9

Levelling

9.1. DEFINITIONS (Ref. Fig. 9.1)

Levelling. Levelling is a branch of surveying the object of which is : (1) to find the elevations of given points with respect to a given or assumed datum, and (2) to establish points at a given elevation or at different elevations with respect to a given or assumed datum. The first operation is required to enable the works to be designed while the second operation is required in the setting out of all kinds of engineering works. Levelling deals with measurements in a vertical plane.

Level Surface. A level surface is defined as a curved surface which at each point is perpendicular to the direction of gravity at the point. The surface of a still water is a truly level surface. Any surface parallel to the mean spheroidal surface of the earth is, therefore, a level surface.

Level Line. A level line is a line lying in a level surface. It is, therefore, normal to the plumb line at all points.

Horizontal Plane. Horizontal plane through a point is a plane tangential to the level surface at that point. It is, therefore, perpendicular to the plumb line through the point.

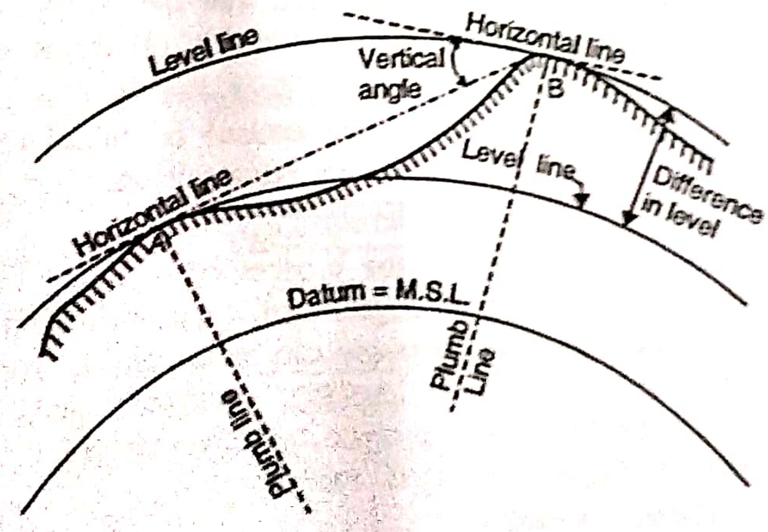


FIG. 9.1

Horizontal Line. It is straight line tangential to the level line at a point. It is also perpendicular to the plumb line.

Vertical Line. It is a line normal to the level line at a point. It is commonly considered to be the line defined by a plumb line.

Datum. Datum is any surface to which elevations are referred. The *mean sea level* affords a convenient datum world over, and elevations are commonly given as so much above or below sea level. It is often more convenient, however, to assume some other datum, specially if only the relative elevations of points are required.

Elevation. The elevation of a point on or near the surface of the earth is its vertical distance above or below an arbitrarily assumed level surface or datum. The *difference in elevation* between two points is the vertical distance between the two level surfaces in which the two points lie.

Vertical Angle. Vertical angle is an angle between two intersecting lines in a vertical plane. Generally, one of these lines is horizontal.

Mean Sea Level. Mean sea level is the avèrage height of the sea for all stages of the tides. At any particular place it is derived by averaging the hourly tide heights over a long period of 19 years.

Bench Mark. Bench Mark is a relatively permanent point of reference whose elevation with respect to some assumed datum is known. It is used either as a starting point for levelling or as a point upon which to close as a check.

9.2. METHODS OF LEVELLING

Three principal methods are used for determining difference in elevation, namely, *barometric* levelling, *trigonometric* levelling and *spirit* levelling.

Barometric levelling. Barometric levelling makes use of the phenomenon that difference in elevation between two points is proportional to the difference in atmospheric pressures at these points. A barometer, therefore, may be used and the readings observed at different points would yield a measure of the relative elevations of those points.

At a given point, the atmospheric pressure does not remain constant in the course of the day, even in the course of an hour. The method is, therefore, relatively inaccurate and is little used in surveying work except on reconnaissance or exploratory surveys.

Trigonometric Levelling (Indirect levelling) :

Trigonometric or Indirect levelling is the process of levelling in which the elevations of points are computed from the vertical angles and horizontal distances measured in the field, just as the length of any side in any triangle can be computed from proper trigonometric relations. In a modified form called *stadia levelling*, commonly used in mapping, both the difference in elevation and the horizontal distance between the points are directly computed from the measured vertical angles and staff readings.

Spirit Levelling (Direct Levelling) :

It is that branch of levelling in which the vertical distances with respect to a horizontal line (perpendicular to the direction of gravity) may be used to determine the relative difference in elevation between two adjacent points. A horizontal plane of sight tangent to level surface at any point is readily established by means of a spirit level or a level vial. In spirit

9.6. TEMPORARY ADJUSTMENTS OF A LEVEL

Each surveying instrument needs two types of adjustments : (1) temporary adjustments, and (2) permanent adjustments. *Temporary adjustments or Station adjustments* are those which are made at every instrument setting and preparatory to taking observations with the instrument. *Permanent adjustments* need be made only when the fundamental relations between some parts or lines are disturbed (See Chapter 16).

The temporary adjustments for a level consist of the following :

(1) Setting up the level (2) Levelling up (3) Elimination of parallax.

1. **Setting up the Level.** The operation of setting up includes (*a*) fixing the instrument on the stand, and (*b*) levelling the instrument approximately by leg adjustment. To fix the level to the tripod, the clamp is released, instrument is held in the right-hand and is fixed on the tripod by turning round the lower part with the left hand. The tripod legs are so adjusted that the instrument is at the convenient height and the tribrach is approximately horizontal. Some instruments are also provided with a small circular bubble on the tribrach.

2. **Levelling up.** After having levelled the instrument approximately, accurate levelling is done with the help of foot screws and with reference to the plate levels. The purpose of levelling is to make the vertical axis truly vertical. The manner of levelling the instrument by the plate levels depends upon whether there are three levelling screws or four levelling screws.

(*a*) **Three Screw Head**

1. Loose the clamp. Turn the instrument until the longitudinal axis of the plate level is roughly parallel to a line joining any two (such as *A* and *B*) of the levelling screws [Fig. 9.29 (*a*)].

2. Hold these two levelling screws between the thumb and first finger of each hand and turn them uniformly so that the thumbs move either towards each other or away from each other until the bubble is central. *It should be noted that the bubble will move in the direction of movement of the left thumb* [see Fig. 9.29 (*a*)].

3. Turn the upper plate through 90°, *i.e.*, until the axis on the level passes over the position of the third levelling screw *C* [Fig. 9.29 (*b*)].

