100 meter (or any suitable value) and we need to construct our plinth in such a way that when we take reading on it we get R.L. of 102 meter.

7.6 METHODS OF BOOKING AND REDUCING LEVELS

There are two methods of booking and reducing the elevation of points from the observed staff readings:

(1) Height of instrument method

(2) Rise and fall method

(i) Height of instrument method: Above explained procedure of levelling is known as 'Height of instrument method'. Firstly we take a back sight on the station (B.M.) whose elevation is known to us. By adding this back sight to the R.L. of B.M. we get height of instrument. After then all other readings taken from that instrument set up are subtracted from the height of instrument to compute their respective reduced levels. The last reading taken on the turning point is fore sight whereas the other readings are intermediate sights. For the next instrument set up a back sight is taken on the turning point and added to the R.L. of the turning point to get the height of instrument of next set up. Further the remaining intermediates sights (if any) and fore sight are subtracted to get the reduced level and this process continues till we reach to the last station. A 'Level field book' is used to record and compute the reduced levels.

Let us take a problem to understand the recording and computing of levels by height of instrument method. Assuming the following readings are taken by a level: 1.635, 1.955, 2.620, 2.225, 1.670, 0.955, 1.230, 1.475, 2.225, 0.865, 2.005 and 1.770. The position of the level was changed after (say) third, fifth and ninth reading. Also let us assume that the first reading is taken on a benchmark with level 211.805 meter. We need to compute the reduced levels of all the stations by height of instrument method. As the level has been shifted three times during levelling so there are four level positions. Reading taken from the different level positions can be grouped as under:

From level position 1: 1.635, 1.955 and 2.620

From level position 2: 2.225 and 1.670

From level position 3: 0.955, 1.230, 1.475 and 2.225

From level position 4: 0.865, 2.005 and 1.770

By definition the first readings are back sights, last readings are fore sights and rest are (if any) intermediate sights. When we record the readings into a level field book we need to assess the correct number of stations. As we know that at every turning point there are two readings, one fore sight from the previous instrument set up and one back sight from the current instrument set up so for every turning point (or instrument shifting) the station remains single with two readings at it. So with this simple definition logic we can conclude that when we subtract the turning points or instrument shifting from total number of readings we get the required number of stations. We can create the formula for this as under:

Total number of stations = Number of readings – number of times instrument shifted ...(7

Using the equation 30 we can calculate the number of stations in the current problem as

Total number of stations = 12 − 3 = 9

Stations third, fifth and seventh are turning points, so there will two readings (F.S. and B.S.) on these stations. Station-wise we can write the readings as follows:

Reading taken at station 1: 1.635 (BS)

Reading taken at station 2: 1.955 (IS)

Reading taken at station 3: 2.620 (FS) and 2.225 (BS)

Reading taken at station 4: 1.670 (FS) and 0.955 (BS)

Reading taken at station 5: 1.230 (IS)

Reading taken at station 6: 1.475 (IS)

Reading taken at station 7: 2.225 (FS) and 0.865 (BS)

Reading taken at station 8: 2.005 (IS)

Reading taken at station 9: 1.770 (FS)

Now as explained in the 'procedure of levelling' above we will calculate the reduced levels of all stations as follows:

Height of instrument for level position 1 = 211.805 + 1.635 = 213.440 m

Reduced level of station 2 = 211.805 − 1.955

= 211.485 m

Reduced level of station 3 = 211.805 − 2.620

= 210.820 m

Now instrument is shifted so height of instrument will be calculated.

Height of instrument for level position 2 = 210.820 + 2.225 = 213.045 m

Reduced level of station 4 = 213.045 − 1.670

= 211.375 m

Again instrument is shifted so,

Height of instrument for level position 3

= 211.375 + 0.955 = 211.375 m

Reduced level of station 5 = 211.375 − 1.230

= 211.100 m

Reduced level of station 6 = 211.375 − 1.475

= 210.855 m

Reduced level of station 7 = 211.375 − 2.225

= 210.105 m

Now instrument is shifted for its final position so

Height of instrument for level position 4 $= 210.105 + 0.865 = 210.105$ m

Reduced level of station 8 $= 210.105 - 2.005$

$= 208.965$ m

Reduced level of station 9 $= 210.105 - 1.770$

$= 209.200$ m

So the reduced level of the last station. i.e., station 9 has been calculated. The best part in both the computing methods is that there is an arithmetic check after all calculations for the ensuring of correct calculations. The check for height of instrument is

$$\Sigma \text{B.S.} - \Sigma \text{ F.S.} = \text{Last R.L.} - \text{First R.L} \qquad \text{....(31)}$$

