राष्ट्रीय भू-सूचना विज्ञान एवं प्रौद्योगिकी संस्थान
भारतीय सर्वेक्षण विभाग
विज्ञान और प्रौद्योगिकी विभाग

National Institute for Geo-Informatics Science & Technology
Survey of India
Department of Science & Technology

Verical Control Survey

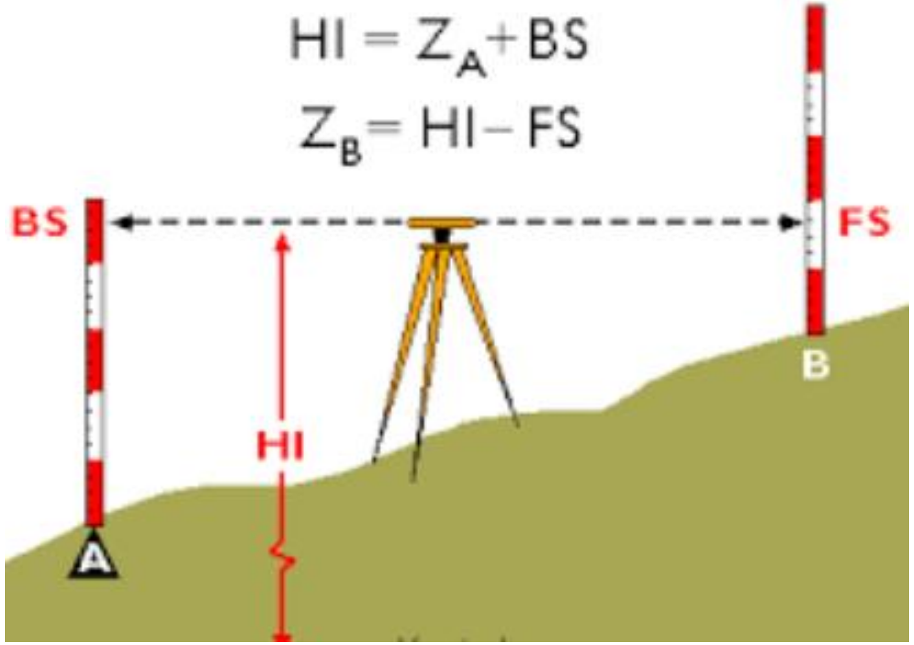
S. D. SHARMA, Officer Surveyor
Faculty of Topo. & GIS, NIGST,
Survey of India, Hyderabad
Email ID: sdsharma.soi@gov.in
Contact: +917097008906

Session Objectives

- To explain the concept, scope, and importance of Vertical Control Survey.
- To understand the fundamental principles and procedures of levelling.
- To familiarize with vertical datums, geoid, and different height systems.
- To explain the classification, accuracy standards, and types of bench marks used in levelling.
- To introduce various methods of height determination, including spirit, trigonometric and GNSS-based levelling.
- To highlight the applications of vertical control data in mapping, engineering, and infrastructure projects.

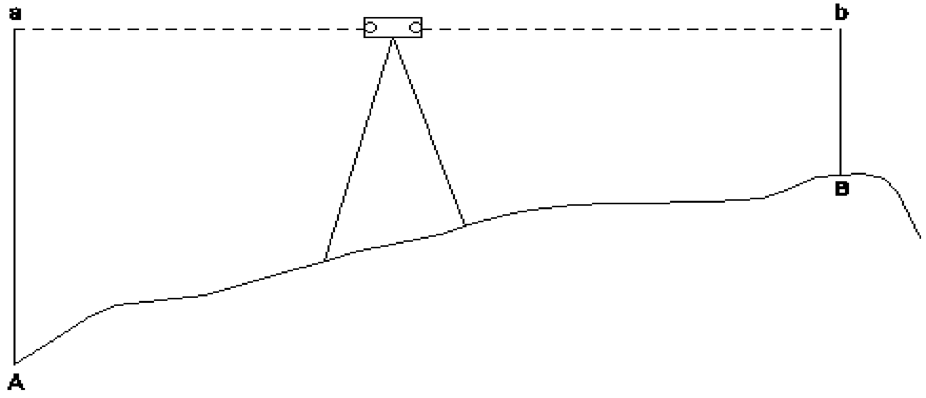
Vertical Control Survey

- A Vertical Control Survey is the process of establishing a network of points with accurately determined elevations referenced to a common vertical datum.
- It provides the height control framework required for mapping, engineering design, construction and geospatial data generation, ensuring that all elevation measurements within a project area are consistent, reliable and comparable.



