1.15 Measurement of Levels

Levelling is a branch of surveying which deals with measurements in vertical planes. It is the operation performed to determine and establish the elevations of points on the surface or beneath the Earth. It is also done to determine differences in elevation between points to draw the contours, find out the slope, and control the grades during construction. Levelling is of prime importance to the engineers for both design as well as execution of a project on the ground. The success of many engineering projects would depend upon accurate determination of elevations. The pre-requisite to compute the elevations of ground points is that the elevation of at least one point should be known with respect to which the elevations of other points can be computed. The point whose elevation is known to start the levelling work is known as the Bench Mark (BM). The instrument used to measure the elevations is known as Level, which is used along with a Levelling staff or Levelling rod.

The object is of levelling, therefore, is to; (*i*) determine the elevations of given points with respect to a datum, and (*ii*) establish the points of required height above or below the datum line. The levelling is used for many applications, such as; (*i*) to determine or to set the plinth level of a building, (*ii*) to decide or set the road, railway, canal or sewage line alignment, (*iii*) to determine or to set various levels of dams, towers, etc., and (*iv*) to determine the capacity of a reservoir.

1.15.1 Technical terms used in levelling

It is necessary to understand few technical terms often used in levelling. These are explained below (Refer to Figure 1.18).

(a) **Level surface**: It is a surface perpendicular to the direction of gravity at all points. The surface of a still lake is a good example of level surface.

(b) **Mean Sea Level (MSL)**: MSL is the average height of the sea for all stages of the tides. At any particular place, the MSL is established by finding the mean sea level (free of tides) after averaging tide heights over a long period of at least 19 years. In India, MSL used is that established at Karachi, presently, in Pakistan. In all important surveys this is used as datum.

(c) **Level lin**e: It is a line lying throughout on a level surface and would be a part of the circle representing the mean sea level (MSL).

(d) **Horizontal plane**: It is a plane tangential to the level surface at a point, and is also normal to the direction of gravity at that point.

(e) **Horizontal line**: It is a line lying in a horizontal plane. The horizontal line is therefore, perpendicular to the vertical line at that point. A horizontal line is always tangential to the level line at that point.

(f) **Datum surface**: It is a level surface used as reference surface, with respect to which elevations of other points are computed.

(g) **Vertical plane:** It is a plane, which contain the vertical line at that point. Infinite number of vertical planes can contain a vertical line.

(h) **Altitude:** The vertical distance of a point above the datum is called the altitude of that point. If the datum surface considered is the MSL, the altitude and the elevation will be the same.

(i) **Elevation or Reduced level (RL)**: It is the level or altitude of a point with reference to the datum surface, measured along the direction of gravity.

(j) **Bench Mark (BM)**: It is a point of known elevation above MSL. Usually the BM is marked on the ground after erecting a small concrete pillar and marking the centre of the top surface with a fixed brass plate is fixed.

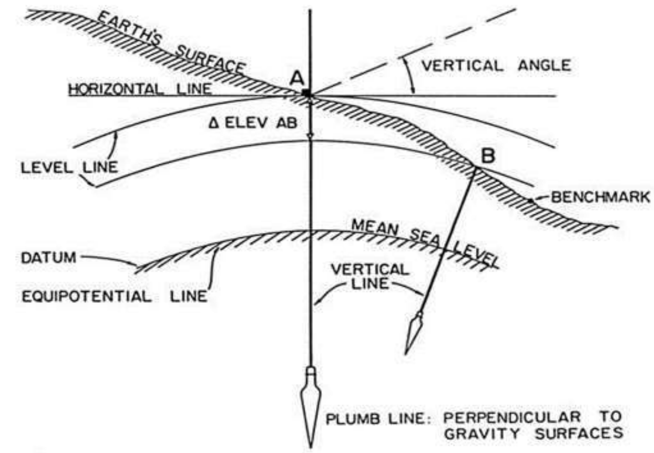

Figure 1.18 Representation of various terms (Schultz, 1987)

(k) **Line of collimation:** It is the imaginary line passing through the centre of the eye piece and intersection of diaphragm (cross-hairs) and its further extension in the telescopic tube (Figure 1.19). The line of collimation may not pass through the centre of objective lens of telescopic tube, if the diaphragm is out of adjustment, and hence may give erroneous results.

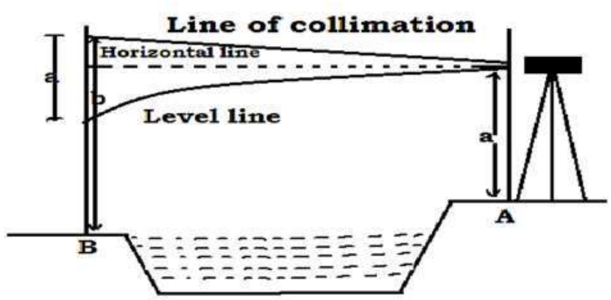

Figure 1.19 Line of collimation

(l) **Line of sight**: In an adjusted telescopic tube, the line of sight is the imaginary line passing through the centre of the eye piece, centre of cross-hairs and centre of objective lens. All these points must lie in one straight line.

