CHAPTER 02

Linear Measurements

2.1 Introduction

- Measurement of horizontal distance is required in **chain surveying, traverse surveying** etc.
- The main purpose of survey is to plot the map of the area.
- Map is plotted on a horizontal plane and thus distances shown in the map are horizontal projections.

2.2 Methods of Linear Measurements

(a) **Direct method:** The direct methods are employed in field using a tape or a chain.

(b) **Optical method:** In optical methods, the distances are measured indirectly using the principles of optics. The instrument used is called as tacheometer which is a theodolite fitted with stadia diaphragm. The stadia intercept and the vertical angles are measured with the tacheometer and the horizontal distances are computed indirectly.

(c) **Electronic Distance Measurement (EDM) method:** EDM is the most recent development in this field and basically is of two types viz. electro-optical instruments using light waves for measuring the distances and microwave instruments which use microwaves for distance measurements.

2.3 Approximate Methods of Linear Measurements

2.3.1 Pacing

In this, the distance travelled is determined by counting the number of steps made. The distance is obtained by multiplying the number of steps with the average length of the step. Average length of a step of an average man varies from 75 cm to 85 cm.

2.3.2 Passometer

It is a mechanical device which registers the number of steps made. It is similar to a pocket watch and operates automatically due to the motion of the body of a person.

2.3.3 Pedometer

It is similar to passometer but it registers directly the distance travelled and not the number of steps. Now as the length of a step varies from person to person, pedometer has to be adjusted according to the length of the step of the person carrying it.

2.3.4 Odometer

It is a simple device which is attached to the wheel of the bicycle or a vehicle. It records the number of revolutions made by the wheel and distance travelled is equal to the number of revolutions multiplied by the circumference of the wheel.

2.3.5 Measuring Wheel

It consists of a wheel mounted on the lower end of a rod, the upper end of which is being held in the hand. The wheel is traversed along the ground and distance travelled is recorded directly on the dial attached to the wheel.

2.3.6 Speedometer

It measures the instantaneous speed and distance travelled by a vehicle.

2.4 Surveying Chains

- Surveying chain is a simple chain commonly used for measuring distances when the requirement of accuracy is not too high.
- It consists of a number of links made of galvanized iron bent into loops. These links are connected in series by small connecting links. These connecting links in fact provide flexibility to the chain. More details of chain are discussed in chapter 3.

2.5 Some Special Types of Chains

Before the advent of metric units, the following special types of chains were used.

2.5.1 Gunter's Chain

- It is also called as surveyor's chain and is of length 66 feet (= 20.12 m). It is composed of 100 links of 0.66 feet each.
- This length of 66 feet is most convenient when distances are required to be measured in furlongs or miles as:

  1 mile = 8 furlongs = 80 Gunter's chain = 5280 ft.
- This length of 66 feet is also convenient when areas are to be measured in acres as:

  1 acre = 4840 sq. yards = 43560 sq. ft. = $(660)^2$ ft. = $(10 \text{ Gunter's chain})^2$

2.5.2 Engineer's Chain

- It is 100 feet long (= 30.48 m) and consists of 100 links of 1 ft. each (= 0.3048 m).
- At every 10 feet, there is a brass tag of a particular type. The number of notches on the tag indicates the number of 10 segment link. e.g. One notch indicate 10 links, 2 notches indicate 20 links, three notches for 30 links, 4 notches for 40 links.
- The 50 link tag is circular without any notch.

2.5.3 Revenue Chain

It is 33 feet long (= 10.06 m) and consists of 16 links of 33/16 feet (= 62.87 cm) each.

2.6 Chain Corrections

(a) Correction for standardization (b) Correction for slope

2.6.1 Correction for Standardization

- If the actual length of the chain is not equal to the designated length, then the distance measured will not conform to the designated length as given on the chain. Hence, the correction for standardization has to be applied.
- If actual length l is shorter than the designated length l_o, then distance measured will be larger than the correct distance and hence correction will be **negative** or error will be **positive.**
- On the other hand, if actual length l is larger than the designated length l_o, then the distance measured will be smaller and hence correction will be **positive** or error will be **negative.**

Thus, error per chain length $= l_o - l$ ...(2.1)