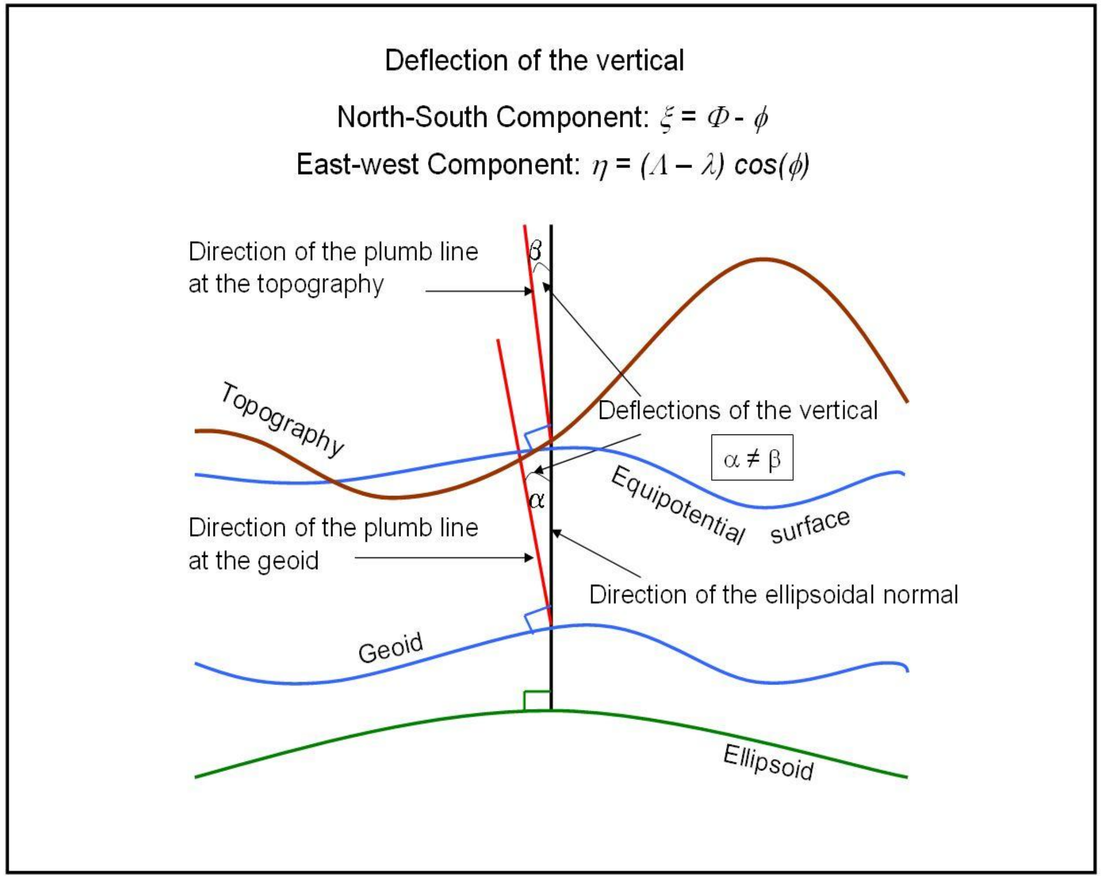
Basic Principles of Levelling

- Levelling is based on the determination of **difference in elevation** between points with respect to a common **vertical datum**
- A **horizontal line of sight** is established using a level instrument
- The line of sight is perpendicular to the **direction of gravity** at the instrument station
- Elevation difference between two points is obtained from **staff readings**, independent of horizontal distance
- Accuracy depends on proper **instrument setup and balancing of back sight and fore sight distances**



Geoid, MSL

- **Geoid:** Equipotential (level) surface of the Earth's gravity field that best fits global Mean Sea Level; reference surface for orthometric heights
- **Mean Sea Level (MSL):** Arithmetic mean height of the sea surface derived from continuous tide-gauge observations, averaged over a **19-year tidal cycle** to remove lunar and solar tidal effects
- **Relationship:** Local MSL does not exactly coincide with the geoid due to ocean currents, temperature, salinity, and atmospheric pressure, producing small hills and valleys relative to the geoid
- **Difference:** Maximum difference between local Mean Sea Level and the geoid is of the order of **about 1 m**.



Vertical Control

- Past -
- HP Levelling Network was established in India during British period.
- Old values of dynamic heights were calculated using normal gravity values.
- The level of mean Sea was considered same throughout the east and west coast.
- Present -
- Precise Gravimeters used to observe accurate gravity values.
- Level of Mean Sea at Apollo Bandar observatory in Mumbai is taken as zero.
- Height and Gravity value will be utilised to compute geo-potential numbers and Helmert Orthometric Heights.
- Repeating the levelling lines in every 30-35 years is essential.
- In coastal region repetition of the levelling needs to be carried out in 10-15 years.

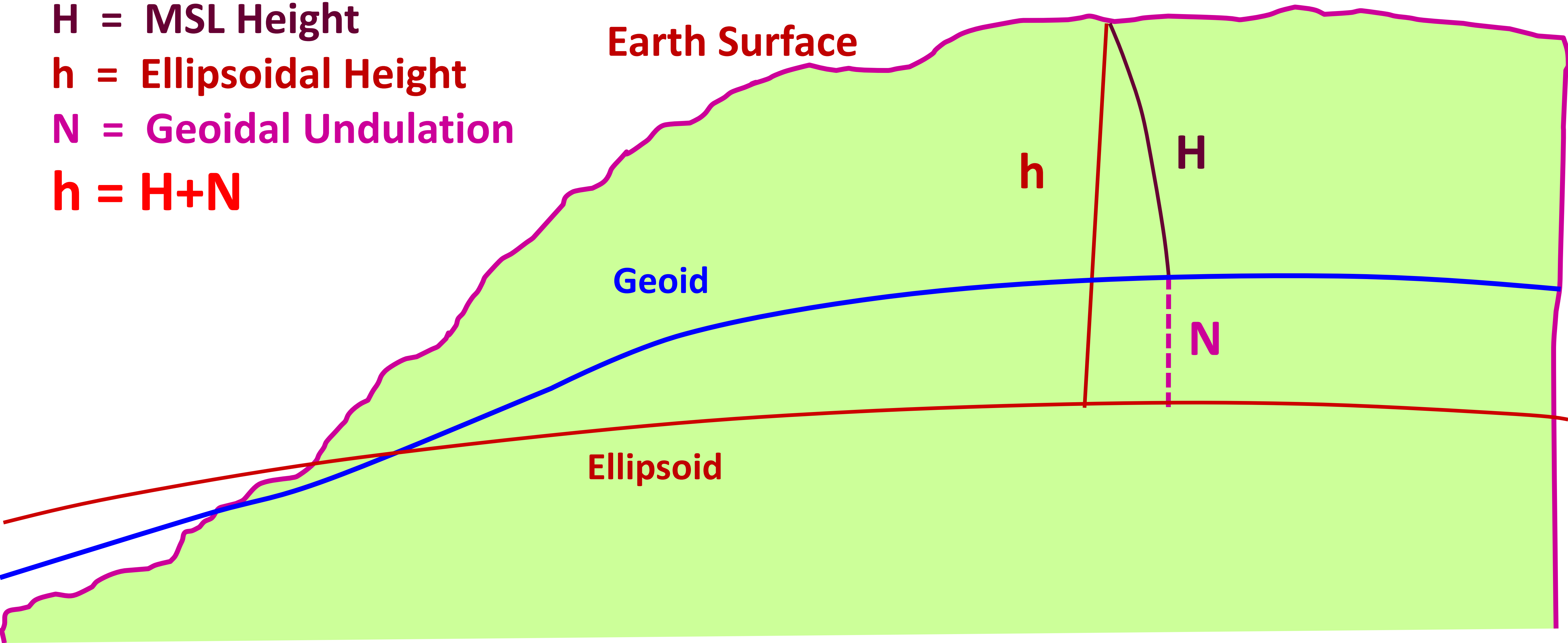
Ellipsoidal, MSL Height and Geoidal Undulation