For the current problem

$$\Sigma \text{B.S.} = 1.635 + 2.225 + 0.955 + 0.865 = 5.680 \text{ m}$$

$$\Sigma \text{F.S.} = 2.620 + 1.670 + 2.225 = 8.285 \text{ m}$$

So $\Sigma \text{B.S.} - \Sigma \text{F.S.} = 5.680 - 8.285 = 2.605$ m

Also Last R.L. – First R.L. $= 209.200 - 211.805$

$= 2.605$ m

As ΣB.S. – ΣF.S. = Last R.L. – First R.L. so we can be ensured that no calculation mistake has been done by us.

All the above calculation is tabulated in a level field book. In the following table the recording and computation of reduced levels by height of instrument method is shown.

Station	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
1.	1.635			213.440	211.805	Benchmark
2.		1.955			211.485	
3.	2.225		2.620	213.045	210.820	Turning point 1
4.	0.955		1.670	212.330	211.375	Turning point 2
5.		1.230			211.100	
6.		1.475			210.855	
7.	0.865		2.225	210.970	210.105	Turning point 3
8.		2.005			208.965	
9.			1.770		209.200	
	Σ B.S. = 5.680		Σ F.S. = 8.285			

Example 12 : ***The following readings are taken from a level: 1.885, 2.770, 1.585, 1.985, 2.115, 1.660, 0.985, 1.110, 0.765, 0.885 and 1.005. Instrument is shifted once after sixth reading.***

Enter the above reading in a level field book and compute the reduced level of all stations using height of instrument method. The first reading was taken when a staff was held at a benchmark of 101.500 meter.

Solution : The problem will be solved by height of instrument method as explained above. Number of stations will be = 11 – 1 = 10. The calculation is tabulated as follows:

Station	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
1.	1.885			103.385	101.500	Bench mark
2.		2.770			100.615	
3.		1.585			101.800	
4.		1.985			101.400	
5.		2.115			101.270	
6.	0.985		1.660	102.710	101.725	Turning point 1
7.		1.110			101.600	
8.		0.765			101.945	
9.		0.885			101.825	
10.			1.005		101.705	
	Σ B.S. = 2.870		Σ F.S. = 2.665			

$$\Sigma \text{ B.S.} - \Sigma \text{ F.S.} = 2.870 - 2.665 = 0.205 \text{ m}$$

Also Last R.L. – First R.L. = 101.705 – 101.500 = 0.205 m

As Σ B.S. – Σ F.S. = Last R.L. – First R.L. (checked)

Example 13 : ***The following readings are taken on an undulating ground: 1.555, 2.025, 1.955, 0.725, 0.925, 1.110, 1.755, 2.100, 2.205, 1.995 and 2.315. Instrument is shifted after second, fourth, seventh and ninth reading.***

Enter the above reading in a level field book and compute the reduced level of all stations using height of instrument method. The first reading was taken when a staff was held at a benchmark of 92.75 meter.

Solution : Number of stations will be calculated by using equation 28.

Station	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
1.	1.555			94.305	92.750	Benchmark
2.	1.955		2.025	94.235	92.280	Turning point 1
3.	0.925		0.725	94.435	93.510	Turning point 2
4.		1.110			93.325	
5.	2.100		1.755	94.780	92.680	Turning point 3
6.	1.995		2.205	94.570	92.575	Turning point 4
7.			2.315		92.255	
	Σ B.S. = 8.530		Σ F.S. = 9.025			

Number of stations = 11 – 4 =7

The calculation is tabulated as follows:

$$\Sigma \text{ B.S.} - \Sigma \text{ F.S.} = 8.530 - 9.025 = -0.495 \text{ m}$$

Also Last R.L. – First R.L. = 92.255 – 92.750

= – 0.495 m

As Σ B.S. – Σ F.S. = Last R.L. – First R.L. (checked)

(ii) Rise and fall method: In rise and fall method, we do not calculate height of instrument instead we use to calculate the difference in two consecutive readings and determine whether the station is above or below the previous station. If the R.L. of the previous station is known we can calculate the R.L. of next station. Let us first understand the concept of the rise or fall.

