Chapter seven
Levelling

7.1 Definition & principles of leveling

Levelling is the process of measuring vertical distances above or below a given reference surface and a point on near or below the earth's surface. It can also be defined as the processes of determining elevation differences between various points on, near or below the surface of the earth. The elevation of a point is its vertical distance above or below a reference level, called datum. The most commonly used datum is the mean sea level (M.S.L)

Levelling is an important method of surveying for many Engineering works and construction projects. Levelling is needed for the design of highways, railways, and canals etc and for locating the gradient lines. The results of levelling can be used to determine the catchments area, volume of the reservoir.

The vertical direction is parallel to the direction gravity at any point; it is the direction of a freely suspended plumb-bob cord or string. The vertical distance of a point above or below a given reference surface is called the elevation of the point. The most commonly used reference surface for vertical distance is mean sea level (MSL). (The words altitude, height, and grade are sometimes used in place of elevation). Vertical distances are measured by surveyors in order to determine the elevations of points, in a process called running levels, or simply levelling.

The importance of levelling cannot be overestimated with a few exceptions, it must always be considered in every form of design and construction.

The determination and control of elevations constitute a fundamental operation in surveying and engineering projects. Levelling provides data for determining the shape of the ground and drawing topographic maps. The elevation of new facilities such as roads, structural foundations, and pipelines can then be designed. Finally, the designed facilities are laid out and marked in the field by the construction surveyor.

The surveyors' elevation marks (such as grade stakes) severs as a reference points from which building contractors can determine the proper slope (''rate of grade'') of a road the first floor elevation of a building, the required cut off elevation four foundation piles, the invert elevation for a storm sewer, and so on.

Basic Definition and terms used in direct levelling

Basic Definitions

The following are a few introductory definitions that are necessary for the understanding of this chapter

i. **A vertical line**- is the line parallel to the direction of gravity. At a particular point it is the direction assumed by a plumb-bob sting if the plumb-bob is allowed to swing freely. Because of the earth's curvature, plumb-bob lines at points some distance apart are not parallel, but in plane surveying they are assumed to be.

ii. **A level surface-** is a surface of constant elevation that is perpendicular to a plumb line at every point. It is best represented by the shape that a large body of still water would take if it were unaffected by tide.

iii. The **elevation** of a particular point- is the vertical distance above or below a reference level surface (normally, sea level)

iv. A **level line**- is a curved line in a level surface all points of which are of equal elevation. Every element of the line is perpendicular to gravity.

v. **Horizontal line** - line in horizontal plane, perpendicular to local vertical

vi. **Vertical datum** – level surface to which elevations is referred i.e. Arbitrarily assigned elevation of zero

vii. **Geoid** – level surface serving as datum for elevations and astronomical observations

viii. **Mean sea level (MSL)** – average height of sea surface for all stages of tide over 19-years

- Derived from 26 gaging stations in Atlantic, Pacific and Gulf of Mexico
- Accepted as vertical datum for North America in past

ix. **Leveling** – process of finding elevations of points, or their differenced in elevation

x. **Vertical control** – series of bench marks of know elevation established throughout area

- In US – series of first-, second-, and lower order leveling

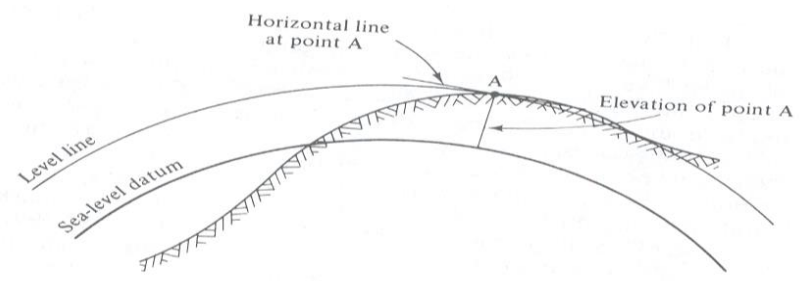


Figure 7.1

Terms used in direct levelling

The following terms are commonly used in levelling.