H = MSL Height

h = Ellipsoidal Height

N = Geoidal Undulation

h = H+N



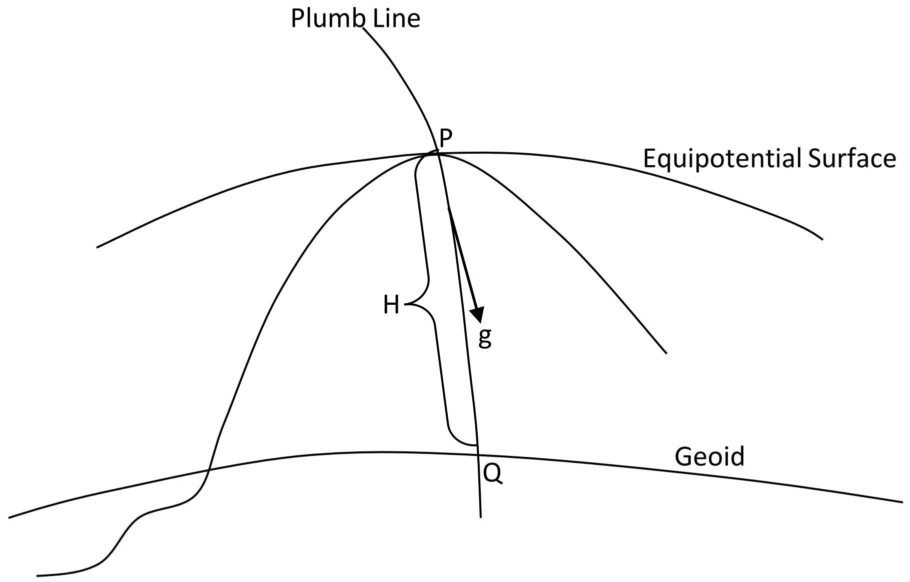
Orthometric Height

- The orthometric H of a point P is defined as the geometric distance between the geoid and the point measured along the plumbline (direction of gravity).

$$H = \frac{C_P}{\bar{g}}$$

$$\bar{g} = g_P + 0.0424\,H$$

- Cp = geopotential number



Classification of Levelling

- Depending upon the type of instrument used, procedure adopted for observations and refinement of computations, the leveling is classified into the following categories:-
- **Leveling of High Precision**
- **Precision Leveling** **Mainly done by G&RB, SOI**
- **Secondary Leveling**
- **Tertiary Leveling**:- **Mainly done by various Geospatial Directorates.**
  - The Tertiary leveling is again sub-divided into :
    - Single Tertiary Leveling (ST) in which the permissible error is **25 √K mm** where K is the distance in km.
    - Double Tertiary Leveling (DT) in which the permissible error is **12.5√K mm** where K is the distance in km.
    - Agreement between two set of observation at a station is **0.002m**

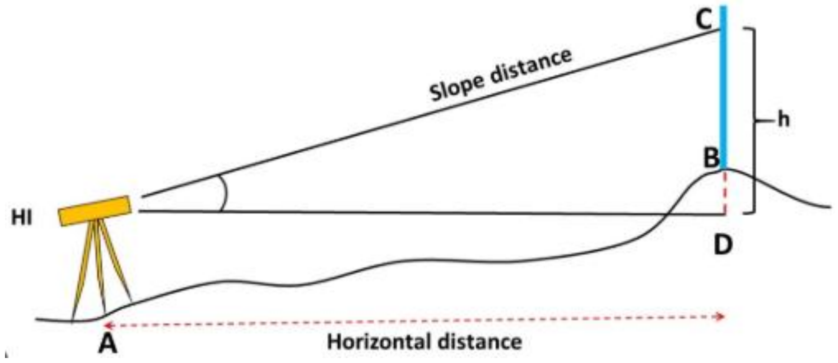
Methods

Methods for determination of height

- Spirit levelling (Differential levelling)
- Trigonometric levelling
- GNSS based Height determination

Special methods of spirit levelling:

- Differential levelling.
- Profile levelling
- Cross-section levelling
- Reciprocal levelling