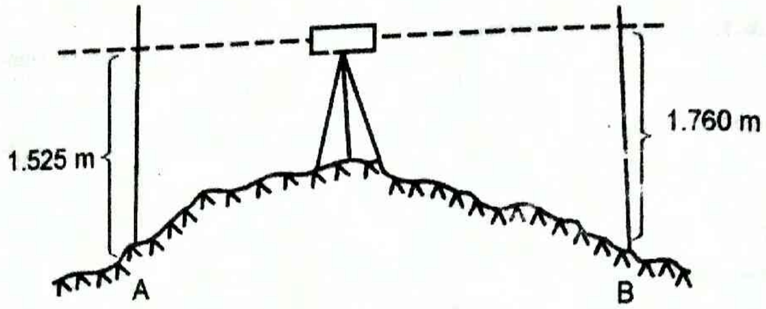

Fig. 54

For an instrument set up we have seen that the line of sight becomes fixed for all the readings taken from it. As shown in figure 54 level is set up. Its horizontal line of sight is shown as dotted lines. Now there are two stations A and B. Let the reading of A is 1.525 m and reading of B is 1.760 m. As the line of sight is same for both the readings, if we compare two readings, the station will be higher than the other if its reading is less than the reading of other station. In this case reading of station A is less than the reading of station B, so we can conclude that station A is higher in elevation than station B. This is evident in figure 54 too, where station A is higher in elevation than station B.

In rise and fall method, we subtract the consecutive readings, like reading 2 from reading 1, reading 3 from reading 2 and so on. The readings must be taken from the same instrument set up. If the difference comes negative that means the next station is lower than the previous one and it will be termed as fall. Similarly, if the difference comes positive that means the next station is higher than the previous one and it will be termed as rise.

Let us take an example to understand this. Assuming the following readings are taken by a level: 2.125, 2.225, 1.635, 0.885, 1.825, 1.425, 1.745, 1.285, 1.725, 1.005, 0.830, 1.365 and 0.955. The position of the level was changed after (say) third, fifth, ninth and eleventh reading. Also let us assume that the first reading is taken at a benchmark with level 117.635m. We need to compute the reduced levels of all the stations by rise and fall method. As the level has been shifted four times during levelling so there are five level positions. Reading taken from the different level positions can be grouped as under:

From level position 1: 2.125, 2.225 and 1.635

From level position 2: 0.885 and 1.825

From level position 3: 1.425, 1.745, 1.285 and 1.725

From level position 4: 1.005 and 0.830

From level position 5: 1.365 and 0.955

Now, consecutive readings of same level position will be subtracted and depending on the value computed as positive or negative and rise or fall will be marked. The calculation is as follows:

2.125 – 2.225 = – 0.100 = 0.100 m (Fall)

2.225 – 1.635 = 0.590 m (Rise)

0.885 – 1.825 = – 0.940 = 0.940 m (Fall)

1.425 – 1.745 = – 0.320 = 0.320 m (Fall)

1.745 – 1.285 = 0.460 m (Rise)

1.285 – 1.725 = – 0.440 = 0.440 m (Fall)

1.005 – 0.830 = 0.175 m (Rise)

1.365 – 0.955 = 0.410 m (Rise)

Now, as we have the R.L. of first point we can calculate the R.L. of all other stations. If there is a rise then it will be added to the R.L. and if it is a fall then it will be subtracted from R.L. The calculation of reduced levels of all stations is as follows:

R.L of station 2 = 117.635 – 0.100 = 117.535 m

R.L of station 3 = 117.535 + 0.590 = 118.125 m

R.L of station 4 = 118.125 – 0.940 = 117.185 m

R.L of station 5 = 117.185 – 0.320 = 116.865 m

R.L of station 6 = 116.865 + 0.460 = 117.325 m

R.L of station 7 = 117.325 – 0.440 = 116.885 m

R.L of station 8 = 116.885 + 0.175 = 117.060 m

R.L of station 9 = 117.060 + 0.410 = 117.470 m

Like this we have calculated the reduced levels of all stations. Rise and fall method has an arithmetic check which is :

$$\Sigma \text{ B.S.} - \Sigma \text{ F.S.} = \Sigma \text{ Rise} - \Sigma \text{ Fall} = \text{Last R.L.} - \text{First R.L.} \quad \ldots(32)$$