4. Turn this levelling screw until the bubble is central.

5. Return the upper part through 90° to its original position [Fig. 9.29 (*a*)] and repeat step (2) till the bubble is central.

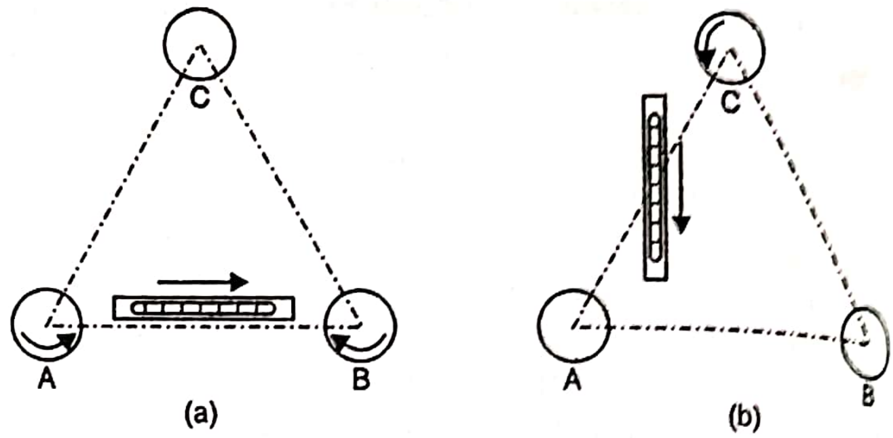


FIG. 9.29. LEVELLING-UP WITH THREE FOOT SCREWS.

6. Turn back again through 90° and repeat step (4).

7. Repeat steps (2) and (4) till the bubble is central in both the positions.

8. Now rotate the instrument through 180° . The bubble should remain in the centre of its run, provided it is in correct adjustment. The vertical axis will then be truly vertical. If not, it needs *permanent adjustment*.

Note. *It is essential to keep the same quarter circle for the changes in direction and not to swing through the remaining three quarters of a circle to the original position.*

(*b*) Four Screw Head

1. Turn the upper plate until the longitudinal axis of the plate level is roughly parallel to the line joining two diagonally opposite screws such as *D* and *B* [Fig. 9.30 (*a*)].

2. Bring the bubble central exactly in the same manner as described in step (2) above.

3. Turn the upper part through 90° until the spirit level axis is parallel to the other two diagonally opposite screws such as *A* and *C* [Fig. 9.30 (*b*)].

4. Centre the bubble as before.

5. Repeat the above steps till the bubble is central in both the positions.

6. Turn through 180° to check the permanent adjustment as for three screw instrument.

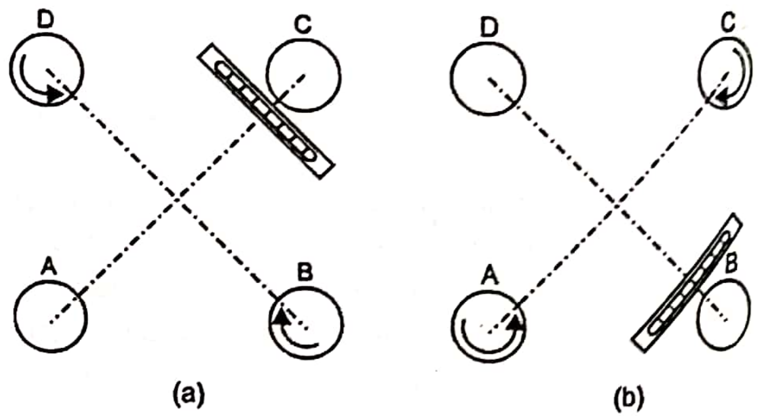


FIG. 9.30. LEVELLING-UP WITH FOUR-FOOT

In modern instruments, three-foot screw levelling head is used in preference to a four foot screw levelling head. The three-screw arrangement is the better one, as three points of support are sufficient for stability and the introduction of an extra point of support leads to uneven wear on the screws. On the other hand, a four-screw levelling head is simpler and lighter as a three-screw head requires special casting called a *tribrach.* A three-screw instrument has also the important advantage of being more rapidly levelled.

3. **Elimination of Parallax.** Parallax is a condition arising when the image formed by the objective is not in the plane of the cross-hairs. Unless parallax is eliminated, accurate

TERMS AND ABBREVIATIONS

(*i*) **Station.** In levelling, a station is that point where the level rod is held and not where level is set up. It is the point whose elevation is to be ascertained or the point that is to be established at a given elevation.

(*ii*) **Height of Instrument (H.I.)** For any set up of the level, the height of instrument is the elevation of plane of sight (line of sight) with respect to the assumed datum. It does not mean the height of the telescope above the ground where the level stands.

(*iii*) **Back Sight (B.S.).** Back sight is the sight taken on a rod held at a point of *known elevation,* to ascertain the amount by which the line of sight is *above* that point and thus to obtain the height of the instrument. *Back sighting* is equivalent to measuring *up* from the point of known elevation to the line of sight. It is also known as a *plus sight* as the back sight reading is always added to the level of the datum to get the height of the instrument. *The object of back sighting is, therefore, to ascertain the height of the plane of sight.*

(*iv*) **Fore Sight (F.S.).** Fore sight is a sight taken on a rod held at a point of unknown elevation, to ascertain the amount by which the point is *below* the line of sight and thus to obtain the elevation of the station. *Fore sighting* is equivalent to measuring *down* from the line of sight. It is also known as a *minus* sight as the fore sight reading is always subtracted (except in speical cases of tunnel survey) from the height of the instrument to get the elevation of the point. *The object of fore sighting is, therfore, to ascertain the elevation of the point.*

(*v*) **Turning Point (T.P.).** Turning point or *change point* is a point on which both minus sight and plus sight are taken on a line of direct levels. The minus sight (fore sight) is taken on the point in one set of instrument to ascertain the elevation of the point while the plus sight (back sight) is taken on the same point in other set of the instrument to establish the new height of the instrument.

(*vi*) **Intermediate Station (I.S.).** Intermediate station is a point, intermediate between two turning points, on which only one sight (minus sight) is taken to determine the elevation of the station.

STEPS IN LEVELLING (Fig. 9.31)

There are two steps in levelling : (*a*) to find by how much amount the line of sight is above the bench mark, and (*b*) to ascertain by how much amount the next point is below or above the line of sight.