Trigonometric levelling

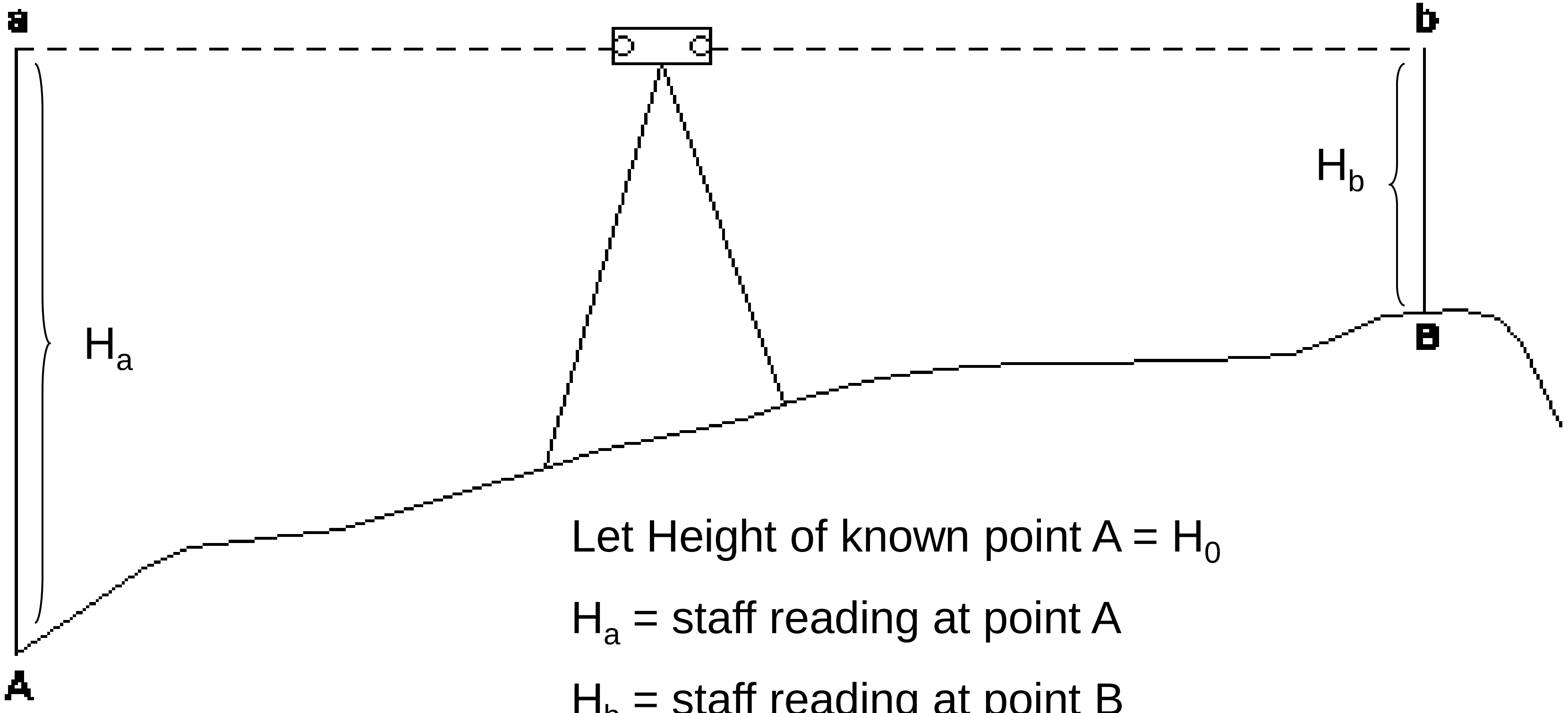
Spirit Levelling

- ❖ If a horizontal line of sight is established between two points A and B then the difference of the readings of this line on a graduated scale, placed successively on the two points A & B will give the difference in elevation between these two points A & B.
- ❖ The horizontal line of sight is established with the help of an instrument, called level. Graduated scales known as levelling staves are normally used to determine the altitude difference.
- Let height of A = H_0
- Height of level surface ab = $H_0 + H_a$
- Height of B can be obtained by subtracting H_b from the height of level surface ab
- i.e. Ht of B = $H_0 + (H_a - H_b)$
- where $(H_a - H_b)$ is the difference of staves reading kept at point A & B.

- This is the basic principle of levelling.

- ❖ By similar way, heights of other points can be established by running the various level net whole over country.

Schematic diagram of Levelling



Let Height of known point A = H_0

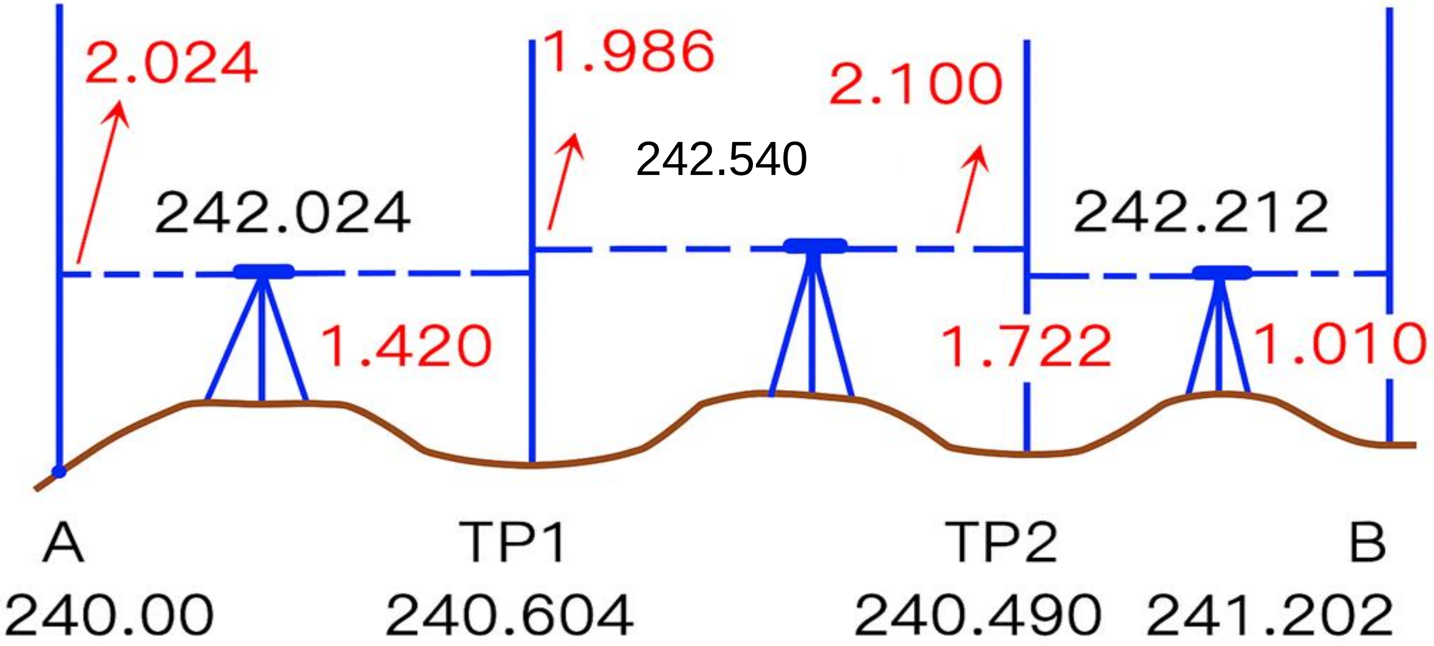
H_a = staff reading at point A

H_b = staff reading at point B

So, Height of point B = $H_0+(H_a-H_b)$

Differential levelling

- To determine the elevations of a number of points, some distance apart, to establish Bench Marks (BM's) in the area