(m) **Height of instrument:** It is the height of instrument above the ground, generally measured with a tape from horizontal axis of telescopic tube. It should not be confused with the elevation of height of telescope as the latter will be the height above a given datum where the instrument is setup.

(n) **Back Sight (BS):** It is the sight taken on a level staff held at the point of known elevation (BM or datum). It is the first reading after the instrument is set in an area for levelling work. This reading is normally added to RL of the point to get the RL of line of collimation.

(o) **Fore Sight (FS):** This is the last reading taken on the level staff from the instrument station before shifting it or just before ending the levelling work. This is normally subtracted with the elevation of line of collimation to get the elevation of the point where BS reading is taken.
(p) **Intermediate Sight (IS):** It is the sight taken on a level staff after back sight and before the fore sight. These readings are taken to find the reduced levels of the points where staff was held.
(q) **Change Point (CP):** It is also known as turning point (TP). On this point, both back sight and fore sight are taken. After taking fore sight on this point, instrument is shifted to some other convenient station, and back sight is taken on the staff held at the same point from the new station. These two readings help in computing the elevations of unknown points on the ground. In addition, the instrument line of collimation error is eliminated is the BS distance and FS distance is kept nearly equal.

1.15.2 Levelling staff

Along with a level instrument, a levelling staff (or rod) is required for taking the measurements to determine amount by which a point is above or below the line of sight. The levelling staff is a straight rectangular wooden or metallic (aluminium) rod having graduations (Figure 1.20). It is protected with a metal shoes at its bottom from wear and tear in the field. The foot of the shoe on levelling staff represents zero reading. These staffs are available in 3 m, 4 m, 5 m length, and may be divided into three groups;

(a) solid staff -which is made up of one single solid piece, and hence sometimes difficult to transport and move in the field during long hours of observations,
(b) folding staff- which is made up of two pieces hinged together, and can be folded when not in use, and
(c) telescopic staff- which is made up of several pieces connected together; one piece slides into another and so on).

The folding and telescopic staffs are convenient to transport and work in the field. The vertical distance between the line of sight and the point over which the staff is held vertically is the staff reading which is recorded by the observer. The least count of normal solid staff is 0.005 m or 5 mm.

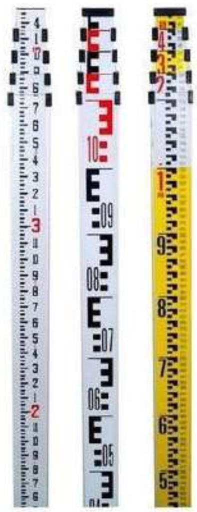

Figure 1.20 Various levelling staff

1.15.3 Levels

The instrument used for collecting the elevation measurements from the field are called levels. The purpose of a level instrument is to establish a horizontal line of sight in order to take the measurement to compute the elevations. The level consists of the following essential parts:

1. A telescopic tube which provides a line of sight.
2. A diaphragm (or cross-hairs) which holds the cross hairs (fitted near the eyepiece within telescope).
3. Eyepiece which is fitted at one end of telescope, and used to magnify the image formed in the plane of the diaphragm. The observer keeps one eye closer to it to read the staff reading during leveling. The eyepiece is fitted with a screw which is moved clockwise or anticlockwise to focus the diaphragm.
4. Objective lens, which is fitted at the other end of the telescope, is used to collect the incoming rays from the levelling staff (objects) that form the image inside the telescopic view.
5. A focusing screw which is used to focus the image at the cross hairs.
6. A level bubble tube which is attached to telescopic tube to make the line of sight horizontal.
7. A levelling head which supports the level instrument, and is fitted with a circular bubble tube, used for making the base of instrument approximately levelled.
8. A tripod for fixing the level instrument.

Various types of leveling instruments are:

(a) Dumpy level
(b) Tilting level
(c) Engineers level
(d) Automatic level
(e) Digital level
(f) Laser level

(a) Dumpy level
The Dumpy level consists of a telescope, generally external focusing type, rigidly fixed to the vertical spindle. The telescope can be rotated in the horizontal plane about its vertical axis. A level tube is attached with the telescope. The level tube is fixed with its axis parallel to telescope tube, so that when bubble is centred, the telescope becomes horizontal. The level tube is graduated on either side of its centre to estimate how much the bubble is out of its centre. The instrument has a levelling head consisting of two parallel plates held apart by three (or four) levelling screws. The upper plate is called tribrach and the lower one is called trivet. A circular bubble tube (or bulls's eye) is fitted with the tribrach. The instrument base is approximately levelled using these foot screws which are rotated in a particular sequence. Exact levelling of line of sight is done by using bubble tube fitted with the telescope. With the availability of Auto levels, Laser levels, and Total Station equipment, the Dumpy level is no more used in levelling work.