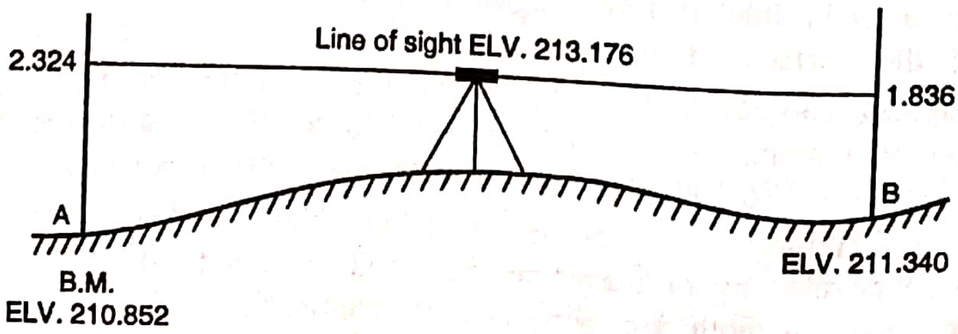


FIG. 9.31.

A level is set up approximately midway between the bench mark (or a point of known elevation) and the point, the elevation of which is to be ascertained by direct levelling. A back sight is taken on the rod held at the bench mark. Then

$$H.I. = Elv.\ of\ B.M. + B.S. \qquad ...(1)$$

Turning the telescope to bring into view the rod held on point B, a foresight (minus sight) is taken. Then

$$Elv. = H.I. - F.S. \qquad ...(2)$$

For example, if elevation of $B.M. = 210.852$ m, $B.S. = 2.324$ m and $F.S. = 1.836$ m.

Then $\quad H.I. = 210.852 + 2.324 = 213.176$ m

and $\quad$ Elv. of $B = 213.176 - 1.836 = 211.340$ m.

It is to be noted that if a back sight is taken on a bench mark located on the roof of a tunnel or on the ceiling of a room with the instrument at a lower elevation, the back sight must be subtracted from the elevation to get the height of the instrument. Similarly, if a foresight is taken on a point higher than the instrument, the foresight must be added to the height of the instrument, to get the elevation of the point.

9.8. DIFFERENTIAL LEVELLING

The operation of levelling to determine the elevation of points at some distance apart is called *differential levelling* and is usually accomplished by direct levelling. When two points are at such a distance from each other that they cannot both be within range of the level at the same time, the difference in elevation is not found by single setting but the distance between the points is divided in two stages by turning points on which the staff is held and the difference of elevation of each of succeeding pair of such turning points is found by separate setting up of the level.

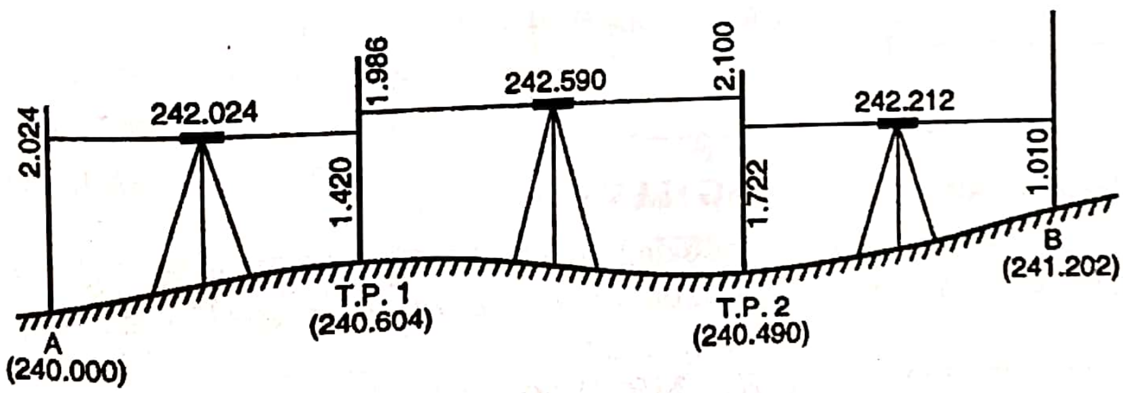


FIG. 9.32

Referring to Fig. 9.32, A and B are the two points. The distance AB has been divided into three parts by choosing two additional points on which staff readings (both plus sight and minus sight) have been taken. Points 1 and 2 thus serve as *turning points*. The $R.L.$ of point A is 240.00 m. The height of the first setting of the instrument is therefore $= 240.00 + 2.024 = 242.024$. If the following $F.S.$ is 1.420, the $R.L.$ of T.P. $1 = 242.024 - 1.420 = 240.604$ m. By a similar process of calculations, $R.L.$ of $T.P.$ 2 $= 240.490$ m and of $B = 241.202$ m.

9.9. HAND SIGNALS DURING OBSERVATIONS

When levelling is done at construction site located in busy, noisy areas, it becomes difficult for the instrument man to give instructions to the man holding the staff at the other end, through vocal sounds. In that case, the following hand signals are found to be useful (Table 9.1 and Fig. 9.33)

TABLE 9.1. HAND SIGNALS

Refer Fig. 9.33	*Signal*	*Message*
(a)	Movement of left arm over 90°	Move to my left
(b)	Movement of right arm over 90°	Move to my right
(c)	Movement of left arm over 30°	Move top of staff to my left
(d)	Movement of right arm over 30°	Move top of staff to my right
(e)	Extension of arm horizontally and moving hand upwards	Raise height peg or staff
(f)	Extension of arm horizontally and moving hand downwards	Lower height peg or staff
(g)	Extension of both arms and slightly thrusting downwards	Establish the position .
(h)	Extension of arms and placement of hand on top of head.	Return to me

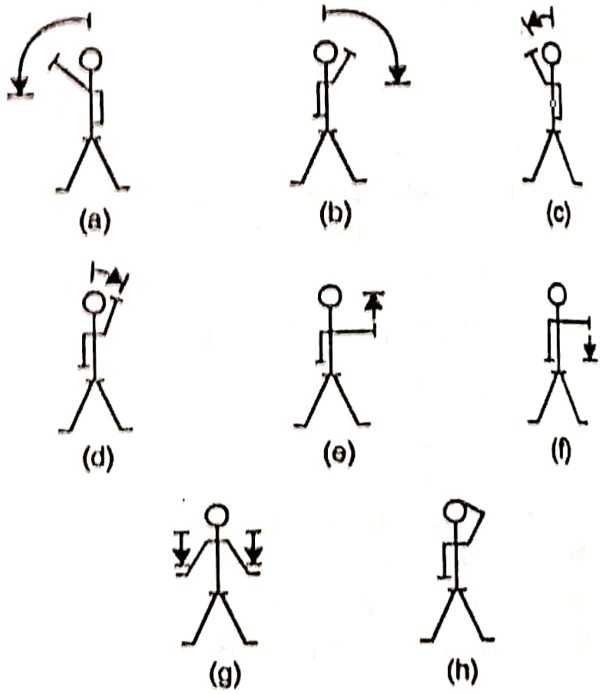


FIG. 9.33. HAND SIGNALS.