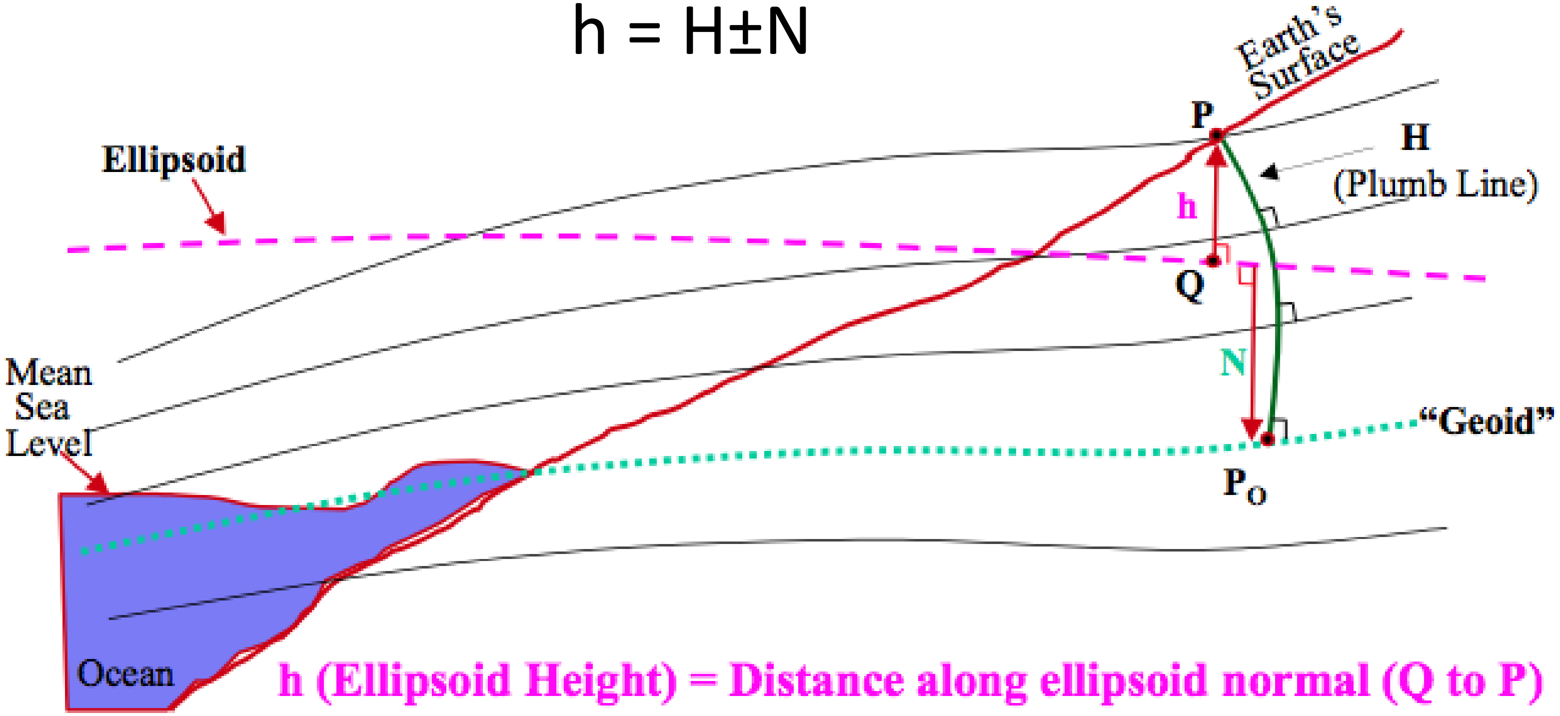


Rise and Fall method

	Staff Reading		Difference in Elevation		Elevation	
Points	B.S (m)	F.S.(m)	Rise (m)	Fall (m)	R.L (m)	Remark
A	2.365				100.000	B.M.
S_1	0.685	1.235	1.130		101.130	$T.P._1$
S_2	1.745	3.570		2.885	98.245	$T.P._2$
B		2.340		0.595	97.650	

GNSS based Height determination

$h = H \pm N$



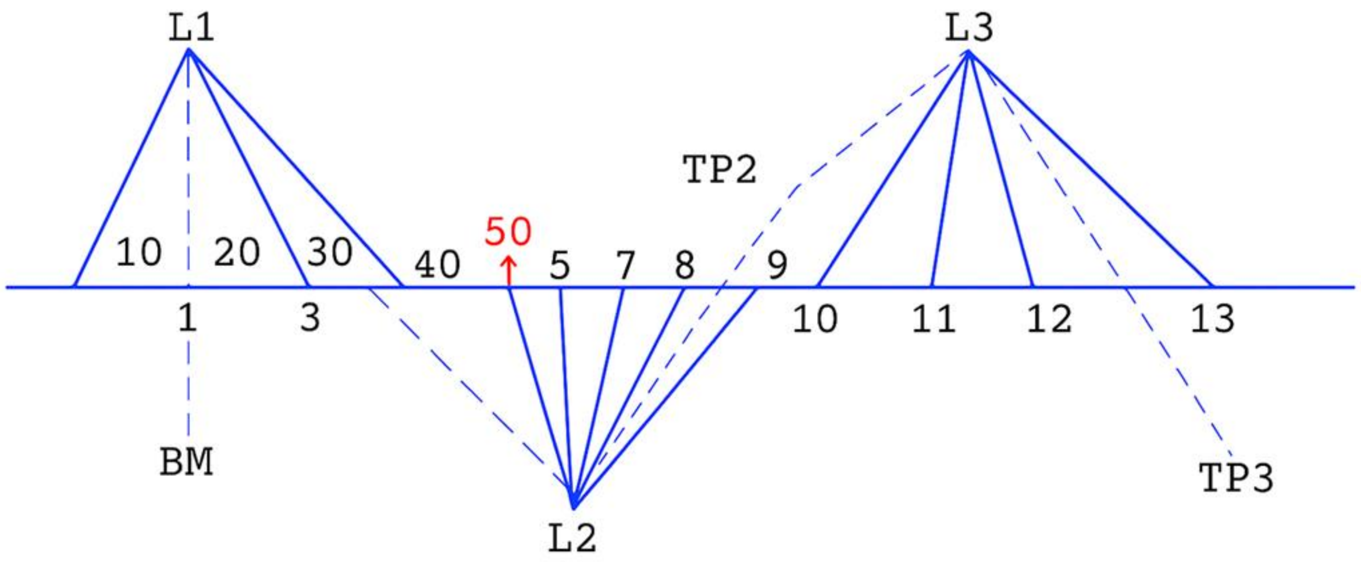
h (Ellipsoid Height) = Distance along ellipsoid normal (Q to P)