(b) Tilting level
The telescope of a tilting level is not rigidly fixed to the vertical spindle as in case of a Dumpy level (Figure 1.21). The telescopic tube, generally internal focusing type, can be tilted on a pivot about horizontal axis in the vertical plane upwards or downward through a small angle $\pm 3^0$ by means of a tilting screw. The line of collimation and the vertical axis of a tilting level need not be at right angles as required in the case of a Dumpy level. The bull's eye or circular bubble tube is fixed to the upper plate of levelling head for approximate levelling the base of instrument by using the three foot screws. For temporary adjustment of a Level, please see section 1.15.4.

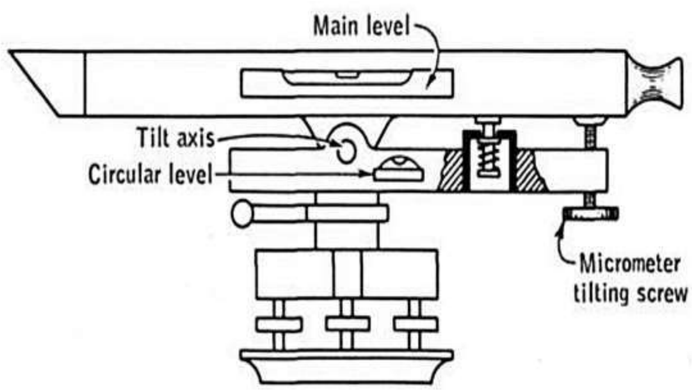

Figure 1.21 Tilting level

After the temporary adjustments are over, the levelling staff is now kept a point whose elevation is to be determined. The cross-hairs are focused and then leveling staff is bisected and focused. The exact levelling of the instrument is then done using the tilting screw before taking every reading. The reading where the horizontal hair intersects the staff is noted. An inclined mirror attached to the level tube enables the observer to view the centering of the bubble from the eyepiece end of the telescope without moving the eye close to bubble tube.

Tilting levels have the advantages over Dumpy level that the line of sight can be tilted upward or downward by $\pm 3^0$ so that observations are possible to take from the levelling staff, in case of undulating ground. These levels are more robust, lighter, compact and accurate than the Dumpy levels. The tilting arrangement saves a lot of time for making the instrument ready to take the readings. Tilting levels are most useful when only few readings to be taken from one setting of the instrument.

(c) Engineer's level

An engineer's level primarily consists of a telescope which is internal focusing type. Their construction is like other level but very compact and light weight. Engineers level and auto-levels provides the advantage of taking faster observation, as the line of sight each time is not required to be levelled with the bubble tube.

(d) Auto level

Auto level or Automatic level is a professional levelling instrument used by contractors, builders, land survey professionals, and engineers who require very accurate levelling work. This level is used to verify the elevation of foundations, footings, and walls; design proper drainage systems for homes and other structures; determine proper elevation for a floor; determining the height of doors and windows, building suspended ceilings, design of swimming pool, roadwork, and excavations.

The tripod of an auto level is kept on a stable ground, and instrument clamped on it with the clamping screw. The auto level needs to be adjusted temporarily, as explained in temporary adjustment of a level. If repeating this process does not solve the problem, the auto level might be out of adjustment. Once the base is levelled, Auto level will be automatically levelled along the line of sight due to incorporation of a self-levelling feature. Once the circular bubble at the base is centered manually, an *automatic compensator* would level the line of sight, and continue to keep it level. The automatic compensator consists of prisms suspended from wires to create a pendulum. The wire lengths, support locations, and nature of the prisms are arranged such that only horizontal rays would reach the intersection of cross hairs. Thus, a horizontal line of sight is achieved even though the telescope itself may be slightly tilted away from horizontal. Damping devices would bring the pendulum to come to rest quickly, saving the operator's time. Various components of an Auto level are shown in Figure 1.22.