For the current problem

$$\Sigma \text{ B.S.} = 2.125 + 0.885 + 1.425 + 1.005 + 1.365 = 6.805 \text{ m}$$

$$\Sigma \text{ F.S.} = 1.635 + 1.825 + 1.725 + 0.830 + 0.955 = 6.970 \text{ m}$$

So

$$\Sigma \text{ B.S.} - \Sigma \text{ F.S.} = 6.805 - 6.970 = 0.165 \text{ m}$$

$$\Sigma \text{ Rise} - \Sigma \text{ Fall} = 1.635 - 1.800 = 0.165 \text{ m}$$

and

$$\text{Last R.L.} - \text{First R.L.} = 117.470 - 117.635 = 0.165 \text{ m}$$

As Σ B.S. – Σ F.S. = Σ Rise – Σ Fall = Last R.L. – First R.L. so we can be ensured that no calculation mistake has been done by us. The recording of readings and calculation of rise and fall and thus calculation of levels in tabulated form is as under:

Station	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
1.	2.125					117.635
2.		2.225			0.100	117.535
3.	0.885		1.635	0.590		118.125
4.	1.425		1.825		0.940	117.185
5.		1.745			0.320	116.865
6.		1.285		0.460		117.325
7.	1.005		1.725		0.440	116.885
8.	1.365		0.830	0.175		117.060
9.			0.955	0.410		117.470
	Σ B.S. = 6.805		Σ F.S.= 6.970	Σ Rise = 1.635	Σ Fall = 1.800	

Example 14 : *The following readings are taken with help of a levelling instrument: 0.775, 1.505, 1.225, 1.445, 1.775, 1.005, 1.695, 0.835, 1.445, 1.215, 2.110, 1.950 and 1.735. Instrument is shifted after third, fifth, seventh and eleventh reading.*

Enter the above reading in a level field book and compute the reduced level of all stations using rise and fall method. The first reading was taken when a staff was held at a benchmark of 77.855 m.

Solution : Number of station can be calculated by using equation 30. So numbers of stations are = 13 – 4 = 9. The calculation is tabulated as follows:

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remark
1.	0.775					77.855	Benchmark
2.		1.505			0.730	77.125	
3.	1.445		1.225	0.280		77.405	Turning point 1
4.	1.005		1.775		0.330	77.075	Turning point 2
5.	0.835		1.695		0.690	76.385	Turning point 3
6.		1.445			0.610	75.775	
7.		1.215		0.230		76.005	
8.	1.950		2.110		0.895	75.110	Turning point 4
9.			1.735	0.215		75.325	
	Σ B.S. = 6.010		Σ F.S. = 8.540	Σ Rise = 0.725	Σ Fall = 3.255		

$$\Sigma \text{ B.S.} - \Sigma \text{ F.S.} = 6.010 - 8.540 = 2.530 \text{ m}$$

$$\Sigma \text{ Rise} - \Sigma \text{ Fall} = 0.725 - 3.255 = 2.530 \text{ m}$$

and

$$\text{Last R.L.} - \text{First R.L.} = 75.325 - 77.855 = 2.530 \text{ m}$$

As

$$\Sigma \text{ B.S.} - \Sigma \text{ F.S.} = \Sigma \text{ Rise} - \Sigma \text{ Fall} = \text{Last R.L.} - \text{First R.L.} \text{ (checked)}$$

Example 15 : ***The following readings are taken with help of a levelling instrument: 1.555, 2.225, 2.115, 2.435, 1.995, 1.755, 2.565, 2.010, 1.425, 1.655, 0.985 and 0.875. Instrument is shifted after seventh reading.***

Enter the above reading in a level field book and compute the reduced level of all stations using rise and fall method. The first reading was taken when a staff was held at a benchmark of 125.440 m.