N (Geoid Height) = Distance along ellipsoid normal (Q to P_O)

H (Orthometric Height) = Distance along plumb line (P_O to P)

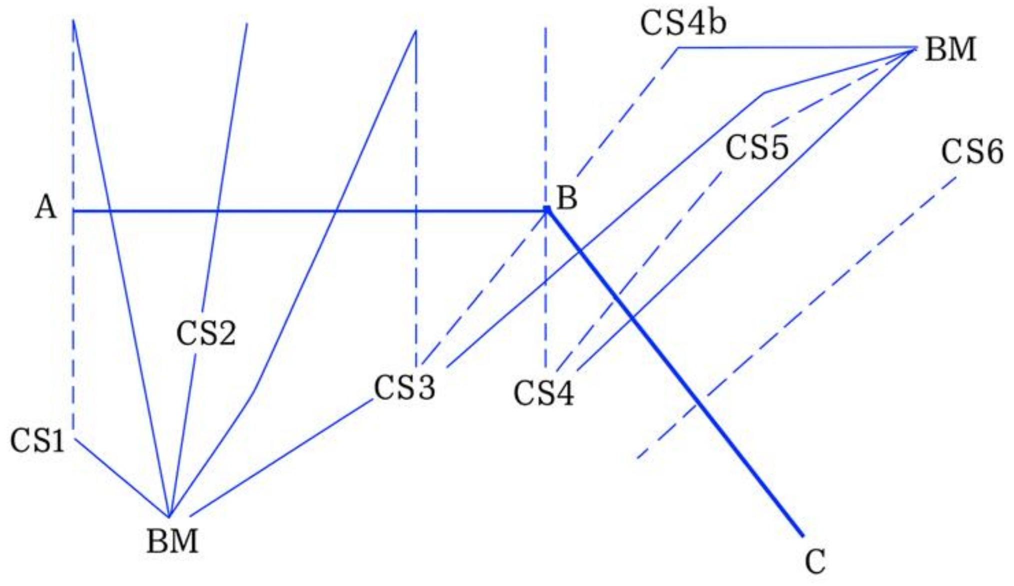
Profile levelling

- It is the method of direct levelling the object of which is to determine the elevations of points at measured interval along a given line in order to obtain a profile of the surface along that line.



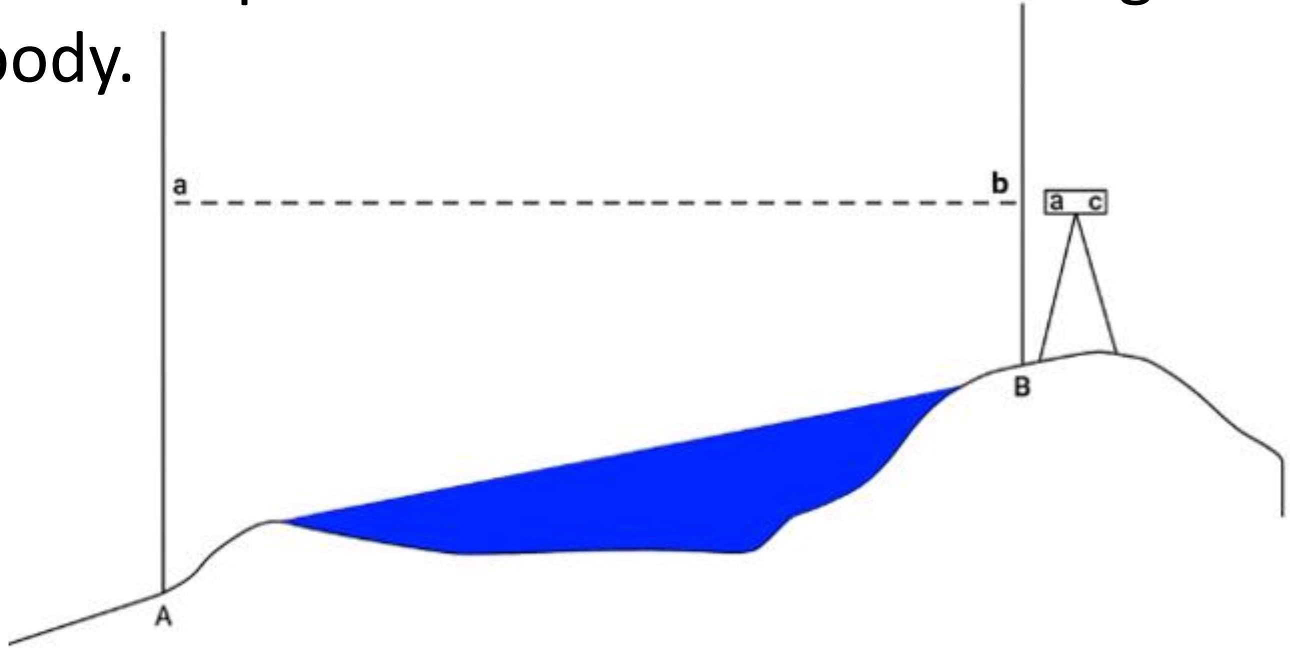
Cross section Levelling

- The operation of levelling, which is carried out to provide heights on either side of the main line at right angles, in order to determine the vertical section of the earth surface on the ground.



Reciprocal levelling

- The operation of levelling in which difference in elevations between the points is determined accurately by two sets of reciprocal observations.
- Reciprocal levelling is employed when it is not possible to setup the level between two points due to an intervening obstruction such as large water body.



Levelling in SOI

- Depending upon the type of instrument used, procedure adopted for observations and refinement of computations, the leveling is classified into the following categories: -

  a)Leveling of High Precision

  b)Precision Leveling.