9.10. BOOKING AND REDUCING LEVELS

There are two methods of booking and reducing the elevation of points from the observed staff readings : (1) *Collimation or Height of Instrument* method ; (2) *Rise and Fall* method.

(1) HEIGHT OF INSTRUMENT METHOD

In this mehtod, the height of the instrument (*H.I.*) is calculated for each setting of the instrument by adding back sight (plus sight) to the elevation of the *B.M.* (First point). The elevation of reduced level of the turning point is then calculated by subtracting from *H.I.* the fore sight (minus sight). For the next setting of the instrument, the *H.I.* is obtained by adding the *B.S* taken on *T.P.* 1 to its *R.L.* The process continues till the *R.L.* of the last point (a fore sight) is obtained by subtracting the staff reading from height of the last setting of the instrument. If there are some intermediate points, the *R.L.* of those points is calculated by subtracting the intermediate sight (minus sight) from the height of the instrument for that setting.

The following is the specimen page of a level field book illustrating the method of booking staff readings and calculating reduced levels by height of instrument method.

Station	*B.S*	*I.S.*	*F.S.*	*H.I.*	*R.L.*	*Remarks*
A	0.865			561.365	560.500	B.M. on Gate
B	1.025		2.105	560.285	559.260	
C		1.580			558.705	Platform
D	2.230		1.865	560.650	558.420	
E	2.355		2.835	560.270	557.815	
F			1.760		558.410	
Check	6.475		8.565 6.475		558.410 560.500	Checked
			2.090	Fall	2.090	

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

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

The method affords a check for the *H.I.* and *R.L.* of turning points but not for the intermediate points.

(2) RISE AND FALL METHOD

In rise and fall method, the height of instrument is not at all calculated but the difference of level between consecutive points is found by comparing the staff readings on the two points for the same setting of the instrument. The difference between their staff readings indicates a *rise* or *fall* according as the staff reading at the point is *smaller* or *greater* than that at the preceding point. The figures for 'rise' and 'fall' worked out thus for all the points give the vertical distance of each point above or below the preceding one, and if the level of any one point is known the level of the next will be obtained by adding its rise or subtracting its fall, as the case may be.

The following is the specimen page of a level field book illustrating the method of booking staff readings and calculating reduced levels by rise and fall method :

Station	*B.S.*	*I.S.*	*F.S.*	*Rise*	*Fall*	*R.L.*	*Remarks*
A	0.865					560.500	B.M. on Gate
B	1.025		2.105		1.240	559.260	
C		1.580			0.555	558.705	Platform
D	2.230		1.865		0.285	558.420	
E	2.355		2.835		0.605	557.815	
F			1.760	0.595		558.410	
Check	6.475		8.565 6.475	0.595	2.685 0.595	558.410 560.500	Checked
		Fall	2.090	Fall	2.090	2.090	

Arithmetic Check. The difference between the sum of back sights and sum of fore sights should be equal to the difference between the sum of rise and the sum of fall and should also be equal to the difference between the *R.L.* of last and first point. Thus,

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

This provides a complete check on the intermediate sights also. The arithmetic check would only fail in the unlikely, but possible, case of two more errors occurring in such a manner as to balance each other.

It is advisable that on each page the rise and fall calculations shall be completed and checked by comparing with the difference of the back and fore sight column summations, before the reduced level calculations are commenced.

Comparison of the Two Methods. The height of the instrument (or collimation level) method is more rapid, less tedious and simple. However, since the check on the calculations for intermediate sights is not available, the mistakes in their levels pass unnoticed. The rise and fall method though more tedious, provides a full check in calculations for all sights. However, the height of instrument method is more suitable in case, where it is required to take a number of readings from the same instrument setting, such as for constructional work, profile levelling etc.

Example 9.1. *The following staff readings were observed successively with a level, the instrument having been moved after third, sixth and eighth readings : 2.228 ; 1.606 ; 0.988 ; 2.090 ; 2.864 ; 1.262 ; 0.602 ; 1.982 ; 1.044 ; 2.684 metres.*

Enter the above readings in a page of a level book and calculate the R.L. of points if the first reading was taken with a staff held on a bench mark of 432.384 m.

Solution.

Since the instrument was shifted after third, sixth and eighth readings, these readings will be entered in the *F.S.* column and therefore, the fourth, seventh and ninth readings will be entered on the *B.S.* column. Also, the first reading will be entered in the *B.S.* column and the last reading in the *F.S.* column. All other readings will be entered in the *I.S.* column.

The reduced levels of the points may be calculated by rise and fall method as tabulated below :

Station	*B.S.*	*I.S.*	*F.S.*	*Rise*	*Fall*	*R.L.*	*Remarks*
1	2.228					432.384	B.M.
2		1.606		0.622		433.006	
3	2.090		0.988	0.618		433.624	T.P.1
4		2.864			0.774	432.850	
5	0.602		1.262	1.602		434.452	T.P. 2
6	1.044		1.982		1.380	433.072	T.P. 3
7			2.684		1.640	431.432	
Check	5.964		6.916 5.964	2.842	3.794 2.842	432.384 431.432	
		Fall	0.952	Fall	0.952	0.952	Checked

Example 9.2. *It was required to ascertain the elevation of two points P and Q and a line of levels was run from P to Q. The levelling was then continued to a bench mark of 83.500, the readings obtained being as shown below. Obtain the R.L. of P and Q.*

B.S.	*I.S.*	*F.S.*	*R.L.*	*Remarks*
1.622				P
1.874		0.354		
2.032		1.780		
	2.362			Q
0.984		1.122		
1.906		2.824		
		2.036	83.500	B.M.

Solution.

To find the *R.Ls.* of *P* and *Q*, we will have to proceed from bottom to the top. To find the *H.I.*, therefore, *F.S.* readings will have to be added to the *R.L.* of the known point and to find the *R.L.* of the previous point, the *B.S.* will have to be subtracted from the so obtained *H.I.* as clearly shown in the table below :

Station	*B.S*	*I.S.*	*F.S.*	*H.I.*	*R.L.*	*Remarks*
P	1.622			84.820	83.198	
	1.874		0.354	86.340	84.466	
	2.032		1.780	86.592	84.560	
Q		2.362			84.230	
	0.984		1.122	86.454	85.470	
	1.906		2.824	85.539	83.630	
			2.036		83.500	B.M.
Check	8.418 8.116		8.116		83.500 83.198	
Rise	0.302				0.302	Checked

Example 9.3. *The following consecutive readings were taken with a level and 5 metre levelling staff on continuously sloping ground at a common interval of 20 metres: 0.385 ; 1.030 ; 1.925 ; 2.825 ; 3.730 ; 4.685 ; 0.625 ; 2.005 ; 3.110 ; 4.485. The reduced level of the first point was 208.125 m. Rule out a page of a level field book and enter the above readings. Calculate the reduced levels of the points by rise and fall method and also the gradient of the line joining the first and the last point.*

Solution.

