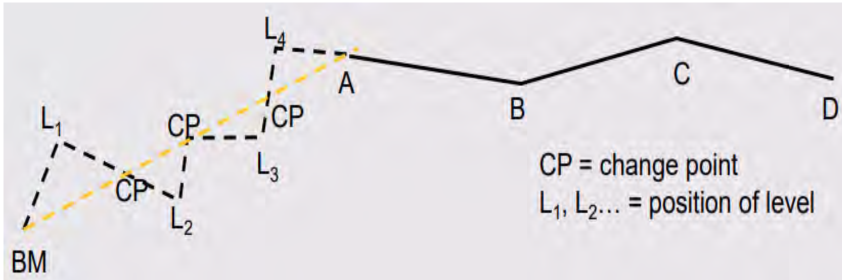


Fig 62: Fly Levelling

6.9 Reciprocal Leveling

Reciprocal leveling helps in compensating for the error due to curvature and refraction and also the line of collimation errors in surveying. It is one of the best methods to eliminate curvature and refraction errors.

In reciprocal levelling, the level is set up on both sides of the levels. Two sets of staff reading are taken. This helps in compensating for the error due to curvature and refraction & also the line of collimation errors in surveying.

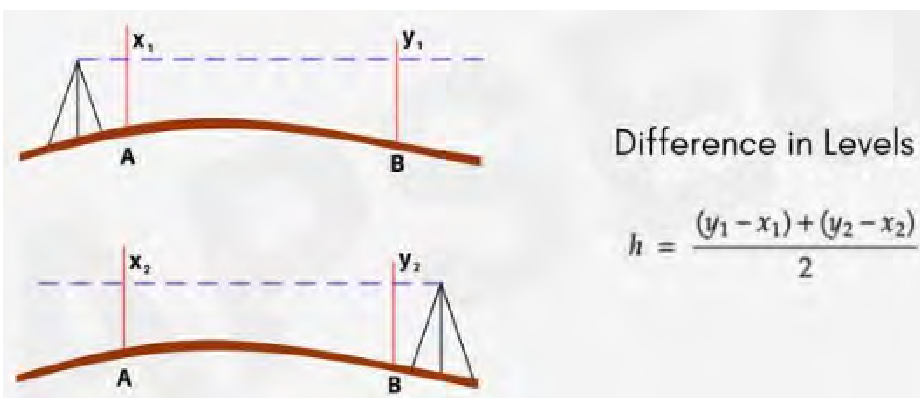


Fig 63: Reciprocal Levelling

6.10 Curvature and Refraction Correction

Curvature and refraction effects should be accounted for in precise levelling work and also if the sights are too long. The effect of curvature is to cause the objects sighted, to appear lower than they really are. The effect of refraction is to make the objects appear higher than they really are.

Curvature

In case of a long sight the horizontal line is not a level line due to curvature of the earth. The vertical distance between a horizontal line and the level line represents the effect of curvature of the earth. In Fig. let ABD be a level line through A, and O be the centre of the earth. A is the instrument position. AC, the line of collimation, will be a horizontal line. R is the radius of the earth.

The curvature correction,

$Cc = BC$

Now,

$OC^2 = OA^2 + AC^2$ or $(R + Cc)^2$

$= R^2 + D^2$ or $R^2 + 2R \times Cc + C^2c$

$= R^2 + D^2$ or $Cc\,(2R + Cc)$

$= D^2$ or Cc

$= D^2 /2R + Cc$

Since Cc is very small as compared to the radius of the earth R,

$Cc = D^2 /2R$

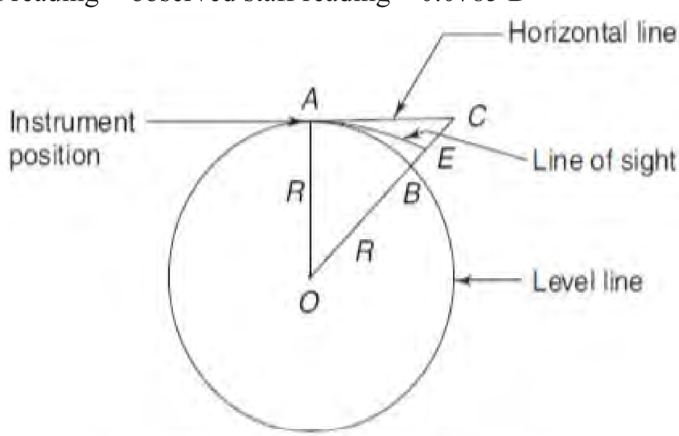
Taking the radius of the earth as 6370 km,

$Cc = 0.0785\ D^2$

where D = distance in km

Since the curvature increases the staff reading, the correction is therefore subtractive.