1. ***Station*:** The station is the point where the rod level is held for taking reading (observation) from a levelling instrument.
   The point where the instrument is set up is not important so far the booking of the readings in a level field book is concerned.
2. **Height of the instrument. (H.I):** It is the elevation of the line of sight with respect to the datum. It should be noted that the height of instrument is not the height of the line of sight above the ground where the levelling instrument is set up.
3. **Back sight (B.S.):** It is the reading taken on a staff held at point of known elevation or at the point whose elevation has already been determined. The back sight is usually the first reading taken after setting up the instrument. The back sight is taken on a bench -Mark (B.M) for the first setting of the instrument and on a turning point (T.P.) for the subsequent settings because the level of turning point can be determined before the shifting of the instrument.

4. **Fore sight (F.S.):** It is the reading taken on the staff either held at the last point whose elevation is required or held at the turning point just before shifting the instrument.
5. **Turning point (T.P***.)*: For levelling over a long distance, the instrument has to be set up a number of times. A turning point is the point selected on the route before shifting the instrument. The turning point should be selected on a firm ground or rock.
6. **Intermediate sight (I.S.):** It is the reading taken on a staff held at point whose elevations is required, but which is not a turning point or the last point.
7. **Balancing of sight:** To reduce the effect of instrumental and other errors, the distance of the point where a back sight is taken and the distance of the point where a fore sight is taken, as measured from the instrument station, should be approximately equal. This is known as balancing of sights.

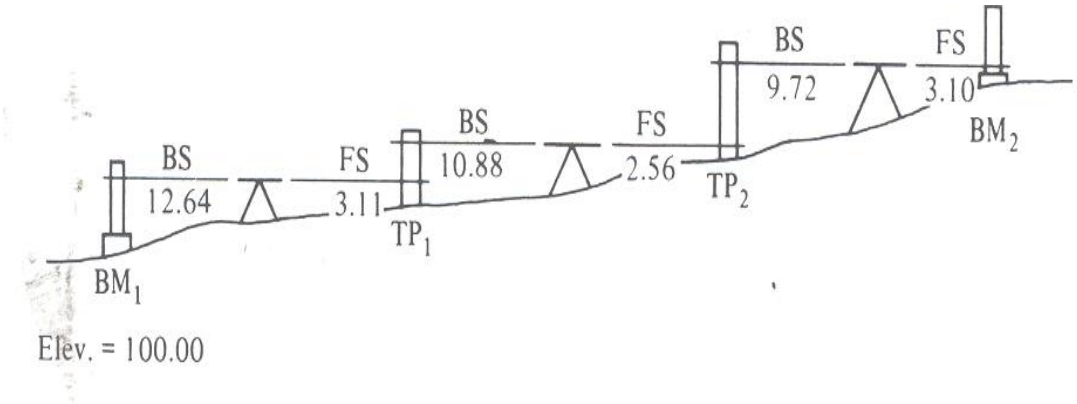


Figure 7.2; levelling terms

7.1.3 Methods of levelling

Differential levelling

Differential levelling is required for the determination of the difference of elevation of two points, which are quite apart. A number of setting ups of the instrument are required in differential levelling.

In *fig. 1* BM_1 represents a point of known elevation (benchmark) and BM_2 represents a benchmark to be established some distance away. It is desired to determine the elevation of BM_2. The level is placed in such a location that a clear rod reading is obtainable, but no attempt is made to keep on the direct line joining BM_1 and BM_2. A **back sight** is taken on BM_1. The rod-man chooses a turning point TP_1 at some convenient spot within the range of the telescope along the general route BM_1 to BM_2. It is desirable, but not necessary, that each foresight distance as I_1–TP_1 is approximately equal to its corresponding back sight distance as BM_1-I_1. The chief requirement is that the turning point shall be a stable object at an elevation and in a location favourable to a rod reading of the required precision. The rod is held on a turning point and a

fore sight is taken. The observer then set up the instrument at some favourable point as I_2 and takes a **back sight** to the rod held on the turning point TP_1. Then the rod-man establishes the second turning point TP2 and the observer takes a **fore sight**. The process is repeated until finally a foresight is taken on the terminal point BM_2.

To check whether there is an error or not the levelling work should always be started from a known point and should be finished at a known point.

The levelling field book should be checked immediately in the field.

Elev B.M.1 + Rod ReadingB.M.1 - Rod Reading T.P.1 = Elev T.P.1

Note: While taking the readings the staff rod has to be held vertically!