Since the readings were taken on a continuously sloping ground, the maximum staff reading can be 5 metres only, and therefore, sixth reading will be a fore sight taken on a turning point and the seventh reading will be a back sight. Also, the first reading will be a back sight and the last reading will be a fore sight. The levels can be readily calculated as shown in the tabular form below:

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remarks
1	0.385					208.125	
2		1.030			0.645	207.480	
3		1.925			0.895	206.585	
4		2.825			0.900	205.685	
5		3.730			0.905	204.780	
6	0.625		4.685		0.955	203.325	
7		2.005			1.380	202.445	
8		3.110			1.105	201.340	
9			4.485		1.375	199.965	
Check	1.010		9.170 1.010	0.000	8.160 0.000	208.125 199.965	
		Fall	8.160	Fall	8.160	8.160	

$$\text{Gradient of the line} = \frac{8.160}{20 \times 8} = \frac{1}{19.61} = 1 \text{ in } 19.61 \text{ (falling).}$$

Example 9.4. *The following figures were extracted from a level field book, some of the entries being illegible owing to exposure to rain. Insert the missing figures and check your results. Rebook all the figures by the 'rise' and 'fall' method.*

Station	*B.S.*	*I.S.*	*F.S.*	*Rise*	*Fall*	*R.L.*	*Remarks*
1	*2.285*					*232.460*	*B.M. 1*
2	*1.650*		×	*0.020*			
3		*2.105*			×		
4	×		*1.960*	×			
5	*2.050*		*1.925*		*0.300*		
6		×		×			
7	*1.690*		×	*0.340*		*232.255*	*B.M. 2*
8	*2.865*		*2.100*		×		
9			×	×		*233.425*	*B.M. 3*

Solution.

(*i*) The *F.S.* of station 2 is missing, but it can be calculated from the known rise. Since station 2 is higher than station 1, its *F.S.* will be lesser than the *B.S.* of station 1 (higher the point, lesser the reading). Hence,

F.S. of station $2 = 2.285 - 0.020 = 2.265$ m

and *R.L.* of station $2 = 232.460 + 0.02 = 232.480$ m

(*ii*) Fall of station $3 = 2.105 - 1.650 = 0.455$ m

$\therefore$ *R.L.* of station $3 = 232.480 - 0.455 = 232.025$ m

(*iii*) *B.S.* of staion 4 can be calculated from the fact that the *F.S.* of station 5, having a fall of 0.300 m, is 1.925 m

Thus, *B.S.* of station $4 = 1.925 - 0.300 = 1.625$ m

Also, Rise of station 4 = 2.105 − 1.960 = 0.145 m

and R.L. of station 4 = 232.025 + 0.145 = 232.170 m

(iv) R.L. of station 5 = 232.170 − 0.300 = 231.870 m

(v) From the known *R.L.* of stations 6 and 5, the rise of station 6 can be calculated

Thus, Rise of station 6 = 232.255 − 231.870 = 0.385

I.S. of station 6 = 2.050 − 0.385 = 1.665

(vi) *F.S.* of station 7 = 1.665 − 0.340 = 1.325

and *R.L.* of station 7 = 232.255 + 0.340 = 232.595

(vii) Fall of station 8 = 2.100 − 1.690 = 0.410

R.L. of station 8 = 232.595 − 0.410 = 232.185

(viii) Since the elevation of station 9 is 233.425 m, it has a rise of (233.425 − 232.185) = 1.240 m.

∴ *F.S.* of station 8 = 2.865 − 1.240 = 1.625 m.

The above results and calculations are shown in the tabular form below :

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remarks
1	2.285					232.460	B.M. 1
2	1.650		2.265	0.020		232.480	
3		2.105			0.455	232.025	
4	1.625		1.960	0.145		232.170	
5	2.050		1.925		0.300	231.870	
6		1.665		0.385		232.255	B.M. 2
7	1.690		1.325	0.340		232.595	
8	2.865		2.100		0.410	232.185	
9			1.625	1.240		233.425	B.M. 3
Check	12.165 11.200		11.200	2.130 1.165	1.165	233.425 232.460	
	0.965	Rise		0.965	Rise	0.965	Checked

Example 9.5. *During a construction work, the bottom of a R.C. Chhajja A was taken as a temporary B.M. (R.L. 63.120). The following notes were recorded.*

Reading on inverted staff on B.M. No. A.	2.232
Reading on peg P on ground :	1.034
Change of instrument	
Reading on peg P on ground :	1.328
Reading on inverted staff on bottom of cornice B :	4.124

Enter the readings in a level book page and calculate the R.L. of cornice B.

Solution

The first reading was taken on an inverted staff and therefore it will have to be subtracted from the *R.L.* to get the *H.I.* Similarly, the last reading was taken on an inverted staff, and the *R.L.* of the cornice *B* will be obtained by adding the *F.S.* reading to the

H.I. Use (−) sign for the *B.S.* of *A* and *F.S.* of *B* since both of these have been taken in reverse directions than the normal ones. The calculations are shown in table the below:

Point	*B.S.*	*I.S.*	*F.S.*	*H.I.*	*R.L.*	*Remarks*
A	− 2 .232			60 .888	63.120	
P	1.328		1.034	61.182	59.854	
B			− 4.124		65.306	
Check	− 0.940 − 3.090 +		− 3.090		65.306 63.120	
Rise	+ 2.186			Rise	2 .186	Checked

9.12. CURVATURE AND REFRACTION

From the definition of a level surface and a horizontal line it is evident that a horizontal line departs from a level surface because of the curvature of the earth. Again, in the long sights, the horizontal line of sight does not remain straight but it slightly bends downwards having concavity towards ea rth surface due to refraction.