True staff reading = observed staff reading – $0.0785\ D^2$



Curvature and refraction

Refraction

Refraction of the ray passing through the atmosphere from the signal to the observer is the main source of external error. The rays of light while passing through layers of air of different densities refract or bend down. These densities depend upon the temperature and pressure at all points along the track of the rays. Consequently, ray from a staff follows a curved path, let us say AE (Fig.). CE is the amount of refraction correction and varies considerably with climatic conditions. The average refraction correction can, however, be taken as 1/7th of the curvature correction.

Refraction correction = $0.0785\ D^2/7 = 0.0112\ D^2$

The correction due to refraction is additive.

Combined Correction

Since, the effect of curvature and refraction, when combined, is to make the objects sighted appear low, the overall correction is subtractive.

Combined correction = $0.0785\ D^2 - 0.0112\ D^2$

$= 0.0673\ D^2$

True staff reading = observed staff reading – $0.0673\ D^2$

Error due to curvature and refraction can be eliminated by equalising F.S. and B.S. distances or by reciprocal levelling. For a length of sight of about 400 m, combined correction will be 1 cm and may be neglected when running indirect levelling.

6.11 Plotting

Longitudinal Sections

The data are represented as a profile, which is a representation of a vertical cross section. The primary objective of longitudinal sectioning is to determine the slope, grade, and vertical alignment of the surveyed feature.

The process of creating a longitudinal section typically involves the following steps:

- **Establishing a Base Line**

  A straight line is marked along the path of the feature being surveyed. This line serves as the reference for all subsequent measurements.

- **Taking Elevation Measurements**

  At regular intervals along the base line, surveyors measure the elevation of the ground surface using an instrument like a leveling instrument or a total station. These measurements are recorded to create a profile of the land.

- **Plotting the Profile**

  The collected elevation data is plotted on graph paper or entered into specialized software to create a longitudinal section. The resulting graph shows the variations in ground level along the surveyed line.