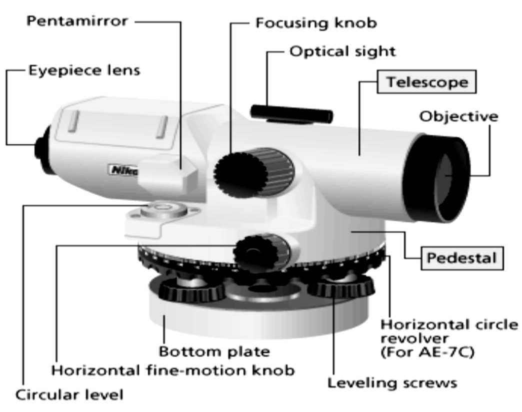

Figure 1.22 Various components of an Auto level

Auto levels are quick to level with greater accuracy which have made it more demanding amongst the surveyors. For general use, these are popular because of their ease and rapid operation, however the reading is manually recorded. They are fast and easy to use, and therefore can save a great deal of time and money in the field. An auto level has additional benefits, as it gives the upright reading that can be seen from the eyepiece, as compared to Dumpy/Tilting level where reading is inverse which is sometimes difficult and confusing to read, and becomes an important source of error. In addition, the line of sight is automatically adjusted with an internal compensator. The drawback is that some automatic compensators are affected by magnetic fields, which can result in systematic errors in staff readings.

(e) Digital level

The electronic digital level is further modification of automatic level. It also uses a pendulum compensator to level itself, after an operator accomplishes rough levelling with a circular bubble (same as in case of auto levels). The instrument could be used to take readings manually, just like an automatic level, however, it is designed to operate by employing digital image processing approach. After levelling the instrument (Figure 1.23a), its telescope is focused toward a special bar-coded rod (Figure 1.23b). At the press of a functional button, the image of bar code is captured in the telescope's field of view, and processed. The processing is done by an onboard computer by comparing the captured image with the levelling staff's entire pattern, which is already stored in memory. When a match is found, the staff reading is displayed digitally. The reading can be recorded manually or automatically stored in a controller of the instrument.

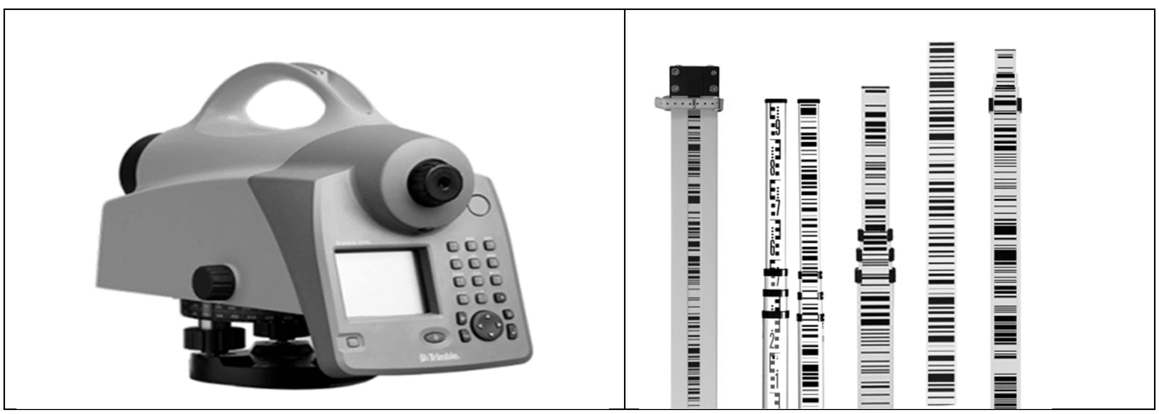

Figure 1.23 (a) Digital level, and (b) Bar code leveling staff

Digital levels have the provision of transferring the digital data to a computer where the measurements are processed to get the elevations, profiles or DEM. The length of the staff appearing within the telescope's field of view is a function of the distance from the staff. Thus, the instrument is also able to automatically compute the distance from staff; a feature quite useful for balancing the backsight and foresight distances. Normally, the instrument's maximum distance range is approximately 100 m, and its accuracy in staff readings is ±0.5 mm. The bar-coded staff is also available with English or metric graduations on reverse side of the bar code. This graduated side of the staff can be used to manually read it in situations where instrument can't read from the bar codes, such as when the staff is used under heavy bush or long grasses.

(f) Laser level

Laser level has an electronic device that emits a laser beam, and a sensor fitted with the levelling staff can sense the laser beam and digitally display the measurements. The laser beam concept was introduced in levelling instruments for automisation. In surveying, the laser has long been recognized as a carrier wave, in electro-optical distance measurement. However, in the last ten years or so, laser levels have been frequently used for levelling operations required in measurement of land surface, and determination of the height and depth of large or small object on the terrain.

The laser levels enhance the working with speed of data collection and automisation. They provide more accurate reduced levels, and are frequently used for levelling, plumbing, machine control, excavation work, landscaping, construction, measuring elevation, alignment, grading of sites, construction stake out, concrete levelling, drainage design, and many more jobs (Ali and Al-garni, 1996). The architects have benefited extensively from the use of laser-based instruments in monitoring interior height control of buildings, decorations, setting out of individual walls and suspended ceilings and control of elevator guide rails.

