Leveling

3.1 Definitions

- **Leveling** is the procedure used to determine differences in elevation between points that are remote from each other.
- **Elevation** is a vertical distance above or below a reference datum.
- (Mean Sea Level) MSL = 0.000 m.
- **Vertical line** is line from surface of the earth to the earth center → ***plumb line*** *or* ***line of gravity.***
- **Level line** is a line in level surface.
- **Level surface** is carved surface parallel to the mean surface of the earth.
- **Horizontal line** is a straight line perpendicular to vertical line.

3.2 Theory of Differential Leveling

- **Differential leveling** is used to determine in elevation between remote points using surveyor's level with graduated measuring rod
- **Level** is a cross hair equipped telescope

Elevation of A + rod reading A - rod reading at B = elevation of B

- All rods reading contain an error C over distance d.
- The divergence between a **level** and **horizontal** line is quite small for short distances.
- For distant of 1000 ft: divergence = 0.024 ft

300 ft → 0.002 ft

100 m → 0.0008 m

3.3 Curvatures and Refraction Concept of Curvature Error

Divergence between level line & horizontal line over specified distances.

→ All sight lines are refracted downword by the earth's atmosphere.

→ Magnitude depends on atmospheric condition

Generally considereal one-seventh of curvature error.

$(R + C)^2 == R^2 + KA^2$

$R^2 + 2RC + C^2 = R^2 + KA^2$

$C (2R + C) = KA^2$

$C = KA^2 /(2R + C) = KA^2/2R$

Take R == 6,370 km

$C = KA^2$ X 103/2 x 6370 = 0.0785 KA^2

Refraction is affected by atmospheric pressure and temperature

Geometric location usually = 1/7 C

If r = 1/7 C

$C + r = 0.0675 K^2$

K = KA length of sight in km

3.4 Types of Surveying Levels

3.4.1 Automatic level

- Employs gravity referenced prism or mirror compensator to automatically orient the line of sight (line of collimation)
- The instrument is quickly leveled using circular spirit level.
- Compensator maintains horizontal LOS even telescope slightly titled
- 2, 3 or 4 screws leveling base.
- 2 & 3 Screws can change elevation of line of sight
- Methods of sitting

Advantage

- Popular, quick sitting
- Compensator prisms and mirror are hanged by fine wire if broken → no accuracy.
- Constant check by tapping telescope end or turning one leveling screw or push button.
- Concave base attached to domed head : Screws not used if compensator is active.
- Least count 0.01 ft or 0.001 m : Precise level with optical micrometer can read one or two place beyond least count.

3.4.2 Digital Level

- Electronic image processing for determining height and distance
- Electronic mode with rod face graduated in bar code (Fig. 3.12)
- Compare image with the whole rod image. - Auto determination of height & dist and recorded

Horizontal angle has to be read and recorded manually if rod is not plumb or upside down error message

3.4.3 Tilting Level

- Equipped with circular spirit level for rough leveling which telescope is pointed to the rod.
- The telescope is precisely leveled by tilting screw which raise or lower eyepiece end of telescope until tube level is leveled.
- Tube level is viewed through separate eyepiece lens or telescopes its self.
- 3 screws leveling base.
- Screws can change elevation of line of sight.

3.5 Leveling Rod

- Wood, metal, fiberglass
- Graduated in ft or meter 0.01 ft 0.0 m with mm estimated
- Optical micrometer can be read more precise values.
- One piece rod → more precise.
- Normal leveling 2-3 piece rods
- Metal plate at bottom (zero mark).
- Wide verity of marks see p. 69
- Surveyor most be familiar with graduation
- Rectangular see rod → folding or sliding
- Bench mark leveling → uses folding rods or invar rods with built in handles and rod level.

3.6 Definitions for Differential Leveling

- **Benchmark** (BM) is a permanent point of known elevation.
- **Temporary benchmark** (TBM) is a semi-permanent point of known elevation.
- **Turning point** (TP) is a point temporarily used to transfer an elevation.
- **Back sight** (BS) is a rod reading taken on a point of known elevation in order to establish the elevation of the instrument line of sight.
- **Height of instrument** (HI) is the elevation of the line of sight through the level (i.e. elevation of BM + BS = HI).
- **Foresight** (FS) is a rod reading taken on a turning point, benchmark, or temporary benchmark in order to determine its elevation (i.e., HI - FS = elevation of TP (BM or TBM).
- **Intermediate foresight** (IS) or (IFS) is a rod reading taken at any other point where the elevation is required.

HI - IS = elevation of the point

3.7 Techniques for Leveling

- Choose convenient location (e.g. hard surface)
- Hard surface & spreading the legs of tripod improve stability
- Soft surface: push legs hard into ground
- On hills one leg uphill, tow leg downhill
- Attach the inst. to tripod head and level it
- Use 2 screws at a time to level the inst
- Revolve the inst. to check leveling
- Focus the eyepiece lenses on the rod (sharp image)
- If both focusing operations are correct the cross hairs are super imposed

on leveling Rod.