Total error in measured length L is $(l_0 - l)\left(\frac{L}{l}\right)$ ...(2.2)

Correction per chain length = – error per chain length $= -(l_o - l)$ ...(2.3)

Total correction in measured length L is $-(l_0 - l)\left(\frac{L}{l}\right)$ ...(2.4)

2.6.2 Correction for Slope

Let, L = Sloped distance i.e. distance measured along the slope

D = Horizontal projection of the measured sloped length L

θ = Angle of slope

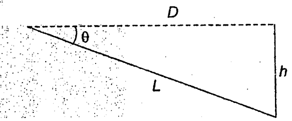

Fig. 2.1 *Measurement on sloping ground*

The slope correction is,
$$C_S = \sqrt{(L^2 - h^2)} - L \approx -h^2/2L \quad ...(2.5)$$

where, h = Difference in elevations of the two ends of the tape

This correction is always **negative.** Usually, slope correction is ignored if angle of slope is less than 30°.

2.7 Measuring Tapes

Depending on the type of material, tapes are classified as:

(a) Cloth or linen tapes (b) Glass-fiber tapes (c) Metallic tapes
(d) Steel tapes (e) Invar tapes

2.7.1 Cloth or Linen Tapes

- These tapes are made of linen or cloth. These types of tapes are very convenient and handy but not very accurate.
- The linen tape consists of 10-15 mm wide long strip wounded on a flat circular disc. One end of the tape is tied to a small spindle made of plastic or metal inside the disc and the other end is free and fitted with a metal key. The tape comes out through a narrow opening in the disc. Provision of handle on the disc facilitates the winding and unwinding of the tape.
- These tapes are available in lengths of **10 m, 20 m, 25 m** and **30 m.**
- **Drawbacks:** They change in length due to shrinkage and stretching. These tapes are also affected by dampness and heat and are also liable to get twist.

- To overcome these limitations, these tapes are coated with plastic that are tougher than the ordinary linen tapes and also they are water resistant.

2.7.2 Glass Fiber Tapes

- These tapes are similar to linen or plastic coated tapes except that these are made of glass fiber. These tapes are very flexible, strong and non-conductive.
- These tapes are quite safe for use in the vicinity of electrical installations.
- They do not shrink or stretch due to temperature changes. Therefore these tapes are more useful than the ordinary linen or cloth tapes.

2.7.3 Metallic Tapes

- These tapes are an improvement over the above two types of tapes.
- These tapes are made of water proof fabric or the glass fiber in which metallic wires are interwoven.
- In general, the strands of copper wires are used as metallic wires but brass or bronze are also sometimes used.
- The provision of metallic wires prevents the excess stretching of the tapes.
- Like linen tapes, these are also attached to a spindle inside a flat circular disc with the other end being provided with a metallic key and coming out from a fine slit in the disc.
- **Advantages:** These tapes are comparatively more durable than the linen tapes, but these are also prone to temperature variations and dampness.

2.7.4 Steel Tapes

- Steel tapes are more accurate than the linen tapes and are made up of steel or stainless steel strips. The widths of these tapes vary from 6 mm to 13 mm and even sometimes upto 16 mm.
- The thickness of these tapes is normally 0.15 mm or 0.2 mm or 0.4 mm.

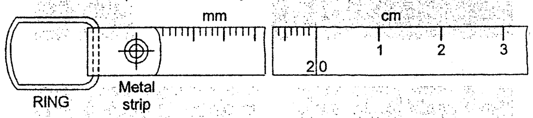

Fig. 2.2 *A typical steel tape*

- The steel tapes are graduated either by engraving the letters on the tape or by the use of paint markings.
- The slit opening in the flat circular disc is provided with rollers on the two sides of the opening which act as bearings for the tape. Similar to linen tapes, handle is also provided here.
- An accuracy of 1 in 2000 can be obtained with these tapes.
- Care is required to protect the tape from corrosion.
- **IS: 1270** provides specifications of these steel tapes.

2.7.5 Invar Tapes

- Invar is an alloy of steel (64%) and nickel (36%) having very low coefficient of thermal expansion. These tapes are generally 6 mm wide and are commercially available in lengths of 20 m, 30 m and 60 m. Invar alloy is very soft and thus must be handled carefully to avoid kinks and bends.
- Due to above reason only, invar tapes are rolled on reels of large diameter to avoid kinks. These tapes are very accurate but are expensive and are liable to break easily.