Solution : Number of station are = 12 – 1 = 11. The calculation of rise and fall and then of reduced level is as shown:

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remark
1.	1.555					125.440	Benchmark
2.		2.225			0.670	124.770	
3.		2.115		0.110		124.880	
4.		2.435			0.320	124.560	
5.		1.995		0.440		125.000	
6.		1.755		0.240		125.240	
7.	2.010		2.565		0.810	124.430	Turning point 1
8.		1.425		0.585		125.015	
9.		1.655			0.230	124.785	
10.		0.985		0.670		125.455	
11.			0.875	0.110		125.565	
	Σ B.S. = 3.565		Σ F.S. = 3.440	Σ Rise = 2.155	Σ Fall = 2.030		

$$\Sigma \text{ B.S.} - \Sigma \text{ F.S.} = 3.565 - 3.440 = 0.125 \text{ m}$$

$$\Sigma \text{ Rise} - \Sigma \text{ Fall} = 2.155 - 2.030 = 0.125 \text{ m}$$

and $$\text{Last R.L.} - \text{First R.L.} = 125.565 - 125.440 = 0.125 \text{ m}$$

As $$\Sigma \text{ B.S.} - \Sigma \text{ F.S.} = \Sigma \text{ Rise} - \Sigma \text{ Fall} = \text{Last R.L.} - \text{First R.L. (checked)}$$

(iii) Comparison between the height of instrument method and rise and fall method:

Height of instrument method is considered to be more rapid, less tedious and simple. Height of instrument is best suited when instrument is not moved much, as the once calculated height of instrument can be used for computing reduced levels of many stations. Rise and fall method in such cases proves to be a better method. Also the disadvantage in height of instrument method is that it does not provide any check on intermediate sights whereas rise and fall method provides full check on calculation of all sights. So in height of instrument method, if there is any mistake in level, it may remain unnoticed.

8. TOTAL STATION

Total station is the most widely used surveying instrument in modern era. The total station is an electronic theodolite (transit) integrated with an Electronic Distance Meter (EDM), plus internal data storage and/or external data collector. It is also integrated with microprocessor, electronic data collector and storage system. Figure 55 shows the parts of a total station whereas figure 56 and figure 57 shows the front and rear view of a total station.