A laser level generates a laser line across the point where it's pointed. It can be visible as a bright red or green colour, or completely invisible for survey work at places with high movement of people, such as roads. These laser levels are available in manual-levelling, auto levelling and self-levelling modes. Further advancements in laser level have led to the development of Rotary laser levels which emit laser in 360º rotation, covering vertical or horizontal planes, instead of just emitting a single line in one direction. Since the continuous rotation of the laser beam about its vertical axis determines the projection of the beam, it is important to keep laser level accurately levelled. Rotary levels (Figure 1.24a) have a greater range than line levels, and are more ideal for larger and exterior work sites. An integral part of using a rotor laser level is a laser detector which is typically mounted to level rod (Figure 1.24b) and detects the laser beam during outdoor survey. It can detect signals that make easier to find laser lines. In outdoor woks, they are to be used along with a laser detector and a graduated rod. The best laser levels for surveying are the ones that can generate several laser lines at the same time in both horizontal and vertical directions. The use of laser levels in construction industry has dramatically reduced the time to complete the project. It helps engineer check the perfect angles of a building during construction.

Figure 1.24 (a) Self-levelling rotary laser, (b) Laser detector and levelling staff

1.15.4 Temporary adjustment of level

Temporary adjustment of a level is required to be carried out prior to taking any observation on staff from an instrument station. It involves some operations which are required to be carried out in a proper sequence. It consists of three steps; Setting, Leveling and Focusing.

(a) Setting: Firstly, the tripod stand is set up at a convenient height so that its head is horizontal (through eye judgement only). If the ground is flat, the three legs of tripod are kept at equal spacing to form equilateral triangle so that the levelling of the base is quick (Figure 1.25). The Level is then fixed on the tripod head by screws. The Level instrument is set up over a ground station by suspending the Plumb bob with the instrument base, and ensuring that the pointed tip of the Plumb bob touches the instrument station.

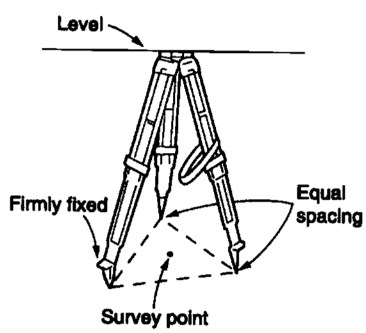

Figure 1.25 Setting up a tripod

(b) Leveling: Secondly, the instrument is leveled approximately with the help of leveling screws till the circular bubble comes in the centre. Then, the bubble of the level tube is brought to the centre by using the designated screw. For approximate levelling of base, the telescope of the instrument is kept parallel to any two of the three levelling screws, and using these two screws the bubble should be brought in the centre of the levelling bubble tube, either by uniform inward or outward rotation of screws (as shown in Figure 1.26a). And once the bubble is centered, the telescope is brought perpendicular to its current position. Now, using the third screw, the bubble is brought exactly inside the circle, by either clockwise or anticlockwise rotation of levelling screw (Figure 1.26b). The telescope is now rotated 90º (original position as at Figure 1.26a), and the bubble is checked. If the bubble doesn't stay in the center of the circle, the previous steps are repeated to bring it in the centre. Normally, two-three repeat processes will bring the bubble perfectly in the centre. Turn the telescope by 360°, and check the bubble. It should ideally remain in the centre in all positions of telescope.

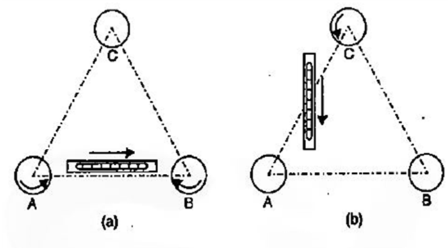

Figure 1.26 Levelling the base of the instrument using three foot screws

(c) Focusing: Thirdly, focusing is required to be done in order to form the clear image through objective lens at the plane of the diaphragm and to view the clear image of through the eye-piece. The diaphragm is a cross-hairs at which the object is focused. These are available in different shapes, as shown in Figure 1.27. The focusing is carried out in two steps by removing parallax with proper focusing of objective lens and eye-piece. For focusing the eye-piece, screw attached to it is rotated till the diaphragm or cross-hairs are seen sharp and distinct. Focusing of cross-hairs might change from observer to observer, as it depends on the vision of the observer. For focusing the objective lens, the telescope is first pointed towards the Levelling staff (object), and the focusing screw is turned until the image of the Staff (object) appears clear and sharp, and also there is no relative movement between the image and the cross-hairs. Focusing of objective lens is required to be done before taking each and every observation.