2.8 Tape Corrections

(a) Correction for standardization
(b) Correction for slope
(c) Correction for pull
(d) Correction for temperature
(e) Correction for sag
(f) Correction for misalignment

2.8.1 Correction for Standardization

This correction is need to be applied when the absolute or the true length of the tape is not equal to the designated or the nominal length of the tape.

Let, l = Designated length of the tape
l' = Actual length of the tape

This correction is **positive** if $l' > l$
and this correction is **negative** if $l' < l$

The correction in the measured length (L) is,

$$C_a = (l' - l)\frac{L}{l} \quad ...(2.6)$$

2.8.2 Correction for Slope

Let, L = Sloped distance i.e. distance measured along the slope
D = Horizontal projection of the measured sloped length L
θ = Angle of slope

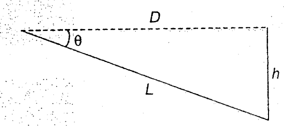

Fig. 2.3 *Correction for slope*

The slope correction is,

$$C_S = \sqrt{(L^2 - h^2)} - L \quad ...(2.7)$$

$$\approx -\frac{h^2}{2L} \quad ...(2.8)$$

where, h = Difference in elevations of the two ends of the tape

This correction is always **negative.**

2.8.3 Correction for Pull

When tension or pull applied at the two ends of the tape, (P) differ from the standard pull/tension (P_o) at which the tape was calibrated, then a correction is need to be applied to the measured length.

When, $P > P_o$ then pull correction is **positive**
And when, $P < P_o$ then pull correction is **negative**

The correction for pull is given by,

$$C_p = (P - P_o)\frac{L}{AE} \quad ...(2.9)$$

where, P = Pull applied for measurement
P_o = Standard pull at which the tape was calibrated
L = Measured length
A = Cross sectional area of the tape
E = Modulus of elasticity of the tape material
$= 2 \times 10^5$ N/mm^2 for steel

2.8.4 Correction for Temperature

If measurement is done at a temperature different from the standard temperature (which is often the actual case), then temperature correction is needed to be applied to the measured length.

Let, L = Measured length

T_o = Standard temperature at which the tape is calibrated

T_m = Mean temperature of the tape during measurement

α = Coefficient of thermal expansion of the tape material

The correction for temperature is given by,

$$C_t = \alpha (T_m - T_o) L \quad ...(2.10)$$

When, $T_m > T_o$ then, correction is **positive**

and when, $T_m < T_o$ then, correction is **negative**

2.8.5 Correction for Sag

When tape is supported at the two ends, then it always sag downwards due to its own weight. Thus apparent length measured is large as compared to the actual length and thus this correction is **negative**.

The sag correction is given by,

$$C_g = \frac{w^2 l_1^3}{24P^2} \quad ...(2.11)$$

where, w = Weight per unit length of the tape

P = Applied pull

l_1 = Length of the tape suspended between the supports

2.8.6 Correction for Misalignment

- This type of error occurs when the survey line is not properly ranged out.
- The measured distance is always greater than the actual distance and hence this correction is always **negative**.
- The correction is computed similar to the way adopted in correction for slope with the only difference that '*h*' here will now be the distance by which line is out from the straight alignment.

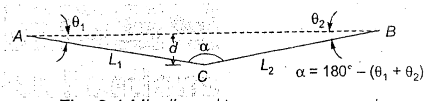

Fig. 2.4 *Misaligned tape measurement*

For Fig. 2.4, the correction due to misalignment is given by,

$$C_m = (L_1 \cos\theta_1 + L_2 \cos\theta_2) - (L_1 + L_2) \quad ...(2.12)$$

2.8.7 Combined Correction

After having the corrections computed for the cases as may be applicable, combined correction is applied to the measured length with individual corrections added algebraically.