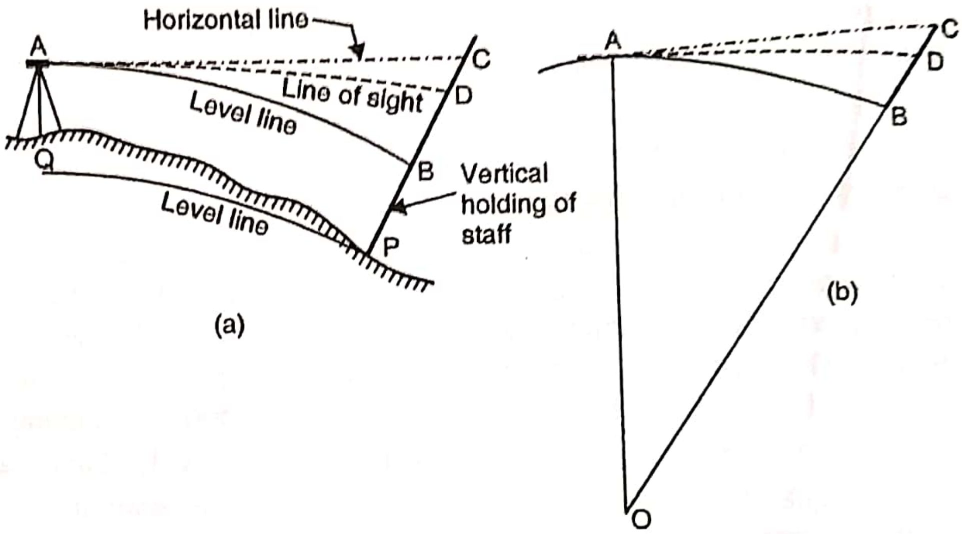


FIG. 9.38. CURVATURE AND REFRACTION.

In Fig. 9.38 (*a*), *AC* is the horizontal line which deflects upwards from the level line *AB* by an amount *BC*. *AD* is the actual line of sight.

Curvature. *BC* is the departure from the level line. Actually the staff reading should have been taken at *B* where the level line cuts the staff, but since the level provides only the horizontal line of sight (in the absence of refraction), the staff reading is taken at the point *C*. Thus, the apparent staff reading is *more* and, therefore, the object appears to be *lower* than it really is. *The correction for curvature is, therefore, negative as applied to the staff reading,* its numerical value being equal to the amount *BC*. In order to find the value *BC*, we have, from Fig. 9.38 (*b*).

$$\frac{6}{7}\frac{L^2}{2R} = L \tan\alpha = L \quad (0.0003067)$$

$$\therefore \qquad L = \frac{0.0003067 \times 7 \times 2}{6} \times 6370 = \mathbf{4.557 \ km.}$$

9.13. RECIPROCAL LEVELLING

When it is necessary to carry levelling across a river, ravine or any obstacle requiring a long sight between two points so situated that no place for the level can be found from which the lengths of foresight and backsight will be even approximately equal, special method *i.e., reciprocal levelling* must be used to obtain accuracy and to eliminate the following: (1) error in instrument adjustment ; (2) combined effect of earth's curvature and the refraction of the atmosphere, and (3) variations in the average refraction.

Let A and B be the points and observations be made with a level, the line of sight of which is inclined upwards when the bubble is in the centre of its run. The level is set at a point near A and staff readings are taken on A and B with the bubble in the centre of its run. Since B.M. A is very near to instrument, no error due to curvature, refraction and collimation will be introduced in the staff readings at A, but there will be an error e in the staff reading on B. The level is then shifted to the other bank, on a point very near B.M. B, and the readings are taken on staff held at B and A. Since B is very near, there will be no error due to the three factors in reading the staff, but the staff reading on A will have an error e. Let h_a and h_b be the corresponding

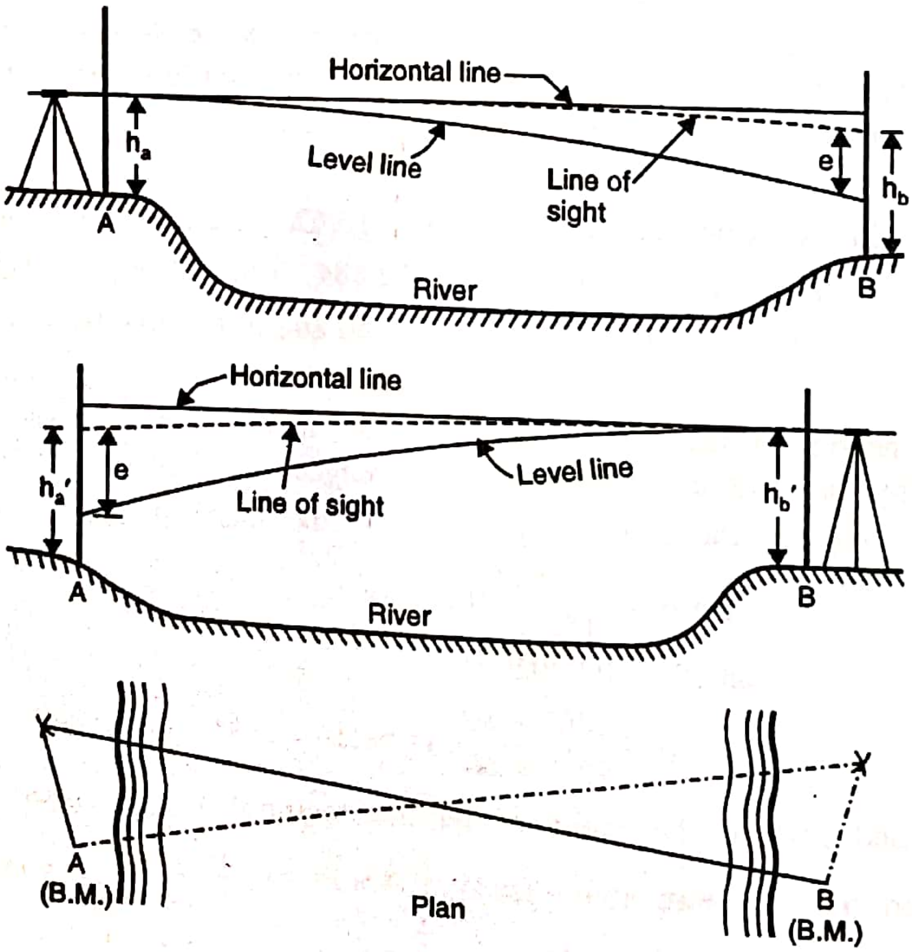


FIG. 9.41. RECIPROCAL LEVELLING.