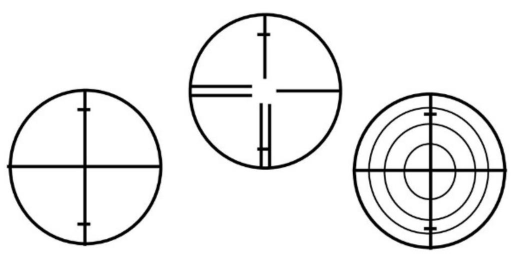

Figure 1.27 Various diaphragms

1.15.5 Reduction of levels

The reduction of level is the operation where the observed staff readings are used to find out the elevation (RLs) of points. There are two methods for reduction of levels:

(a) Rise and Fall method, and

(b) Height of instrument method

(a) Rise and Fall Method

Since the ground is undulating, the Staff reading will be more if kept at a lower point, and less if kept at a higher point. Thus, the staff readings provide information regarding relative rise and fall of ground points. The difference in the staff readings indicates a rise or fall according to if the staff reading is smaller or greater than that at the preceding point, respectively. The difference between consecutive points is calculated by comparing each point after the first with that immediately preceding it. The RL of each point is then determined by adding rise or subtracting fall to/from the RL of the preceding point. This is the basic concept behind rise and fall method for finding out the elevations of unknown points.

If BS - FS is positive. then it is the rise, and if BS - FS is negative, it is fall
RL of the point = RL of previous point ± (rise or fall)
At the end of all computations, check is applied as:
Σ BS – Σ FS = Σ Rise – Σ fall = First RL – Last RL (1.6)

This method is a laborious method as staff reading of each point on the ground after the first is compared with that preceding it, and the difference of level is entered as a rise or fall. It is slow and simple method. But, it is more precise because intermediate sights are also considered in calculations and checking the results. There are three checks for arithmetical calculations. The method is popularly used for earthwork calculations and other precise levelling operations.

(b) Height of Instrument method
Height of Instrument (HI) method deals with obtaining the RL of the line of collimation by adding BS reading of a point whose RL is known, as shown in Figure 1.28. The RL of line of collimation is called the Height of Instrument. From this, the staff readings of all intermediate stations are subtracted to get the RL at those points. It is always measured from the benchmark. The HI method involves less computation in reducing the levels, so when there are large numbers of intermediate sights, it is used. It is a faster than the rise and fall method, but it has a disadvantage of not having check on intermediate sights.

HI = RL of BM + BS
RL of point = HI - FS of that point
At the end of all computations, check is applied as:
Σ BS – Σ FS = First RL – Last RL (1.7)

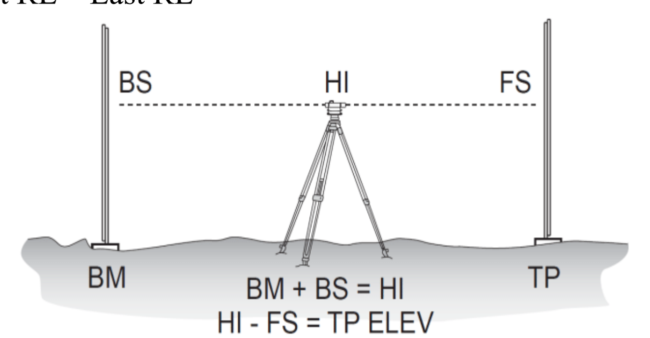

Figure 1.28 Height of instrument method

1.15.6 Types of direct levelling
The following are the different types of direct levelling used in the field:
(a) Simple levelling
(b) Differential levelling

(c) Fly levelling
(d) Profile and Cross section levelling, and
(e) Reciprocal levelling.

(a) Simple levelling

This method is used for finding out the difference between the levels of two nearby points. Figure 1.29 shows one such case in which level of BM is given as 100.000 m. RL of unknown point is computed as-

RL = BM + BS - FS
= 100.000 + 0.973) – 4.987
= 95.986 m

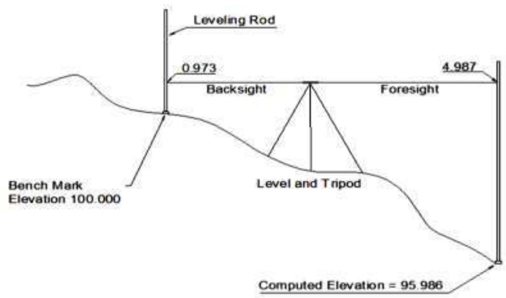

Figure 1.29 Simple levelling observations

(b) Differential levelling

Differential levelling is used for finding the difference between the levels of two far-off points. If case of a large distance between two points A and D, it may not be possible to take the readings on A and D from a single setting of instrument, so differential levelling is used (Figure 1.30). In this method, the level instrument is set at more than one stations along the survey line, and at each shifting station both BS and FS readings are taken to determine the elevation difference between A and D. The following example in Figure 1.30 shows how the RLs of various points on the ground are calculated from BS and FS readings. The last point is another BM which could be used to check the levelling work.