  - 1st order—permissible error—$0.003125\sqrt{k}$
  - 2nd order--- permissible error—$0.00625\sqrt{k}$
  - 3rd order--- permissible error—$0.0125\sqrt{k}$, where K in km

  c)Secondary Leveling.

  d)Tertiary Leveling**:-** The Tertiary leveling is again sub-divided into

  i)Single Tertiary Leveling (ST) in which the permissible error is **0.025**x**√K** where K is the distance in km.

  ii) Double Tertiary Leveling (DT) in which the permissible error is **0.0125**x**√K** where K is the distance in km.

Types of Bench Marks

- Type ‘A’
- Type ‘B’
- Type ‘C’ Standard Bench Mark
- Type ‘M’
- Type ‘P’
- Ordinary intermediate bench mark
- TG BM

Bench Marks

G T S
O
B M

B O M

B
O
M

B O
M

B M
O

B M
O

B M
O

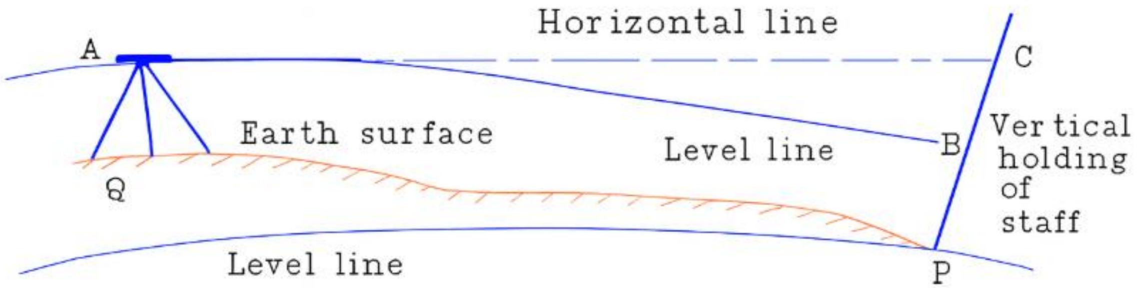
O
B M

O ‘ represent the point at which height of Bench Mark is measured.

In a levelling line, SBM will be constructed at every 30 to 40 Km.

Between two SBM, ordinary Bench Marks will be inscribed which is not continuously same design.

Curvature & Refraction correction



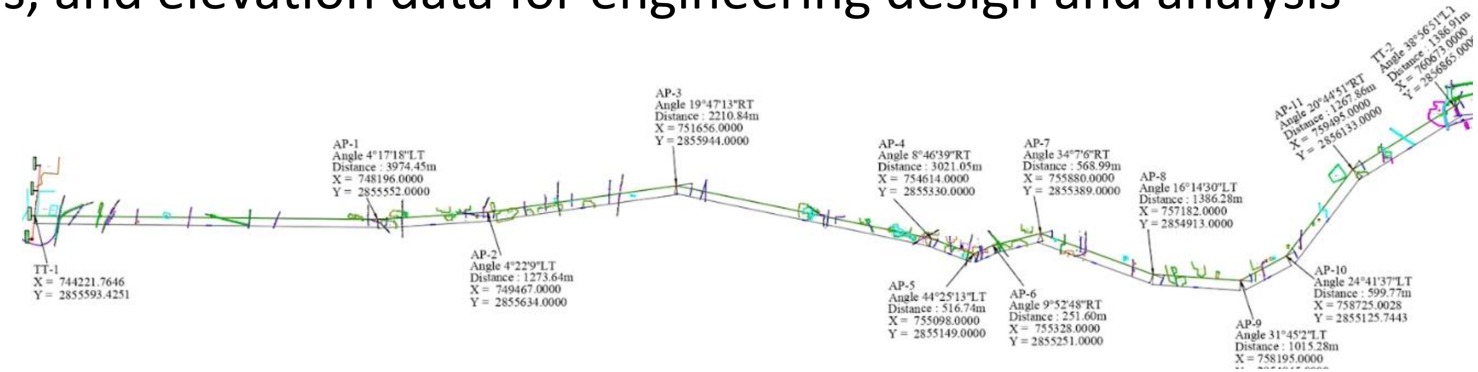
Cc = **$d^2/2R$ = 0.07849 d^2** meters

C**r** = 1/6. **$d^2/2R$ = 0.01121 d^2,** where "d" is in km.

Combined Correction, C = **0.06728 d^2 where "d" is in km.**

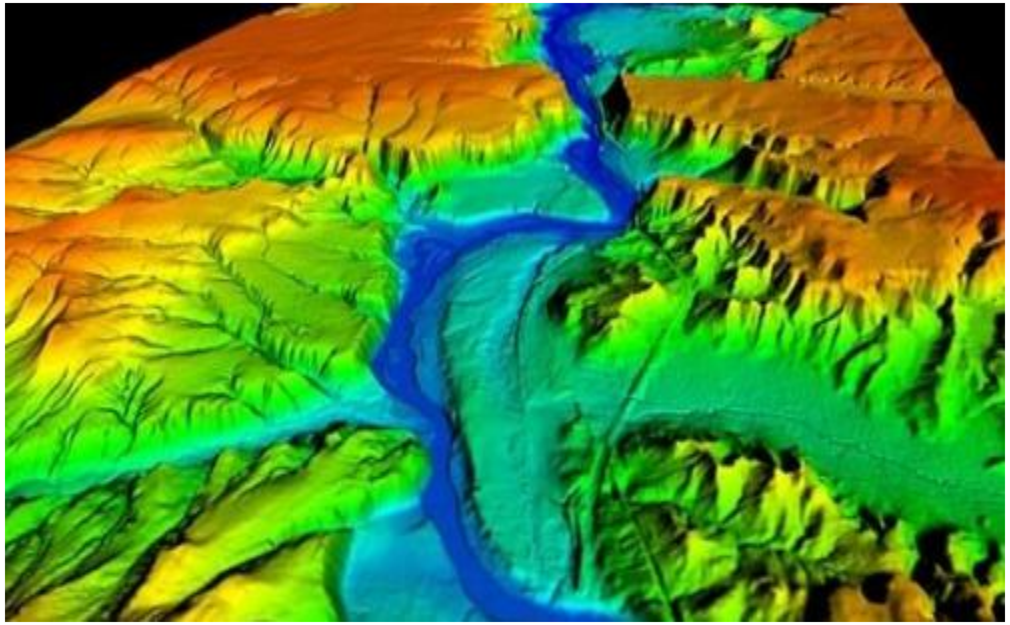
Profile data Collection

- **Purpose:** Measurement of ground elevations along a defined alignment to understand terrain variation
- **Longitudinal Profile:** Continuous elevation data along the centerline of the project (road, canal, pipeline, transmission line)
- **Cross-Sections:** Ground levels taken perpendicular to the alignment at regular intervals and at critical locations
- **Methods:** Spirit levelling, trigonometric levelling using ETS, GNSS-based profiling; UAV/LiDAR where required
- **Applications:** Design of gradients, clearance checks, earthwork estimation, and infrastructure planning
- **Outputs:** Profile drawings, spot levels, and elevation data for engineering design and analysis