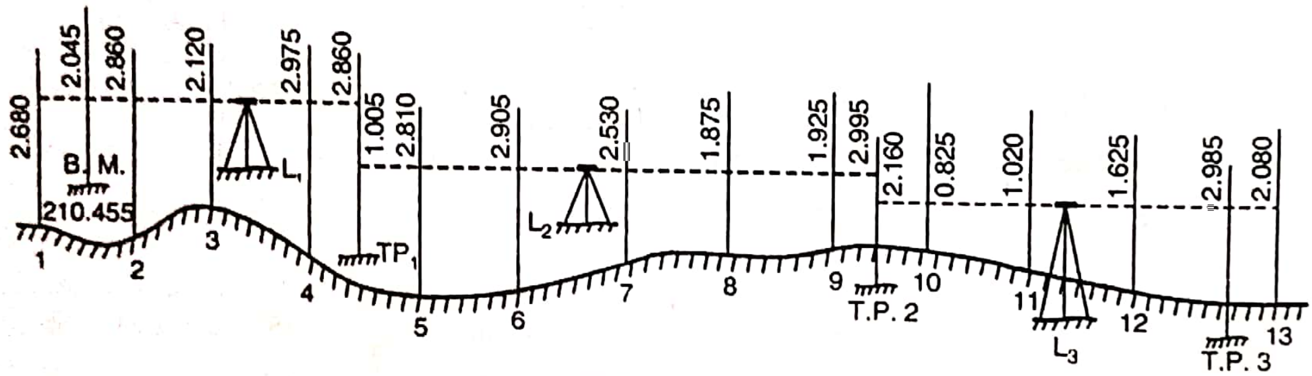
or

9.14. PROFILE LEVELLING (LONGITUDINAL SECTIONING)

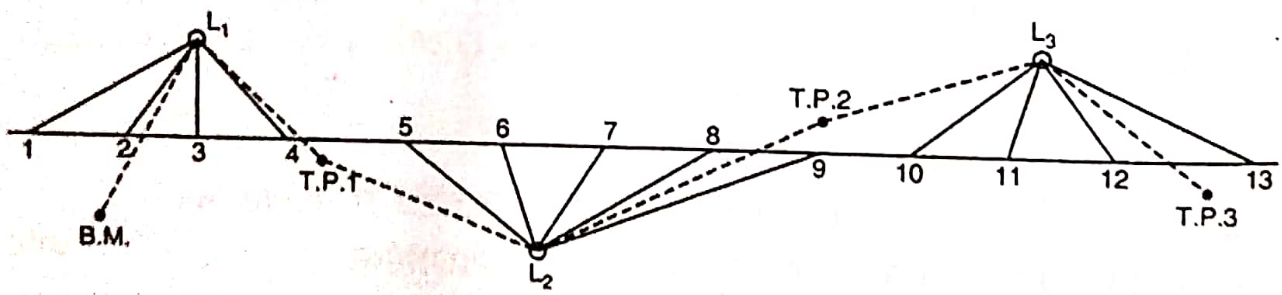
Profile levelling is the process of determining the elevations of points at short measured intervals along a fixed line such as the centre line of a railway, highway, canal or sewer. The fixed line may be a single straight line or it may be composed of a succession of straight lines or of a series of straight lines connected by curves. It is also known as *longitudinal sectioning*. By means of such sections the engineer is enabled to study the relationship between the existing ground surface and the levels of the proposed construction in the direction of its length. The profile is usually plotted on specially prepared profile paper, on which the vertical scale is much larger than the horizontal, and on this profile, various studies relating to the fixing of grades and the estimating of costs are made.

Field Procedure : Profile levelling, like differential levelling, requires the establishment of turning points on which both back and foresights are taken. In addition, any number of intermediate sights may be obtained on points along the line from each set up of the instrument (Fig. 9.42). In fact, points on the profile line are merely intermediate stations. It is generally best to set up the level to one side of the profile line to avoid too short sights on the points near the instrument. *For each set up, intermediate sights should be taken after the foresight on the next turning station has been taken.* The level is then set up in an advanced position and a backsight is taken on that turning point. The position of the intermediate points on the profile are simultaneously located by chaining along the profile and noting their distances from the point of commencement. When the vertical profile of the ground is regular or gradually curving, levels are taken on points at equal distances apart and generally at intervals of a chain length. On irregular ground where abrupt changes of slope occur, the points should be chosen nearer. For purose of checking and future reference, temporary bench marks should be established along the section.

Field notes for profile levelling are commonly kept in the standard form shown in the table on next page. The method is almost the same as given for 'collimation height' method as computations are easier by that method. The distances of the points on the profile are also recorded. The values shown in the table are same as those illustrated in Fig. 9.42.



(a) Section



(b) Plan

FIG. 9.42. PROFILE LEVELLING.

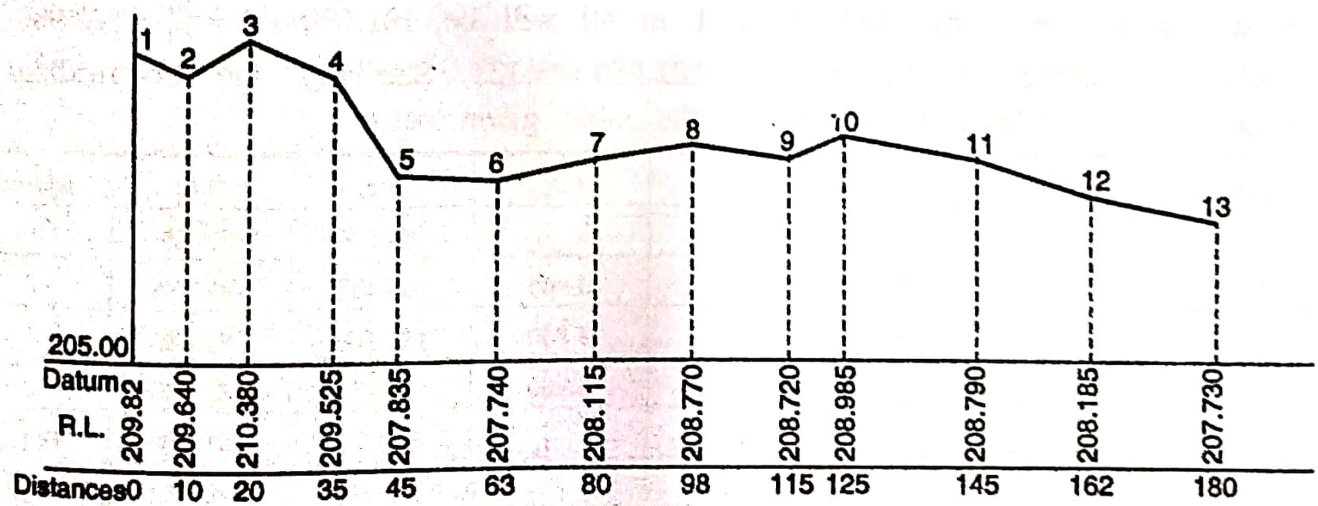
Plotting the Profile (Fig. 9.43)

The horizontal distances are plotted along the horizontal axis to some convenient scale and the distances are also marked. The elevations are plotted along the vertical axis. Each ground point is thus plotted by the two co-ordinates (*i.e.*, horizontal distance and vertical elevation). The various points so obtained are joined by straight lines, as shown in Fig. 9.43, where the readings of the above table are plotted.