2.9 Instruments Used for Linear Measurement

In chain or tape surveying, obviously a tape or a chain is required. But in addition to that, the following instruments and accessories are also required:

(a) Pegs (b) Arrows (c) Ranging rods (d) Offset rods

(e) Plumb bob (f) Clinometer (g) Cross-staff

2.9.1 Pegs

- Pegs are used to mark the survey stations and end points of survey lines on the ground. These pegs are also used to mark the intersection of lines and other such points which are more or less permanent.
- Pegs are generally made of wood (preferably hard timber) with square section and tapers at one end.
- The most common size of these pegs are 25 mm × 25 mm × 150 mm long, 40 mm × 40 mm × 400 mm long.
- The pegs are driven into the ground using a mallet with about 40 mm length projecting above the ground. A nail is driven into the peg to mark the exact location of the station.
- For very hard stratum, instead of wooden pegs, steel dowels are used of about 10 mm diameter.

2.9.2 Arrows

- Arrows are used to mark the position of end of the chain or tape on the ground. These arrows are made of hard tempered steel wire (minimum tensile strength of 700 N/mm²) of 4 mm diameter. Generally 10 arrows are provided with a single chain.
- The arrow is pointed at one end and is provided with a loop at the other end.
- The length of the arrow varies from 250 mm to 500 mm.

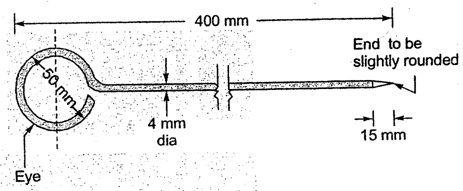

Fig. 2.5 *A typical arrow*

- IS : 1842 specifies the overall length of the arrow as 400 mm with 50 mm diameter loop.
- Uses:
  (a) Arrows are used to have a record of number of chain lengths or the tape lengths already laid while measuring a long survey line.
  (b) In case where the ground surface is hard (like in case of pavements) where it is not possible to dig the arrow in to the ground, in that case, a marking is drawn on the surface and the arrow is kept horizontally on the mark.
- Sometimes **drop arrows** are used which are provided with a ball of heavy metal fitted at the pointed end. When this arrow is dropped on to the ground from a height, it sticks vertically on the ground.

2.9.3 Ranging Rods

- Ranging is the process of locating a number of points on a long survey line.
- For this, ranging rods are used to locate intermediate points such that these points lie on the straight line joining the two end stations.
- Ranging is required generally in case where the length of the chain or the tape is small as compared to distance between the two stations..
- Ranging rods are made from well-seasoned timber with 30 mm nominal diameter.

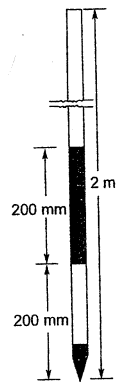

Fig. 2.6 *A typical ranging rod*

- **IS: 2288** specify ranging rod of two lengths viz. small and large. Small ranging rod is of 2 m length with 10 bands of 200 mm each. The large ranging rod is of 3 m length with 15 bands of 200 mm each. These bands are painted alternatively black and white. (or sometimes red and white). This is done to make the rod visible even from a long distance.
- When the distance is very large, then in that case, flags of red and white color (or sometimes yellow and white color) of size 250 mm x 500 mm are used which are tied to the top of ranging rod.
- The bottom of a ranging rod is fitted with a hollow cast iron shoe or a steel sheet shoe so that its end may not wear easily.
- For ranging very long lines, **ranging poles** are used. These are similar to ranging rods but are made of heavier sections and greater lengths. The diameter of ranging poles varies from 60 mm to 100 mm and length from 4 m to 8 m. The foot of the ranging pole must be sunk into the ground to about 500 mm depth to provide lateral stability. In order to check the vertical alignment of the ranging pole, a plumb bob is generally used.

2.9.4 Offset Rods

- These are used to set out offset lines at right angles to the survey lines and also for measuring small offsets.
- It is similar to ranging rod but is provided with two short slots passing through the section of the rod just like in cross staff. These slots are made at right angles to each other.
- The length of the offset rod is usually 3 m and is provided with a pointed iron shoe at one end.
- The offset line is aligned at right angles to the survey line by looking through the two slots.