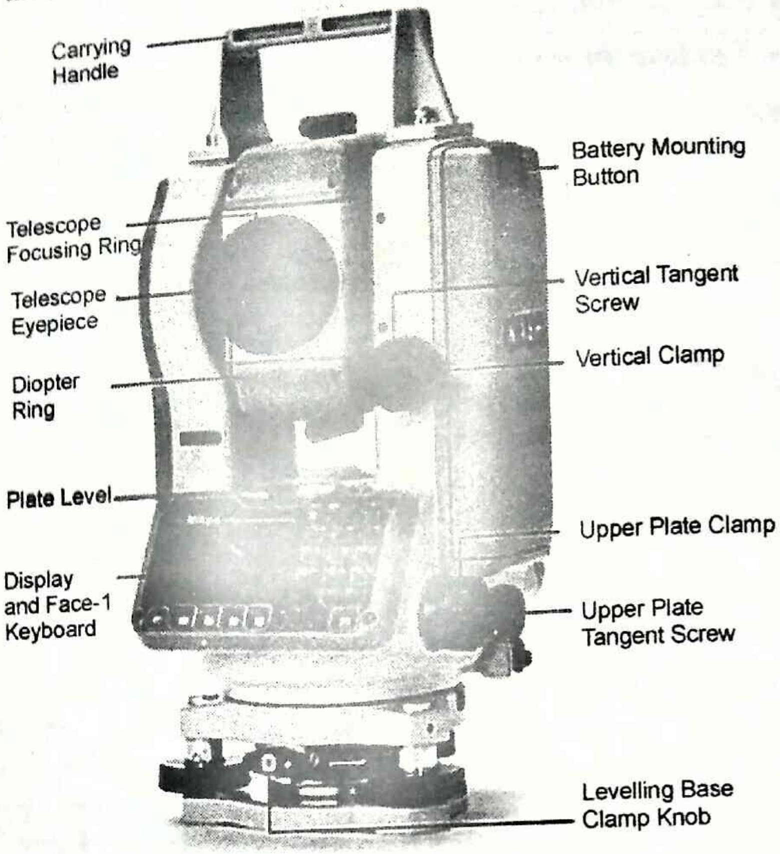

Fig. 55

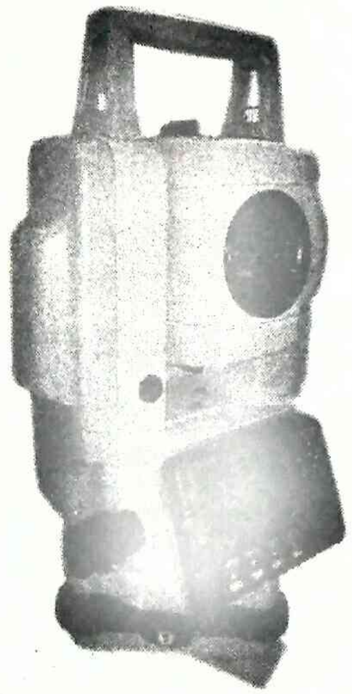

Fig. 56

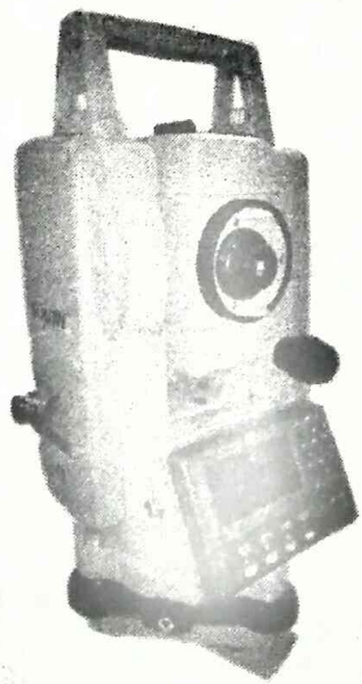

Fig. 57

The total station is designed for measuring of slant distances, horizontal and vertical angles and elevations in topographic and geodetic works, tachometric surveys, as well as for solution of application geodetic tasks. Angles and distances are measured from the total station to points under survey, and the coordinates (X, Y, and Z or northing, easting and elevation) of surveyed points relative to the total station position are calculated using trigonometry and triangulation. The measurement results can be recorded into the internal memory and transferred to a personal computer interface with help of data cable. Application software is then used to compute results and generate a map of the surveyed area. Total station can also be used by archaeologists to record excavations as well as by police, crime scene investigators, private accident re-constructionists and insurance companies to take measurements of scenes.

Microprocessor unit in total station processes the data collected to compute the following:

(1) Average of multiple angles measured

(2) Average of multiple distance measured

(3) Horizontal distance

(4) Distance between two points

(5) Elevation of objects

(6) All the three coordinates of the observed points

8.1 Important Operations of Total Station

(i) **Distance Measurement:** Electronic distance meter consists as the major part of a total station. Range of EDM varies from 2.8 km to 4.2 km. The accuracy of measurement varies from 5 mm to 10 mm per kilometer for linear measurement and 1" to 20" for angular measurement. The distance measured is always sloping distance from instrument to the object. For measurement of horizontal angles any convenient direction may be taken as reference direction whereas for vertical angle measurement zenith direction is taken as reference direction.

(ii) **Data Processing:** Total station is provided with an inbuilt microprocessor. The microprocessor averages multiple observations. When we provide instrument as well as target height from ground, with help of slope distance and horizontal and vertical angles the microprocessor computes the coordinates. The processor is capable of applying temperature and pressure corrections to the measurements, if atmospheric temperature and pressures are supplied.

(iii) **Display:** Electronic display unit is capable of displaying various values when respective keys are pressed. The system is capable of displaying horizontal distance, vertical distance, horizontal angle, vertical angle, difference in elevations of two observed points and all the three coordinates of the observed points.

(iv) **Electronic Book:** Total station has the capability of saving point data. The capacity of electronic note book varies from 2000 to 4000 point data. The data can be downloaded to computer and the note book can be reused to store more data.