Generally, the horizontal scale is adopted as 1 cm = 10 m (or 1" = 100 ft). The vertical scale is not kept the same but is exaggerated so that the inequalities of the ground appear more apparent. The vertical scale is kept 10 times the horizontal scale (*i.e.* 1 cm=1 m). The reduced levels of the points are also written along with the horizontal distances.

LEVEL FIELD NOTES FOR PROFILE LEVELLING

Station	*Distance*	*B.S.*	*I.S.*	*F.S.*	*H.I.*	*R.L.*	*Remarks*
B.M.		2.045			212.500	210.455	
1	0		2.680			209.820	
2	10		2.860			209.640	
3	20		2.120			210.380	
4	35		2.975			209.525	
T.P. 1		1.005		2.860	210.645	209.640	
5	45		2.810			207.835	
6	63		2.905			207.740	
7	80		2.530			208.115	
8	98		1.875			208.770	
9	115		1.925			208.720	
T.P. 2		2.160		2.995	209.810	207.650	
10	125		0.825			208.985	
11	145		1.020			208.790	
12	162		1.625			208.185	
13	180		2.080			207.730	
T.P. 3				2.985		206.825	
		5.210		8.840 5.210		210.455 206.825	
Check			Fall	3.630	Fall	3.630	



Longitudinal Section

Scale { Hor. 1 cm = 10 m
Ver. 1 cm = 1 m

FIG. 9.43

Levelling to Establish Grade Points : This kind of levelling, often referred to as *giving elevations* is used in all kinds of engineering construction. The operation of establishing grade points is similar to profile levelling and follows the latter. After the profile has

9.15. CROSS-SECTIONING

Cross-sections are run at right angles to the longitudinal profile and on either side of it for the purpose of lateral outline of the ground surface. They provide the data for estimating quantities of earth work and for other purposes. The cross-sections are numbered consecutively from the commencement of the centre line and are set out at right angles to the main line of section with the chain and tape, the cross-staff or the optical square and the distances are measured left and right from the centre peg (Fig. 9.44). Cross-section may be taken at each chain. The length of cross-section depends upon the nature of work.

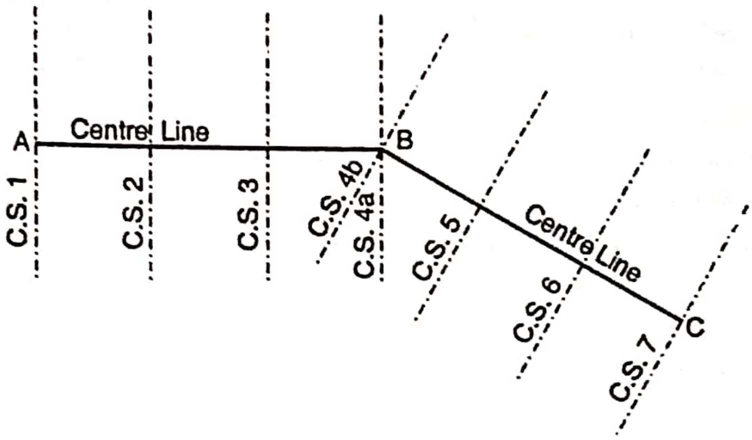


FIG. 9.44

The longitudinal and cross-sections may be worked together or separately. In the former case, two additional columns are required in the level field book to give the distances, left and right of the centre line, as illustrated in table below. To avoid confusion, the bookings of each cross-section should be entered separately and clearly and full information as to the number of the the cross-section, whether on the left or right of the centre line, with any other matter which may be useful, should be recorded.

Station	*Distance (m)*			*B.S.*	*I.S.*	*F.S.*	*H.I.*	*R.L.*	*Remarks*
	L	*C*	*R*						
B.M.				1.325			101.325	100.000	
0		0			1.865			99.460	Cross–section at 0 m chainage
L_1	3				1.905			99.420	
L_2	6				2.120			99.205	
L_3	9				2.825			98.500	
R_1			3		1.705			99.620	
R_2			7.5		1.520			99.805	
R_3			10		1.955			99.370	
I		20			1.265			100.060	Cross-section at 20 m chainage
L_1	3				1.365			99.960	
L_2	6				0.725			100.600	
L_3	9				2.125			99.200	
R_1			3		1.925			99.400	
R_2			7		2.250			99.075	
R_3			10		0.890			100.435	
T.P.						2.120		99.205	
Check				1.325		2.120 1.325		100.000 99.205	
					Fall	0.795	Fall	0.795	

Plotting the Cross-section (Fig. 9.45)

Cross-sections are plotted almost in the same manner as the longitudinal sections except that in this case both the scales are kept equal. The point along the longitudinal section is plotted at the centre of the horizontal axis. The points to the left of centre point are plotted to the left and those to the right are plotted to the right. The points so obtained are joined by straight lines.

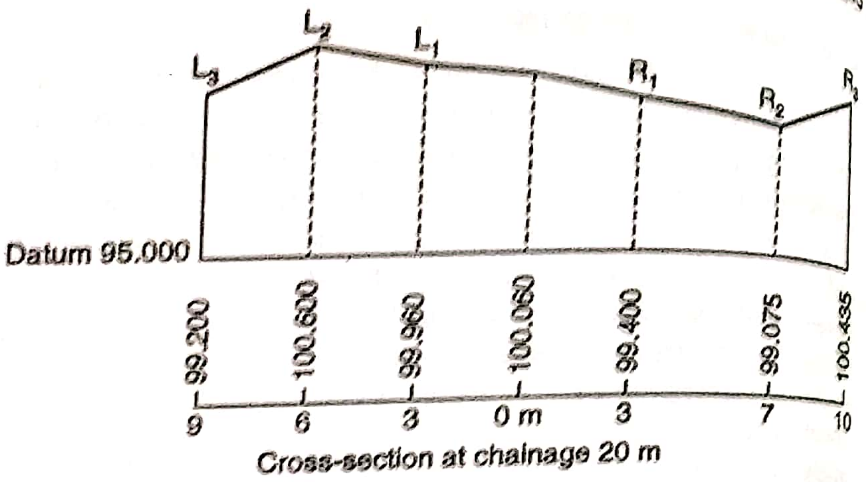


FIG. 9.45