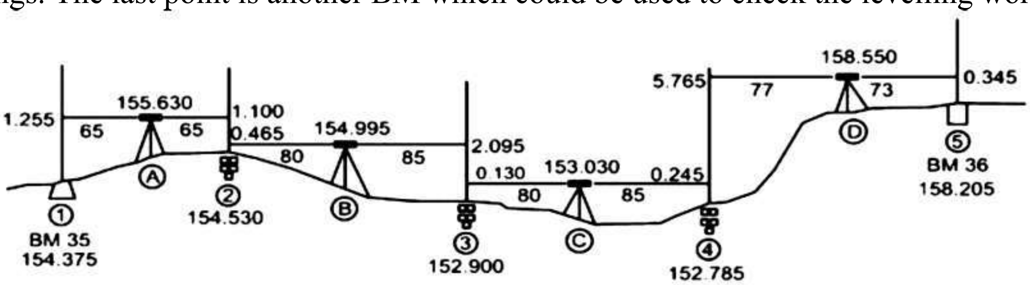

Figure 1.30 Differential levelling observations

(c) Fly levelling

If the survey site is away from the bench mark, the level instrument is set up near the BM and a back sight reading is taken on the BM. The survey work proceeds towards the site by taking fore sights and back sights on a number of change points till a temporary BM is established at the survey site. Now the levelling work is carried out at the site as per differential levelling method. At the end of the work, last reading is taken again on temporary BM. It will help determining the closing error in levelling work. The purpose of fly levelling is to connect the survey site to a BM away from the site, and then carry out the levelling work using differential levelling approach.

(d) Profile and cross-section levelling

This type of levelling, also known as longitudinal levelling, is required to be carried out in highway, railway, canal, pipeline, transmission line, or sewage line projects to know the profile of the ground along selected alignments. It is most popular levelling method to estimate the amount of earth work (cutting or filling) required in large number of engineering projects dealing with the land surface. At regular interval, level readings are taken and RLs of various points along and across the alignment are determined. For drawing the profile of the route, distance is plotted against x-axis and RLs are plotted along y-axis. The vertical scale is usually larger as compared to scale for horizontal distances. It gives clear picture of the profile of the route. If the graph is plotted taking the values along the route, it is known as *longitudinal profile*, whereas if the elevation values across the route are plotted, it is known as *cross-section profile*. The cross-section profiles are usually drawn from the centre of the route on either side. Figure 1.31 shows the plan view of the scheme of profile levelling and cross-section levelling of the route.

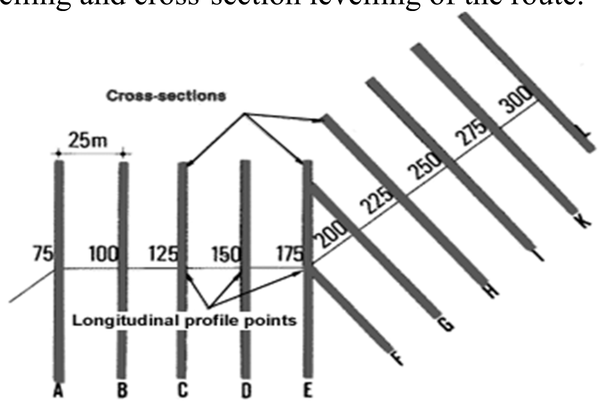

Figure 1.31 Longitudinal and cross-section profiles observations

In many engineering projects, not only longitudinal profile but also cross-section profiles are required at regular intervals. Both these profiles are used in calculating the earth works involved in the execution of projects. Figure 1.31 shows the scheme of such work in which cross-section profiles are taken at 25 m interval along the alignment line, and readings are taken in the perpendicular direction at an interval of 3 m on either side of the alignment line (from A to L). The distances on the cross-sections will be defined as left or right of the lines while doing the survey in forward direction. The length of the cross-section would depend upon the type of project occupying the land width.

(e) Reciprocal levelling

In levelling, the distance of back sight and distance of fore sight is kept equal, as far as possible. It is done to eliminate the following errors:

(*a)* Error due to non-parallelism of line of collimation and axis of bubble tube, and

(*b*) Errors due to curvature and refraction.

While doing the levelling across features, like river, big ponds and reservoirs, it is not possible to maintain equal distance for fore sight and back sight distances. In such situations, the reciprocal levelling is used and the height difference between two points is precisely determined by two sets of correlation observations. In this method, the instrument is set up at a point A on one side of the valley, and readings are taken on the staff held near A (Figure 1.32a) and on the staff held at B on the other side of the valley. Let these readings be h^a and h_b, respectively. Reading h_a is considered to be accurate, but reading h_b may have an error 'e' due to collimation. The instrument is then moved at the other side of valley at point B, and again the reading is taken on the staff held near B and on the staff held at A on other side of valley. Let these readings be $h_{b'}$ and $h_{a'}$, respectively (Figure 1.32b). Reading $h_{b'}$ is considered to be accurate while reading $h_{a'}$ may have an error 'e' due to collimation. Let h be the true difference in height between A and B.