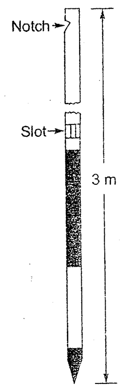

Fig. 2.7 *A typical offset rod*

2.9.5 Plumb Bob

- A freely suspended plumb bob always aligns itself in the direction of gravity and point towards the center of the earth.
- It indicates whether a line is truly vertical or not.
- Plumb bobs are used to place the tape directly over a point when a tape or a chain is suspended over it. These are also used to transfer the point on the tape to the ground (generally in case of sloping ground). In surveying, plumb bob is mainly used for centering the instrument like magnetic compass, theodolite, plane table etc.
- A plumb bob is made up of bronze or brass in the shape of an inverted cone. A hook is provided at the top to attaching a string.
- The weight of the plumb bob varies from 2 N to 5 N. The length of the bob is about 50 mm.

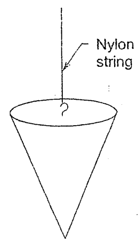

Fig. 2.8 *Plumb bob*

2.9.6 Clinometer

- It is used for measuring the slope of the ground.
- It consists of a graduated protractor with a pin-hole at the eye vane.
- A plumb bob is suspended from the center of the protractor.
- When the ground surface is horizontal, then plumb bob marks zero reading. When the ground surface is sloping, the plumb bob marks the corresponding reading and thus gives the slope of the ground.

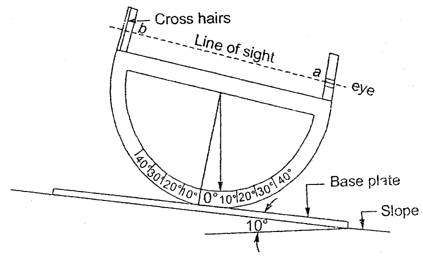

Fig. 2.10 *Clinometer*

2.9.7 Cross Staff

- It is a simple instrument used for setting out the offsets to the chain line from a given point.
- It is also used for setting out a right angle.
- For very high accuracy demanding works, a theodolite is used to lay off right angles to the chain line.

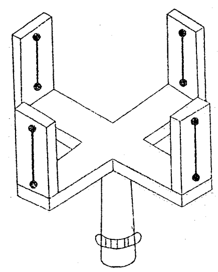

Fig. 2.11 *A typical cross staff*

2.10 Mistakes in Linear Measurements

(a) Misreading

(b) Calling and recording wrong readings

(c) Accidental displacement of arrows

(d) Failure to detect the position of zero mark

(e) Reading the fraction of a length incorrectly

2.11 Degree of Accuracy in Linear Measurements

- The degree of accuracy required in a linear measurement depends upon the purpose and extent of survey.
- Different degrees of accuracy are obtained by different methods as shown Table 2.1.

Table 2.1 : Degree of accuracy of different methods of linear measurement

S. No.	Method of linear measurement	Degree of accuracy	Purpose of survey
1.	Chaining	1/250 to 1/1000	Chain traverse, compass traverse
2.	Steel tape	1/2000 to 1/20000	Triangulation
3.	Invar tape	1/20000 to 1/1000000	Base line measurement in triangulation

Example 2.1 A base line measured with a steel tape was found to be 1050 m. Find the correct length of base line at MSL when the pull at standardization is 20 kg and the applied pull was 28 kg. The cross sectional area of tape is 0.0675 cm^2 and $E = 2 \times 10^6$ kg/cm^2. The temperature while measuring was 35°C and standardization temperature is 25°C. Coefficient of thermal expansion of the tape material

is 12×10^{-6} °C^{-1}. The difference in levels of the two leads of the tape was 2.5 m. Elevation of base line above MSL is 1000 m and radius of earth is 6400 km.

Solution:

Correction for pull,

$$C_P = (P - P_0)\frac{L}{AE} = (28-20)\frac{1050}{0.0675 \times 2 \times 10^6} = 0.0622 \text{ m (+ve)}$$

Correction of temperature,

$$C_t = \alpha(T_m - T_o)L = 12 \times 10^{-6}(35-25)1050 = 0.126 \text{ m (+ve)}$$

Correction for slope,

$$C_s = \frac{h^2}{2L} = \frac{2.5^2}{2 \times 1050} = 0.0029762 \text{ m (–ve)}$$

Correction for MSL,
(More details in Chapter 15)

$$C_R = \frac{h}{R}L = \left(\frac{1000}{6400 \times 1000}\right)1050 = 0.1640625 \text{ m (–ve)}$$