- If either focusing operation is not correct it will appear that cross hair is moving up and down as observer-head moves slightly up or down.
- If one or both not focus the result and error is known as **parallax**.

Signals

- Inst. man and Rodman are away from each other (traffic, noise)
- Arm signals are used to communicate information
- Turning point hold, arm erect and slowly make horizontal circle
- Task accomplished: extend both hands and wave up and down
- Raise the rod: inst. man up word motion with one hand
- Use portable ratio on noisy sites

To determine elevation of selected point with respect to a point of known elevation:

Elevation of A	=	220.15
BSA	=	+1.80
HI	=	221.95
FS B	=	- 2.45
Elevation B	=	219.40 m

The elevation of any point lower than LOS, and the rod is visible from level, can be determined.

For any instrument setup:

Existing elevation + B S = HI

HI -FS = new elevation

Distance of BS should ≈ FS to eliminate or minimize errors due to curvature and refraction

- Numerous setups may be required before reading desired pint.
- Survey must be closed to a point of known elev. (BM) or loop

To determine accuracy and acceptability of survey:

- If closure is not within allowable limit the survey must be repeated.
- To insure rod is plumb use rod level or rod man gently waves the rod toward and a way from inst.
- Avoid sitting the rod on the back edge

Arithmetic check

Original elevation + ΣBS - ΣFS = new elevation

- Verify first BM can be down through leveling to the closest alliance BM.

3.8 Benchmark Leveling (Vertical Control Survey)

- This type is employed when system of benchmarks is to be established or when an extension to existing system
- High level of precision → Table 3.2
- Precision level coincidence tabular bubble sensitive 10" per 20 mm
- Micrometer
- Invar rods with base plate & rod level and supports
- Tripod is larger than usual minimize reflection (LOS is higher)
- Identical work closely windless days, protect inst. from sun
- For municipal & regional grid specification are relaxed some what

3.9 Profiles and Cross Section

For route survey:

- **Plan view** top view
- **Profile** side view along CL define xyz coordinates
- **Cross section** side view at right angle of CL

(Fig. 3.17, 3.19 and Fig. 3.20)

- Profile taken on ***Centerline*** (proposed ***Centerline*** staked out at even interval 50- 100 ft (20-30 m)

- Choose level setup in convenient location so that BM and as many as intermediate points can be measured

  Rod reading at each significant change of slope.

  - Call for turning point TP

- Turning point TP on wood stake, corner of concrete monument (hard surface or stakes driven), Should be easy to describe and found later.
- BM to BM or loop back
- Field note BS, IS, FS on separate columns
- Rod reading on soft ground closest 0.1 Ft or 0.01 m on hard surface 0.01 ft, 0.003 m
- Cross section are taken at each even station with rod pending taken at each significant change in slope
- Uniform slope : reading at each station
- Cross section note (municipal format) (Fig. 3.21)
- Cross section note (highway format) (Fig. 3.22)
- Borrow pits (gravel pits) determine the volume of material (costing)
- Reference base lines away from stripping and stockpiling
- Grid elevation of original surface and excavated surface (Fig. 3.23)

3.10 Reciprocal Leveling

- BS and FS with equal distances from level setup
- Obstacle river, change level position and obtain 2 differences in elevation take average (Fig. 3.24)

3.11 Peg Test

- Test to check that L.O.S through level is horizontal

  Fig. 3.26) Ex. 3.2

  True difference and apparent difference

  Error in 60 m → error in m/m

  Collimation correction (C factor)

  Equal distance → eliminate collimation error

  In ordinary work → negligible.

3.12 Three-Wire Leveling

(Calibrated or invar rod)

Stadia cross hairs

Each BS and FS is recorded

As three figures and average, then

Correction for collimation (determined once a day for precise work)

Correction in Sum of FS

Fig. 3.28

3.13 Trigonometric Leveling

$$V = S \sin \theta$$

Elev. At A + hi ± V – RR = elev. At B

hi = height of instrument from ground to center of telescope

- Used if there is steep cliff on CL of road, pipe, …… etc.
- Slope is measured by tape, EDM or stadia
- Angle measured by theodolite or clinometer for low order survey

Fig. 3.30, Ex. 3.3

- If hi can be seen on the road → facilitate computation

3.14 Level Loop Adjustment

- If the error is within allowable tolerances then adjust for it. If not, repeat

- Do adjustment according to distance or number of setup.
- Ex. 3.4, Fig. 3.31

Error E = Initial BM reading – Calculated BM Reading

Correction = (-) Cumulative dist./Total dist. * E