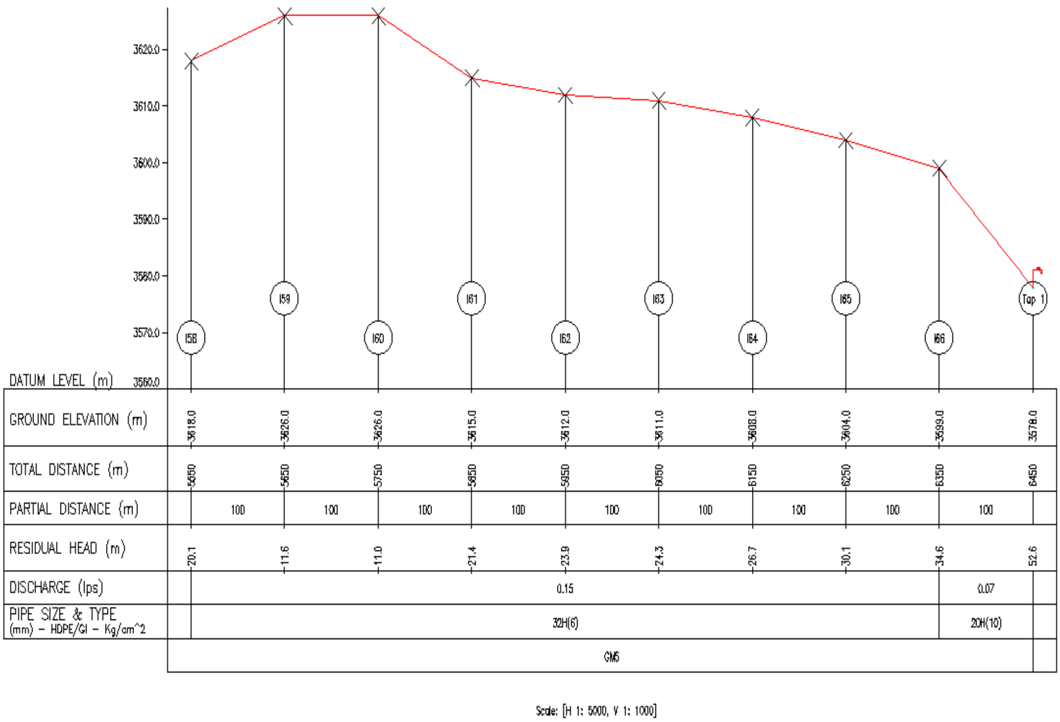


Fig 64: Longitudinal Section Plotting

Cross Sections

Cross sectioning involves the creation of horizontal cross-sectional views of the land perpendicular to the alignment being surveyed. This technique provides valuable information about the terrain's shape, dimensions, and features at specific locations. Cross sections are particularly useful for designing and analyzing infrastructure elements like roads, canals, or embankments.

The process of creating a cross section typically involves the following steps:

- **Establishing Cross-section Lines**

  Surveyors mark perpendicular lines to the alignment being surveyed at regular intervals. These lines are known as cross-section lines or station lines.

- **Taking Measurements**

  Along each cross-section line, surveyors measure the ground level at predetermined intervals using leveling instruments or total stations. Additional measurements may be taken for features such as buildings, utilities, or natural elements.

- **Plotting the Cross Section**

  The measured data is then plotted on graph paper or entered into specialized software to create a cross section. The resulting diagram provides a detailed view of the land's features and elevations along the surveyed line.

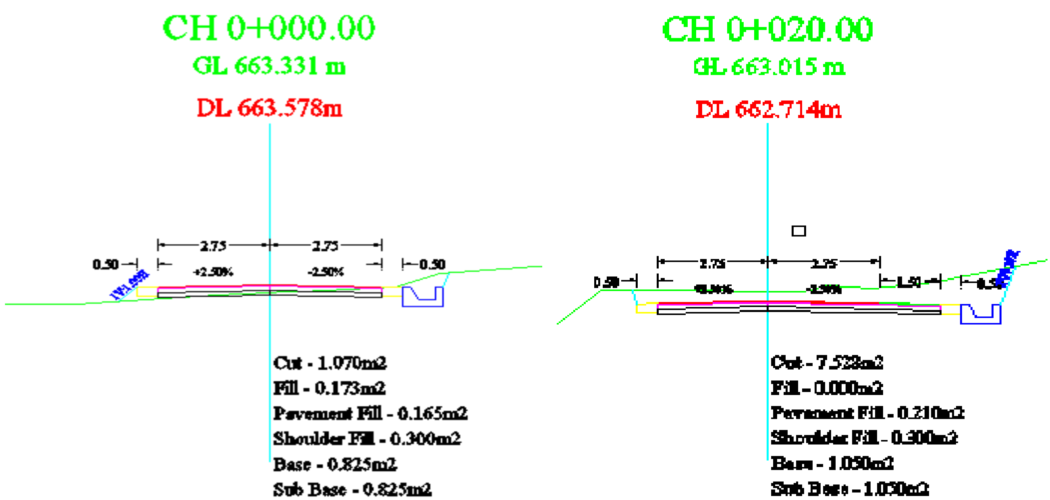


Fig 65: Cross Section Plotting

6.12 Errors in Leveling – Instrumental Error, Personal Error, Natural Error

Errors in levelling may be of following types:

i) Instrumental Errors

Instrumental errors arise due to several factors which are given below:

1. Imperfect Adjustment of the Level

In a perfectly adjusted level, the line of collimation remains horizontal when the bubble in the level tube is centered. However, if the level is not properly adjusted, the line of collimation may become inclined, either upward or downward. This results in observed readings being either too high or too low.