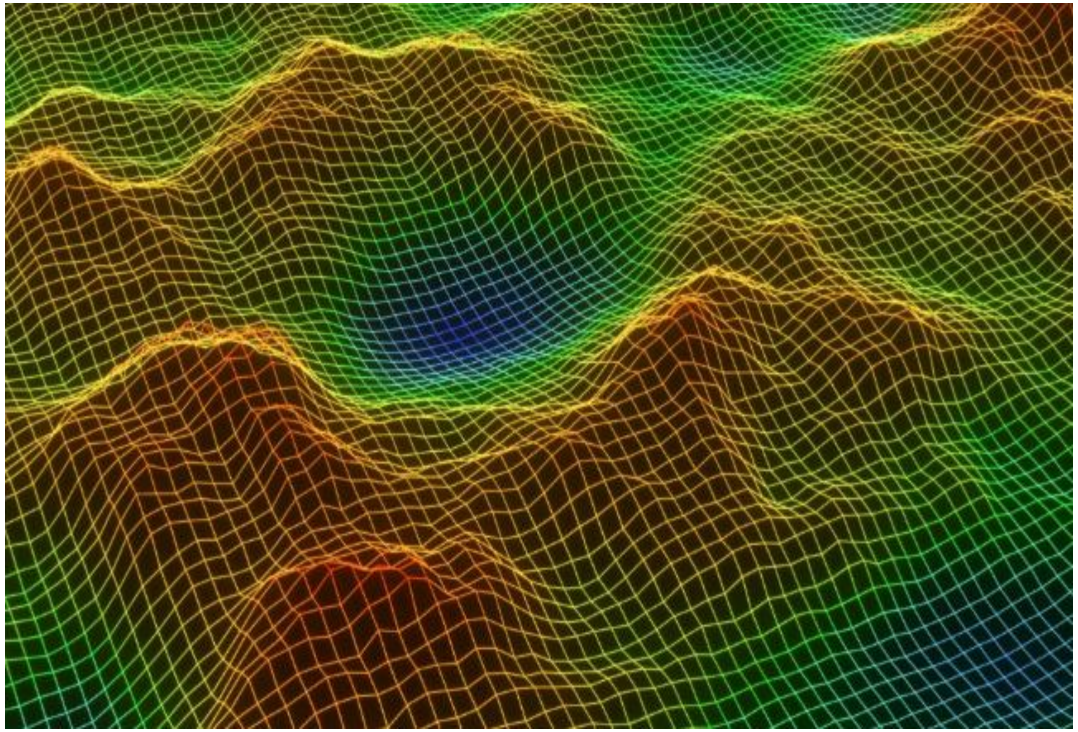
Digital Elevation Model (DEM)

- Raster representation of **bare-earth elevations**
- Buildings, vegetation, and man-made objects removed
- Derived from photogrammetry, LiDAR, or GNSS surveys
- Used for contour generation, slope analysis, and watershed studies



Digital Terrain Model (DTM)

- Refined terrain model based on DEM
- Incorporates **breaklines, ridges, valleys, embankments, and terrain features**
- Provides a more realistic representation of ground surface
- Used for **engineering design**, road/rail alignment, and earthwork computation



Digital Surface Model (DSM)

- Represents the **Earth's surface including objects** such as buildings, trees, and structures
- Captures top-of-surface elevations
- Used for **urban planning, line-of-sight analysis, and power line clearance studies**

Sources of Errors in Levelling

1. Instrumental Errors

- Collimation error (line of sight not truly horizontal)
- Imperfect adjustment of level tube or compensator
- Faulty staff graduations or damaged staff
- Instrument settlement during observation

2. Personal Errors

- Incorrect focusing causing parallax
- Improper staff holding (staff not vertical)
- Mistakes in staff reading or recording
- Unequal back sight and fore sight lengths

3. Natural Errors

- Curvature of the Earth
- Atmospheric refraction
- Wind affecting staff stability
- Temperature variations affecting instrument and staff

Adjustments of level

a) Temporary adjustments:

- Setting up of the level
- Leveling
- Elimination of Parallax

b) Permanent adjustment:

- To make the vertical axis perpendicular to Bubble axis.
- The line of collimation should be parallel to the level tube axis.

Instruments used in Levelling

- **Dumpy Level:**
  Traditionally used in Survey of India for **routine levelling and control extension**; known for robustness and stability.
- **Tilting Level:**
  Used where **higher precision** is required than dumpy level; bubble is centered for each sight using a tilting screw.
- **Automatic Level:**
  Widely used in modern SOI field operations for **levelling** before the advent of Digital level due to speed and reliability.
- **Digital Level:**
  Used for **precise and high-precision levelling**, benchmark establishment, and modernization of vertical control networks; minimizes observer bias.

Exercise

1. The reduced level (RL) of Bench Mark A is 242.540 m.
   A level is set up and the following staff readings are observed:

   Back Sight (BS) on BM A = 1.325 m

   Fore Sight (FS) on point B = 2.115 m

   Determine the Reduced Level of point B.

2. At a point P, the following data are given:

   Geopotential number, $C_P=3.60\times104\ m^2/s^2$

   Observed gravity at point P, $g_p=9.803\ m/s^2$.

   Using the Helmert mean gravity expression, $\bar{g}=g_P+0.0424\ H$,

   Determine the orthometric height (H).

Summary

End of Session – Thank You!