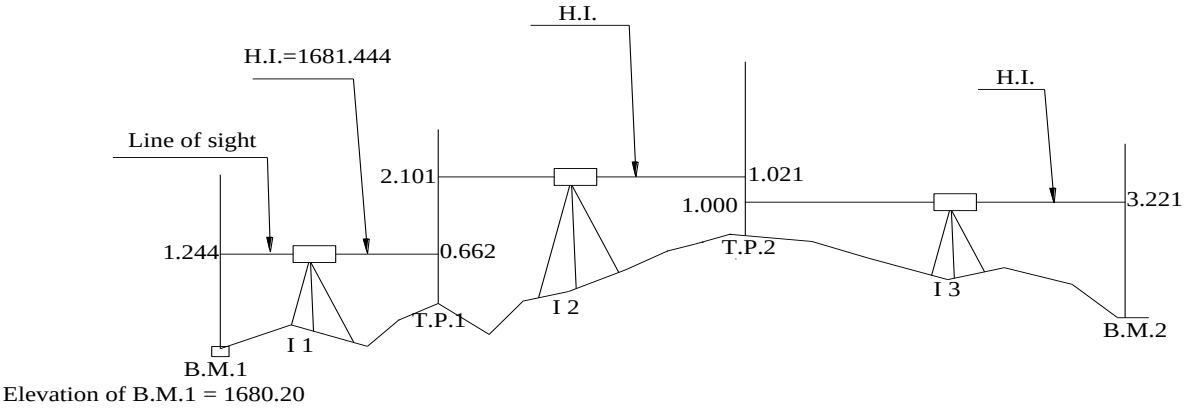


Figure 7.3 Compound differential levelling

Profile levelling

The process of determining the elevation of points at short measured intervals along a fixed line is called profile levelling. The need of profile levelling arises during the location and construction of highways, railroads, canal, and sewers.

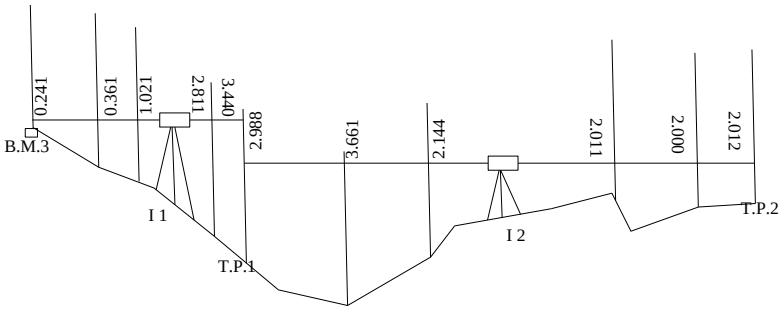


Figure 7.4: Illustrates the steps in levelling for profile

The instrument is set up in some convenient location not necessarily on the line (as at I_1) and the rod is held on benchmark (BM_3). A back sight is taken and the height of instrument is obtained as in differential levelling. Readings are then taken with the rod held on the ground at successive stations along the line. These rod readings, being for points of unknown elevation, are foresights

regardless of whether they are in front or ahead of the level. They are frequently designated as **intermediate foresights** to distinguish them from foresights taken on turning points or benchmarks. The intermediate foresights subtracted from the height of the instrument give ground elevations of stations. When the rod has been advanced to a point beyond which further readings to ground points cannot be observed, a turning point (TP_1) is selected and a foresight (3.440m) is taken to establish its elevation. The level is set up in an advanced position (I_2) and a back sight (2.988m) is taken on the turning point (TP_1) just established. Rod readings on ground points are then continued as before.

Note: While taking the readings the staff rod has to be held vertically!

Cross Sectional levelling

Cross sections are lines of levels or short profiles made perpendicular to the center line of a project. They provide the information necessary for estimating quantities of earth work.

There are two general types of cross-section:

The ones required for route projects such as roads and the ones required for borrow pits.

This section is devoted to the first of these two types. For route surveys, cross-sections are taken at regular intervals such as the 50-or 100 ft stations and at sudden changes in the center- line profiles. To serve their purpose, the sections must extend a sufficient distance on each side of the center line so that the complete area to be affected by the project is included. Where large cut or fill seem probable greater distances from the center line should be sectioned.