These errors can be compensated for by ensuring that the back sight and fore sight distances are equal, as in the process of fly-levelling. However, in cases involving intermediate sights, where the distances vary significantly, the readings are thrown off by different amounts. On steep slopes, where the back-sight distances are usually longer or shorter than the fore sight distances, these errors accumulate, leading to even greater inaccuracies.

Errors resulting from improper adjustment are both common and significant. Therefore, it is crucial to regularly test and adjust the level before each use. Additionally, care should be taken to ensure that the back sight and fore sight distances remain equal during the levelling process.

2. Imperfect Adjustment of the Level

A defective level tube can introduce significant errors into levelling work. If the bubble within the tube is sluggish, it may stay centered even when the bubble axis is not truly horizontal, leading to inaccurate readings. Conversely, if the bubble is overly sensitive, a great deal of time may be required to accurately center it.

Another potential issue is irregular curvature in the tube, which can cause similar inaccuracies. Fortunately, the impact of a defective level tube can be minimized if the back sight and fore sight distances are kept equal, as this helps neutralize the error.

3. Shaky Tripod

A shaky tripod can cause the instrument to become unstable, leading to inaccurate readings and wasted time while attempting to make precise observations. To prevent this, it is essential to ensure that every bolt, nut, and screw on the tripod, including the screws of the foot shoes, is properly tightened before starting any observations.

A simple method to check the stability of the tripod is to twist one of its legs after taking a staff reading and then release it. If the reading changes after releasing the leg, this indicates that the tripod is unstable and adjustments should be made.

4. Incorrect Graduations of the Staff

Errors can arise if the graduations on a staff are not accurate. In routine levelling, this error is often negligible, as readings are typically recorded with a precision of around 0.005 m. However, for precise levelling applications, it is crucial to ensure the accuracy of the graduations. This can be achieved by comparing the staff graduations against an invar tape using magnification to identify any discrepancies.

ii) Personal Errors

Personal errors arise from the mistakes made by the surveyor during the levelling process and include the following:

1. Sighting Errors

Sighting errors occur when it becomes difficult to align the crosshairs with the staff graduations accurately. This may be due to factors like excessive distance between the instrument and the staff , the thickness of the crosshairs, or poor visibility conditions. Atmospheric factors such as haze or glare can also contribute to this issue. These errors are often accidental and can offset each other, making them compensatory in nature.

2. Errors in Manipulation

Manipulation errors occur due to improper handling or use of the levelling instrument. The following are common causes of such errors:

a) Careless Setup of the Instrument

The levelling instrument must be set up on stable ground and carefully adjusted to ensure accuracy. Once the instrument is in position, neither the telescope nor the tripod should be touched during the observation process, as any movement can lead to errors.

b) Imperfect Focusing of the Eyepiece and Objective

To prevent focusing errors, the eyepiece should be adjusted until the crosshairs are sharp and clear against a white background. Additionally, parallax (the apparent shift of the crosshairs relative to the staff) must be eliminated by properly focusing the objective lens before each reading.

c) Bubble Not Centered During Reading

The leveling bubble must be exactly centered before taking any readings. When the bubble is centered, the vertical axis of the instrument is properly aligned, making the telescope's horizontal axis truly horizontal. If the bubble is off-center, the horizontal axis tilts, leading to inaccurate staff readings. This error becomes more significant over long distances. To prevent this, the surveyor should develop the habit of checking the bubble's position both before and after taking each reading.

d) Non-Verticality of the Staff

When a staff is not held perfectly vertical, it can result in inaccurate readings. This issue is especially common if there is no plumb bob attached to ensure proper alignment. When the staff tilts, the readings tend to be larger than the true value. The degree of error increases with the length of the staff, making the verticality check more critical for larger readings.

- **Impact of Inclination**

  If the staff is inclined, the reading will be exaggerated. The greater the angle of tilt, the larger the error, especially for higher readings. For smaller readings, the error is less noticeable. Therefore, it is essential to ensure the staff is vertical, particularly when dealing with large readings. The staff person can be instructed to slightly move the staff forward or backward until the minimum reading is observed.

- **Checking Verticality**

  The non-verticality of the staff in the transverse direction (perpendicular to the line of sight) can be checked using two vertical crosshairs on the instrument. If the staff is not vertical in this direction, the horizontal crosshair will not align parallel to the graduations on the staff.