$\therefore$ Total correction $= 0.0622 + 0.126 - 0.0029762 - 0.1640625$
$= 0.0211613 \text{ m} = 0.0212 \text{ m}$

$\therefore$ Corrected base length $= 1050 + 0.0212 = 1050.0212$ m

Objective Brain Teasers

Q.1 Invar is an alloy of
(a) Fe and Ni (b) Ni and Cu
(c) Cu and Pb (d) CO and Fe

Q.2 The most precise method of measuring the horizontal distance is
(a) Chain (b) Tape
(c) EDM (d) Tacheometer

Q.3 Check lines are marked
(a) for plotting the offsets
(b) to check the correctness of survey work
(c) to increase the details in the plan
(d) All of the above

Q.4 Offsets are referred to as
(a) Parallel measurements made w.r.t. survey lines
(b) Measurements that are omitted from survey work
(c) Lines that give more details for the plan
(d) Lateral measurements being made w.r.t the main survey lines

Q.5 Field work required in chain surveying are
(a) angular measurements only
(b) both linear and angular measurements
(c) linear measurements only
(d) Data insufficient

Q.6 Which of the following will give higher accuracy for measuring horizontal distances on rough grounds?
(a) Chain (b) Tape
(c) Tacheometer (d) None of these

Q.7 Correction for temperature in tape
(a) is always greater than zero
(b) is always less than zero
(c) may be greater than or less than zero
(d) is always equal to zero

Q.8 Match List-I with List-II and choose the correct answer

List-I
A. Sag correction
B. Temperature correction
C. Correction for pull
D. Correction for standardization

List-II
1. $(P - P_0)\frac{L}{AE}$
2. $(l' - l)\frac{L}{l}$
3. $\alpha(T - T_0)L$
4. $\frac{w^2 l_1^3}{24P^2}$

Codes:

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

Q.9 If the downhill end of a 20 m tape is held 80 cm too low, then its horizontal length will be
(a) 19.894 (b) 20.016
(c) 19.984 (d) 20.984

Q.10 Highest degree of accuracy is obtained in which of the following?
(a) Tape measurement
(b) Tacheometric measurement
(c) Chain measurement
(d) All of the above

Q.11 Correctness of survey work is indicate by
(a) Chain line
(b) Tie line/check line
(c) Oblique offsets
(d) None of these

Q.12 Points collected by main survey lines are called as
(a) Subsidiary stations
(b) Observation stations
(c) Preliminary stations
(d) Main survey stations

Q.13 Perpendicular to a chain line is set out in the field by
(a) Ranging rod (b) Plumb bob
(c) Clinometer (d) Cross staff

Q.14 Chain surveying is suitable for
(a) Large areas in relatively flat ground
(b) Small areas in relatively flat ground
(c) Mountainous areas
(d) None of these

Q.15 Sag error is
(a) always positive
(b) always negative
(c) may be negative or positive
(d) always zero

Q.16 The pull required in chain which nullifies the sag effect is called as
(a) standard tension (b) tension
(c) normal tension (d) nominal tension

Q.17 Pick out the correct statement
(a) Glass fiber tape is made from woven glass fiber and brass wires
(b) Invar is an allow of steel (64%) and Ni (36%)
(c) Steel tapes are less accurate than lines tapes
(d) None of above

Q.18 Slope correction is given by
(a) $-\frac{h}{2L}$ (b) $+\frac{h^2}{2L}$
(c) $-\frac{h^2}{2L}$ (d) $+\frac{h^2}{2L^2}$

Answers

1. (a)	2. (c)	3. (b)	4. (d)	5. (c)
6. (c)	7. (c)	8. (b)	9. (c)	10. (b)
11. (b)	12. (d)	13. (d)	14. (b)	15. (a)
16. (c)	17. (b)	18. (c)		

Student's Assignments

Ex.1 A 100 m tape is suspended between two ends under a pull of 165 N. The weight of the tape is 25 N. What is the correct distance between the two ends.

Ans. 99.904 m

Ex.2 The down hill end of a 20 m tape is held 80 cm too low. What is the correct horizontal distance?

Ans. 19.984 m

■■■■