In Figure 1.32a
$h = (h_b – e) – h_a$
In Figure 1.32b,
$h = h_{b'} – (h_{a'} – e)$
Adding the above two relationahips, we get-
$2 h = (h_b – h_a) + (h_{b'} – h_{a'})$
$h = 1/2 [(h_b – h_a) + (h_{b'} – h_{a'})]$
or $e = 1/2 [(h_b – h_a) – (h_{b'} – h_{a'})]$ (1.8)

In the above relations, it is assumed that the collimation error is the same when making observations from both the sides. However, in reality if we take reading from one end, there will a time difference to shift time to the instrument to the other side, and the value of refraction may change over time.

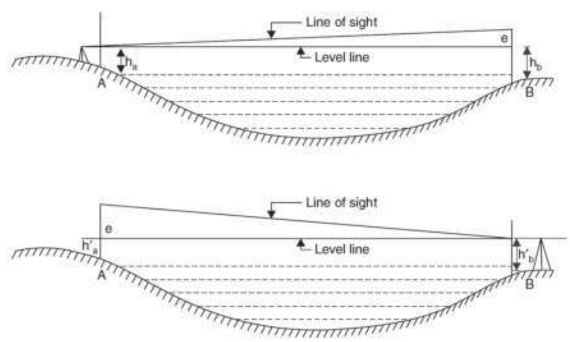

Figure 1.32 Reciprocal levelling observations (a) from side A and (b) from side B

1.15.7 Different types of errors
While taking observations, several types of errors might occur, such as instrumental errors, personal errors, natural errors. These are briefly discussed below;

(a) Instrumental errors: These are of several types:
(i) Error in permanent adjustment of level: For any major surveying work, the instrument needs to be tested and if required, gets to be adjusted. For small works, bubble of the level tube should be brought to the centre before each reading and balancing of sights are to be maintained.

(ii) Staff defective and/or of non-standard quality: If the graduation in staff are not standardized that may cause error in reading. In an ordinary leveling, the error may be negligible but in case of precise leveling, the defective graduations in staff may cause significant error.
(iii) Error due to defective level tube: The bubble of the level tube may be in the center, otherwise it may cause error. Sometimes improper curvature of the bubble tube can also cause error.
(iv) Error due to defective tripod: The tripod should be set up on a stable and firm ground. The tripod stand should be strong and stable otherwise it takes considerable time to make the instrument level. The nuts provided at the joints of the legs to the tripod head should be well-tightened before mounting the instrument.

(b) Personal errors: These include;
(i) Due to imperfect temporary adjustment of the instrument: These errors are caused due to careless setting up of the level, improper leveling of the instrument, lack in focus of eyepiece or/and objective and error in sighting of the staff.
(ii) Error in sighting: This occurs when the horizontal cross-hair does not exactly coincide with the staff graduation or it is difficult to see the exact coincidence of the cross hairs and the staff graduations. The error can be minimised by keeping the small sight distance.
(iii) Error due to staff held incorrectly: If the staff is not held vertical, the staff reading obtained is greater than the correct reading. To reduce the error, the staff should be held exactly vertical taking help of a bubble level tube.
(iv) Error in reading the staff: These errors occur if staff is read upward, instead of downward, read against the top or bottom hair instead of the central hair, mistakes in reading the further graduations wrongly.
(v) Error in recording: The common errors are entering a wrong reading (with digits interchanged or mistaking the numerical value of a reading), recording in wrong column, e.g., BS as IS, omitting an entry, entering the inverted staff reading without a minus sign etc.
(vi) Error in computing: Errors may cause by adding the fore sight reading instead of subtracting it and or subtracting a back sight reading instead of adding.

(c) Error due to natural causes: These may include;

(i) Error due to Earth's curvature: In case of small sight distance, error due to the curvature is negligible, but if the sight distances are large, the error should be accounted for. However, the error can be minimized through balancing of sight or reciprocal observations. The combined error due to curvature and refraction (e_{comb}) is thus given by:

$$e_{comb}\ (m) = 0.0675\ D^2 \qquad (1.9)$$

where D is the distance in km

It is finally subtractive in nature as the combined effect provides increase in staff reading.

(ii) Error due to wind: Strong wind disturbs the leveling of an instrument and verticality of staff. Thus, the levelling work should not be performed in strong winds.

(iii) Error due to sun: Due to bright sunshine on the objective, sometimes the staff reading cannot be read properly. To avoid such error, it is recommended to cover objective lens with a shed.
(iv) Error due to temperature: Temperature of the atmosphere disturbs setting of parts of instrument as well as causes fluctuation in the refraction of the intervening medium. These lead to error in staff reading. The instrument therefore is placed under the shade or survey umbrella is used.