  When the staff is not held vertically, the error in the reading can be calculated using the following formula:

  $\text{Error} = AB\ (\sec\theta - 1)$

  where AB is the true vertical distance and θ is the angle of tilt. The greater the tilt angle, the larger the error in the reading.

3. Errors in Reading the Staff

Staff reading errors often occur due to inexperience, particularly among beginners. Common mistakes include:

a) Reading the Staff Upwards Instead of Downwards

The correct way to read the staff is from the bottom to the top, but beginners sometimes mistakenly read it in reverse, leading to incorrect measurements.

b) **Reading the Top or Bottom Hair Instead of the Central Hair**

The central crosshair should be used for readings, but confusion may arise, causing the observer to read against the top or bottom hair instead.

c) **Misreading the Whole Metre**

Sometimes, attention is focused too much on the decimal part of the reading, causing an incorrect interpretation of the whole metre value.

d) **Misreading an Inverted Staff**

If the staff is inverted (for example, during overhead readings) and is mistakenly read as if it were held vertically, it leads to significant errors in measurement.

4. Errors in Recording and Computation

Errors in recording and computation are often due to mistakes in entering or processing data. Common errors include:

a) **Incorrect Column Entry**

This happens when a foresight (F.S.) reading is mistakenly recorded in the intermediate sight (I.S.) or back sight (B.S.) column, or vice versa.

b) **Digit Interchange**

Sometimes, digits are accidentally swapped during recording, such as writing 1.239 instead of 1.932.

c) **Omitting an Entry**

Missing a reading entry can lead to gaps in the data, causing inaccuracies in the levelling calculations.

d) **Mishearing or Mis recording the Reading**

Errors may occur when the numerical value called out by the level operator is recorded incorrectly.

e) **Omitting the Minus Sign for Inverted Staff Readings**

If the staff is inverted during overhead readings, the negative sign must be included. Forgetting this leads to incorrect results.

f) **Incorrect Arithmetic**

Mistakes in basic arithmetic, such as adding a foresight (F.S.) reading instead of subtracting it, or subtracting a back sight (B.S.) reading instead of adding it, can significantly impact the final calculations.

iii) Errors Due to Natural Causes

Errors due to natural causes arise from environmental factors affecting levelling accuracy. These include:

1. Errors Due to Curvature

The curvature of the Earth's surface causes the observed staff readings to be slightly higher than they would be on a perfectly flat surface. This is because the line of sight is straight, while the Earth's surface is curved, resulting in a slight lowering of the station's elevation relative to the observer.

- **Effect of Curvature**

  The error due to curvature increases with the square of the horizontal distance between the staff position and the observation point. This effect is typically small in ordinary levelling (e.g., only 0.003 meters for a sight length of 300 meters), but it should still be corrected for greater accuracy.

- **Curvature Correction Formula**

  To correct for curvature, the following formula is

  Curvature Correction (Cc) = $d^2 / (2R)$

Where:

–d = horizontal distance between the staff and the level

– R = radius of the Earth (approximately 6,370 km)

Approximation:

Cc = 0.0785 * d2 (in meters, where d is in kilometers)

2. Errors Due to Refraction

Refraction impacts observed readings in a manner opposite to that of curvature. While curvature lowers the elevation of the station, refraction raises it. The error introduced by refraction is directly proportional to the square of the horizontal distance between the level and the station. For short distances, this error is negligible and is often disregarded in routine leveling.

However, refraction occurs because the line of sight, when passing through layers of air with varying densities, bends toward the Earth. This bending causes points to appear higher than their actual positions. Under normal atmospheric conditions, the effect of refraction can be approximated as an arc with a radius seven times that of the Earth. The refraction correction is always added to the staff readings, and its magnitude is 1/7th of the curvature effect, but in the opposite direction.

To calculate the correction for refraction, the following formula is used:

$$Cr = (1/7) * (d^2 / 2R) = 0.0112 * d^2$$

where d is the distance in kilometers.