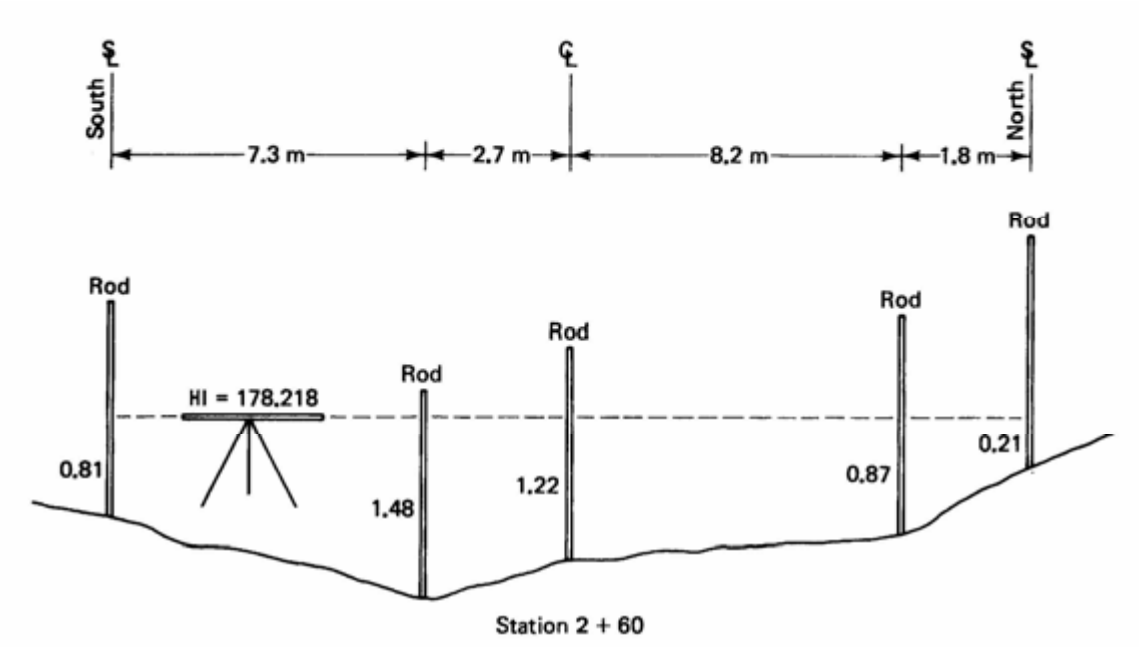
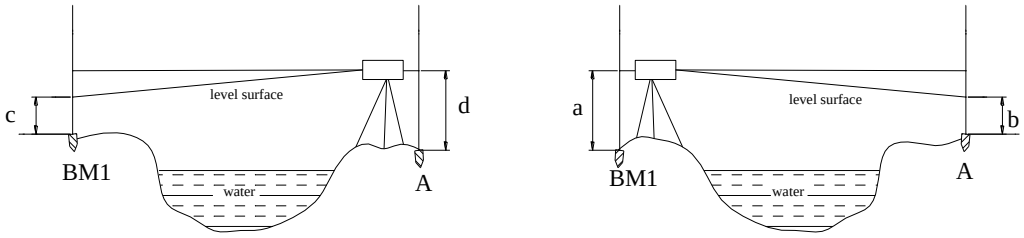


Figure 7.5 : cross sectional

Reciprocal levelling

When a line of levels crosses a broad body of water it is impossible to balance the back sight and foresight distances, it is necessary to take sights much longer than permissible. Under such a measurement errors due to curvature and refraction become significant. To obtain the best results we should have to use the procedure termed as reciprocal levelling.



Set up 2 *set up 1*

Figure 7.6: Reciprocal levelling

The elevation of survey point A is to be determined by levelling from BM1. At a set up near BM1, a back sight is taken on BM1 a fore sight on A. The difference in elevation is computed as (BS – FS). Next the level is set up near point A. Assuming that atmospheric refraction remains constant during the time between the two set ups, the correct differences in elevation is computed as the mean of the two measured differences.

$$\textbf{El of A} = \frac{(a-b)+(c-d)}{2} + \textbf{El of BM1}$$

Example:

If a = 1.442 m
b = 1.911 m
c = 1.768 m
d = 2.325 m

And El of BM1 = 1980.40 m so:

$E1_A = 1980.400 + (-0.514) = 1979.886$m

7.1.4 Level field books and arithmetic check

A level field book or a level book is used for booking and reducing the levels of various points on the surface of the earth. There are a lot of methods for reducing the levels etc. The surveyor should select the level book according to the method of reduction he proposes to use.