8.2 Accessories for Total Station

Following are the required accessories for total station:

(i) Tripods

(ii) Prisms

(iii) Prism poles

(iv) Batteries and chargers

(v) Tribraches

(vi) Data and power cable

8.3 WORKING OF TOTAL STATION

The total station instrument is mounted on a tripod and is levelled by operating levelling screws. The small range total station itself can be adjusted to the level position. Horizontal and vertical reference directions are indexed using onboard keys. Required units for measurements can be set using the given options. When we sight the target, horizontal angle, vertical angle and sloping distances are measured and recorded with point number by using the required keys. Height of instrument and height of targets measured by tape can be keyed in. Then processor computes various information about the points and displays on screen. The information is also stored in the electronic notebook. In case if storage of electronic notebook gets full then the information stored can be downloaded to the computer. The point data downloaded to the computer can be used for further processing with the help of various software like AutoCAD.

8.4 ADVANTAGES OF TOTAL STATION

Following are the main advantages of using of total station:

(i) Accuracy of measurement.

(ii) Field work carried out is very fast.

(iii) Manual errors in measurement are eliminated.

(iv) Calculation of coordinates is very fast and accurate.

(v) Corrections for temperature and pressure are automatically made.

(vi) Computers can be employed for map making and plotting contour and cross-sections. Contour intervals and scales can be changed in no time.

QUESTIONS

❑ ANSWER THE FOLLOWING QUESTIONS IN ABOUT 25 WORDS.

1. Define reciprocal ranging.
2. What is a meridian?
3. Define bearing.
4. Differentiate between fore bearing and back bearing.
5. Convert the following whole circle bearings to quadrantal bearings:

   (i) 17°22' (ii) 150°42'

   (iii) 242°51' (iv) 302°33'
6. Convert the following quadrantal bearings to whole circle bearings:

   (i) N38°28'E (ii) S45°47'E

   (iii) S79°18'W (iv) N20°12'W

7. Write the objects of levelling.
8. What is a benchmark? List out various types of benchmark.
9. How many types of staffs are available in levelling?
10. State the conditions when height of instrument method can be preferred over rise and fall method.

❑ ANSWER THE FOLLOWING QUESTIONS IN DETAIL.

1. List out various types of chains used in linear measurement and discuss in detail metric chains.
2. Discuss various types of tapes used in surveying.
3. Describe direct methods of ranging.
4. Explain the methods for measurement on sloping ground.
5. Describe various tape corrections.
6. A 30 meter long tape was used to measure a base line. The chain was standardized at a temperature of 22°C and pull of 22 kg. The tape was used to measure a survey line and the distance was found to be 254.5 m. The pull applied at field was 24 kg and the mean temperature of the day was recorded as 20°C. The area of the cross-section of tape is 0.069 cm^2 and coefficient of thermal expansion is 8.7 x 10^{-6}per °C. If the modulus of elasticity of tape material is 206 kN/mm^2, find the actual distance of the survey line. Take unit weight of steel as 78 kN/m^3. **[0.0048 m (Subtractive)]**
7. Included angles of a pentagon were measured with help of a theodolite. ∠A = 138°22', ∠B = 97°18', ∠C = 58°8' and ∠D = 66°12'. Bearing of line DE was measured as 63°39'. Find the bearing of all other lines.

   [∠A = 176°9', ∠B = 92°39', ∠C = 119°19', ∠D = 141°21', ∠E = 10°32']
8. Discuss various types of levelling instruments with their relative merits and demerits.
9. Explain the process of levelling taking a suitable example.
10. The following readings are taken from a level: 1.770, 2.120, 2.325, 2.565, 1.895, 1.465, 2.005, 1.675, 0.995 and 1.225. Instrument is shifted after third, fifth and eighth reading.

    Enter the above reading in a level field book and compute the reduced level of all stations using height of instrument method. The first reading was taken when a staff was held at a benchmark of 121.11 meter. Apply checks.
11. The following readings are taken from a level: 0.502, 1.335, 1.865, 2.555, 0.305, 0.910, 1.935, 2.875, 0.560, 1.825 and 2.775. Instrument is shifted after second, fourth and ninth reading.

    Enter the above reading in a level field book and compute the reduced level of all stations using rise and fall method. The first reading was taken when a staff was held at a benchmark of 100.00 meter. Apply checks.
12. What is a total station? Explain the working of a total station.

❑❑❑