The combined correction for both curvature and refraction is given by:

$$\text{Combined correction} = (6 * d^2) / (7 * 2R) = 0.0673 * d^2$$

For practical purposes, this error is typically small enough to be ignored over short distances. However, to minimize its impact over longer distances, the error can be reduced by balancing back sight and fore sight distances or using the method of reciprocal leveling.

3. Errors Due to Wind and Sun

Strong winds make it challenging to maintain the staff in a perfectly vertical position, leading to errors in observed readings due to the staff's non-verticality. Additionally, the wind can cause vibrations in the instrument, preventing the bubble in the level tube from staying centered. During high winds, it is advisable to pause the work, use an umbrella to shield the level, and aim to keep the staff readings minimal to reduce potential errors.

Sunlight can also interfere with the process, particularly when it shines directly on the objective glass of the instrument. To mitigate this, it is recommended to protect the instrument with an umbrella. Moreover, temperature changes caused by the sun may slightly affect the length of the leveling staff. However, in standard leveling operations, this change in length is generally negligible.

6.13 Numerical Practice

1. Calculate the combined correction for curvature and refraction for a distance of:

(i) 5 km (ii) 500 m.

Solution

(i) 5 km:

Cc = 0.0673 × (5)2 = 1.6825 m

(ii) 500 m:

Cc = 0.0673 × (500/1000)2 = 0.016825 m

2. **In order to find the difference in elevation between two points A and B, a level was set up on the line AB, 50 m from A and 1300 m from B. A and B being on the same side of the instrument. The readings obtained on staff held at A and B were 0.435 m and 3.950 m, respectively. Find the true difference in elevation between A and B.**

Solution

The curvature and refraction corrections are applied only if the observations are taken for a length greater than 200 m. Therefore, corrections are not applied to the staff reading at A.

The combined correction for curvature and refraction at B = 0.0673 D^2

= 0.0673 $(1.3)^2$ = 0.1137 m.

Hence, corrected staff reading at B = 3.950 – 0.1137

= 3.8363 m

True difference in elevation between B and A is = 3.8363 – 0.435 = 3.40126 m

3. **Reduced level of Bench Mark A - 50.000m**

Reading on staff held at A - 2.435m

Reading on staff held at station point B - 1.650m

Find:

(a) Height of collimation.

(b) Reduced level of station point B.

(c) Rise/fall of B with respect to A.

Solution

(a) Height of collimation = RL of BM A + BS

(HOC) = 50.000 + 2.435

= 52.435m

(b) Reduced level of station point B.

= HOC - FS.

= 52.435 - 1.650

= 50.785 m

(c) Rise/fall of B with respect to A.

= 2.435- 1.65 (Lower staff reading being higher)

= 0.785m,

= with compare to A, the station point B being 0.785m higher.

4. Following observations were taken during a reciprocal levelling. If reduced level P is 140.815 m then, the reduced level of Q is

Instrument near	P	Q
Staff reading at P(in m)	1.824	0.928
Staff reading at Q (in m)	2.748	1.606

Solution

hP=1.824 m; hQ=2.748 m

h′P=0.928 m; h′Q=1.606 m

Correct difference of elevation between P and Q is

$h = (h'Q - h'P) + (hQ - hp)^2$

$=(1.606 - 0.928) \quad +(2.748 - 1.824)^2$

= 0.801 m > 0 and thus Q is at lower elevation than P.

∴ The reduced level of Q = (140.815 - 0.801)

= 140.014 m

5. The following readings were taken with a level and 4 m staff. Draw up a level book page and reduce the levels by the height of instrument method. 0.578 B.M. (= 58.250 m), 0.933, 1.768, 2.450, (2.005 and 0.567) C.P., 1.888, 1.181, (3.679 and 0.612) C.P., 0.705, 1.810.

Solution

The first reading being on a B.M., is a back sight. As the fifth station is a change point, 2.005 is fore sight reading and 0.567 is back sight reading. All the readings between the first and fifth readings are intermediate sight-readings. Similarly, the eighth station being a change point, 3.679 is fore sight reading, 0.612 is back sight reading, and 1.888, 1.181 are intermediate sight readings. The last reading 1.810 is fore sight and 0.705 is intermediate sight-readings. All the readings have been entered in their respective columns in the following table and the levels have been reduced by height of instrument method. In the following computations, the values of B.S., I.S., H.I., etc., for a particular station have been indicated by its number or name.