The following table shows a page of the more generalized level book.

Levelling field book

Observer: _____Instrument:_____Project:_____Date:_____ Page:_____

Point	Back	Inter mediate sight	Fore	△h	Elevation	Remarks

1	sight 2	3	sight 4	5	6	7
BM1	1.244				1680.200	
TP1	2.101		0.662	0.582	1680.782	
TP2	1.000		1.021	1.08	1681.862	
BM.2			3.221	-2.221	1679.641	

ΣB.S = 4.345 ΣF.S = 4.904

Steps to be followed:

1. Sum up all back sight and fore sight readings
2. Calculate the difference between ΣBS and ΣFS = -0.559
3. Calculate all △h`s following the way of subtraction indicated by an arrow.
4. Sum up all △h`s = -0.559
5. Check whether Σ△h is equal to the value in step no 2 (actual △h) (First check).
6. Add each △h to the previous elevations.
7. At the end you will get the elevation of B.M.2 =1679.641

7.2 Principle of levelling

When the levelling instrument has been properly levelled, the bubble tube axis and the line of sight are horizontal and the vertical axis of the instrument is truly vertical. When the telescope of the instrument is rotated, the line of sight remains in the horizontal plane.

In practice, the levelling instrument is set up at a convenient position, and the one staff is kept at a point of known elevation. The reading is taken on the staff and the level of the line of sight is determined. Now the 2nd level staff is kept on the point of the unknown elevation and a reading is taken. The level of the point is determined from the level of the line of sight already computed and from the 2nd staff reading.

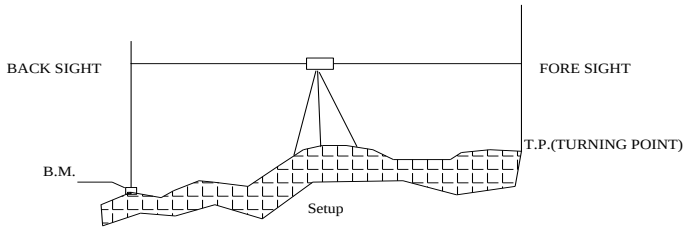


Figure 7.7

7.3 Elevation and contour

The process of tracing contour lines on the surface of the earth is called Contouring.

Purpose of Contouring

Contour survey is carried out at the starting of any engineering project such as a road, a railway, a canal, a dam, a building etc.

- For preparing contour maps in order to select the most economical or suitable site.
- To locate the alignment of a canal so that it should follow a ridge line.
- To mark the alignment of roads and railways so that the quantity of earthwork both in cutting and filling should be minimum.
- For getting information about the ground whether it is flat, undulating or mountainous.
- To find the capacity of a reservoir and volume of earthwork especially in a mountainous region.
- To trace out the given grade of a particular route.
- To locate the physical features of the ground such as a pond depression, hill, steep or small slopes.

Contours and Contour Interval

The graphical portrayal of the configuration of the land surface (relief) is most commonly done with contour lines. It is the most accurate method of representing relief today.
A contour line is a line that connects points of equal level on the surface of the earth. The shoreline of a body of still water (e.g. a lake) is an excellent illustration of a contour line. In addition, if it were possible to cut off the top of a mountain horizontally slice by slice, the edge of each slice would form a contour. They are drawn on the two-dimensional paper to give the impression of a third dimension.

The properties of contours

- an imaginary lines
- have fixed height interval
- represent known height

Contour interval: The constant vertical distance (height difference) between two consecutive contour lines is called the *contour interval or Vertical Interval (VI).*
The proper choice of the contour interval depends on:

- **The nature of the ground**: In flat and uniformly sloping country, the contour interval is small, but in broken and mountainous region, the contour interval should be large otherwise, the contours will come too close to each other.
- **The scale of the map:** The contour interval should be in the inverse ratio to the scale of the map i.e. the smaller the scale, the greater is the contour interval.
- **The purpose of the survey**: Contour interval is small if the area to be surveyed is small and the maps are required to be used for the design work or for determining the

quantities of earthwork etc. while wider interval shall have to be kept for large areas and comparatively less important works.

- **Time and expense of field and office work**: the smaller the contour interval the more points have to be measured in the field and the more time consuming is the plotting. Because of that, the topographic map would become more expensive. In other word smaller the contour interval; the greater is the amount of fieldwork and plotting work.
- **The slopes of the terrain to be represented:** the terrain is very hilly and the contour interval is too small in relation to the scale, the contour lines become too crowded.

7.4 Characteristics of Contours

The contours have the following characteristics:

1. All points in a contour line have the same elevation
2. The contour lines are closed lines. However, they may close either on the map itself or outside the map, depending upon the topography.
3. As the perpendicular distance between two contour lines is the shortest distance, contours are always perpendicular to the direction of the steepest slope. Therefore, surface water always runs downhill at right angle to the contour lines. These contour lines form U's, pointing downhill.
4. In case of a valley lines or streams, the contours run roughly parallel to the valley line or stream and form /\'s pointing uphill where they cross the valley line or stream.
5. If the spacing between the contour lines is small the slope is steep, but for gentle slopes the spacing is large.
6. Contour lines never cross one another or branch into two contour lines of the same elevation because a point on the ground cannot have two elevations; they may overlap and appear to meet only at vertical walls and overhanging cliffs are two examples where this condition is violated.
7. Depression contours form closed loop contours around the lowest point. The elevations of the contours decrease from outside to inside.
8. Summit contours form closed loop contours around the highest point. The elevations of the contours increase from outside to inside.
9. Contours do not have sharp turnings.
10. Contours are not shown going through buildings.
11. Contours crossing a man-made horizontal surface (roads, railway track) will be straight parallel lines as they cross the facility.

12. Horizontal distance between contours is inversely proportional to the ground slope. Hence, on a steep slope, contour lines run close to each other.
13. A uniform slope is indicated when the contour lines are uniformly spaced.

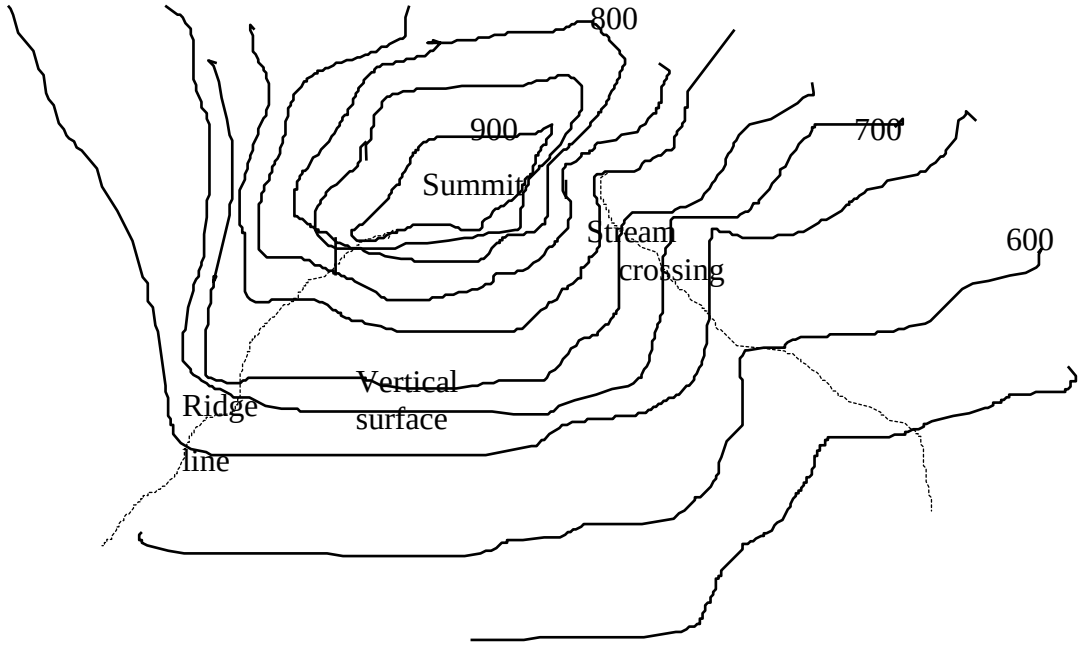


Fig 7.8 Contour lines