Section-1

H.I.1 = h1 + B.S.1 = 58.250 + 0.578 = 58.828 m

h2 = H.I.1 – I.S.2 = 58.828 – 0.933 = 57.895 m

h3 = H.I.1 – I.S.3 = 58.828 – 1.768 = 57.060 m

h4 = H.I.1 – I.S.4 = 58.828 – 2.450 = 56.378 m

h5 = H.I.1 – F.S.5 = 58.828 – 2.005 = 56.823 m

Section-2

H.I.5 = h5 + B.S.5 = 56.823 + 0.567 = 57.390 m

h6 = H.I.2 – I.S.6 = 57.390 – 1.888 = 55.502 m

h7 = H.I.2 – I.S.7 = 57.390 – 1.181 = 56.209 m

h8 = H.I.2 – F.S.8 = 57.390 – 3.679 = 53.711 m

Section-3

H.I.8 = h8 + B.S.8 = 53.711 + 0.612 = 54.323 m

h9 = H.I.8 – I.S.9 = 54.323 – 0.705 = 53.618 m

h10 = H.I.8 – F.S.10 = 54.323 – 1.810 = 52.513 m

Additional Check for H.I. Method

Σ [H.I. × (No. of I.S.s + 1)] – Σ I.S. – Σ F.S. = Σ R.L. – First R.L.

= [58.828 × 4 + 57.390 3 + 54.323 × 2] – 8.925 – 7.494

= 557.959 – 58.250

= 499.709 (O.K.)

Station	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
1	0.578			58.828	58.250	B.M.=58.250 m
2		0.933			57.895	
3		1.768			57.060	
4		2.450			56.378	
5	0.567		2.005	57.390	56.823	C.P.
6		1.888			55.502	
7		1.181			56.209	
8	0.612		3.679	54.323	53.711	C.P.
9		0.705			53.618	
10			1.810		52.513	
Σ	1.757	8.925	7.494		557.956	
Check: 1.757 – 7.494 = 52.513 – 58.250 = – 5.737 *(O.K.)*						

1. Learning Process and Support Materials

Following are the learning process of this unit:

-theoretical notes

-presentation

-group work

Exercises

Choose the correct answer from the given alternatives.

1. The formula for calculating R.L. can be given as .....

   a. H.I + F.S   b. H.I-F. S   c. H.I-B. S   d. H. I+B.S

2. If the staff at the station point is not held vertically, the R.L at the observation would be ....

   a. Less than true R.L   b. Greater than true R. L

   c. Equal to the true R. L   d. Two times the true R.L

3. If the R.L of a B.M is 100m and back sight is 1.225m, find the H.I at the station?

   a. 101.225m   b. -101.225m   c. 98.775m   d. -98.775m

4. The combined correction for curvature and refraction can be given as ......

   a. $C = 14d^2/6R$ b. $C = 6d^2/7R$ c. $C = 7d^2/2R$ d. $C = 6d^2/14R$

5. A reference surface above which the elevations of point are determined is ......

   a. Bench mark   b. MSL   c. Datum   d. Level

Write short answer to the following questions.

1. What are the different kinds of bench marks?
2. Compare height of collimation method and rise and fall method.

Write long answer to the following questions.

1. Describe the various sources of errors in levelling.

2. The following staff reading were taken in succession with a level. The instrument was shifted after 3rd, 6th and 8th reading. By the plane of collimation method, calculate the R.L and all the points. R.L of Bench Mark is 500 meters.

   Readings are: 0.365, 1.450, 2.335, 0.855, 2.225, 2.905, 1.275, 0.725, 1.975, 2.305, 2.610, 3.335

3. The following staff reading were taken in succession with a level. The instrument was shifted after 2nd, 4th, 7th and 9th reading. By the plane of collimation method, calculate the R.L and all the points. R.L of Bench Mark is 481.923 meters. Readings are: 0.422, 0.684, 1.285, 0.506, 1.793, 4.462, 2.416, 3.120, 1.517, 1.234, 1.232

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