LEVELING

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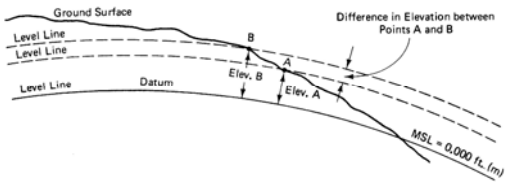
DEFINITIONS

- Vertical line – also known as plumb line - line following direction of gravity
- Level surface – curved surface where every point is perpendicular to plumb line
  - Approximate spheroidal shape – e.g. body of water at complete rest
  - Also known as equipotential surfaces – for a surface, potential of gravity is equal at every point on surface
- Level line – line in level surface - ∴ curved line
- Horizontal plane – plane perpendicular to local direction of gravity
  - Plane perpendicular to local vertical line

DEFINITIONS

- Horizontal line – line in horizontal plane, perpendicular to local vertical
- Vertical datum – level surface to which elevations is referred
  - Arbitrarily assigned elevation of zero
- Elevation – distance measured along vertical line from vertical datum to point or object
- Geoid – level surface serving as datum for elevations and astronomical observations
- Bench mark (BM) – relatively permanent object, natural or artificial, having marked point with elevation above or below the adopted datum

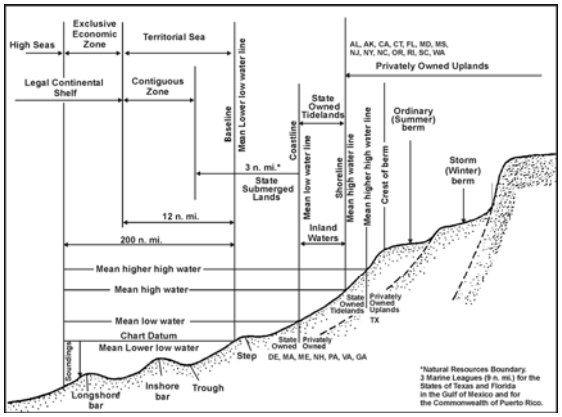
DEFINITIONS



- 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
- Leveling – process of finding elevations of points, or their differenced in elevation
- Vertical control – series of bench marks of know elevation established throughout area
  - In US – series of first-, second-, and lower order leveling

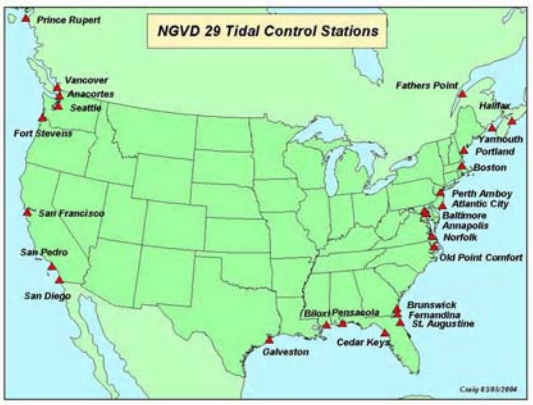
DEFINITIONS

- Tidal datums – vertical datums used in coastal areas for establishing property boundaries of lands bordering waters subject to tides
  - Include: mean high water (MHW), mean low water (MLW) and mean lower low water (MLLW)



NORTH AMERICAN VERTICAL DATUM

- National Geodetic Vertical Datum of 1929 (NGDV29)
  - USC&GS adjusted over 100,000 km of leveling incorporating 26 tidal gaging stations
  - Related to mean sea level and refererred to sea level datum



NORTH AMERICAN VERTICAL DATUM

- National Geodetic Vertical Datum of 1988 (NAVD88)
  - NGVD29 deteriorated due to sea level changes and shifting of earth's crust
  - Included 1.3 million observed elevation differences
  - Also adjusted leveling in Canada and Mexico
  - Reference: father Point/Rimouski in Quebec, Canada, along St. Lawrence Seaway
  - Differences with NGVD29 are small but significant, greater in western part of US (1.5m in Rocky Mountains)

Orthometric Heights
Comparison of Vertical Datum Elements

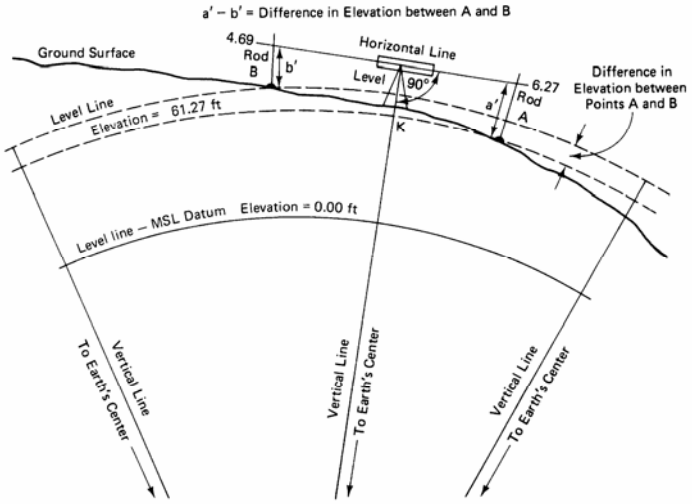
	NGVD 29	NAVD 88
DATUM DEFINITION	26 TIDE GAUGES IN THE U.S. & CANADA	FATHER'SPOINT/RIMOUSKI QUEBEC, CANADA
BENCH MARKS	100,000	450,000
LEVELING (Km)	106,724	1,001,500
GEOID FITTING	Distorted to Fit MSL Gauges	Best Continental Model

THEORY OF DIFFERENTIAL LEVELING

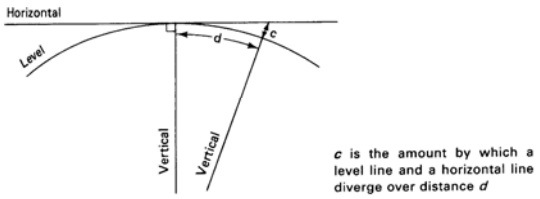
- Used to determine differences in elevation between points by using surveyor's level along with graduated measuring rod
- Level consists of cross-wires in telescope attached to spirit level tune mounted on tripod
  - When set up properly, will give line of sight defining horizontal plane

$$\text{Elev}_A + \text{Rod Reading}_A - \text{Rod Reading}_B = \text{Elev}_B$$

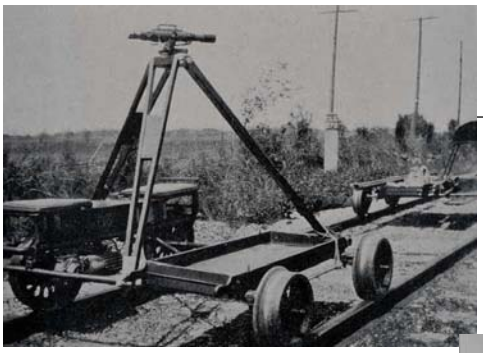
$$61.27 + 6.27 - 4.69 = 62.85$$



DIFFERENTIAL LEVELING



- Problem in figure – elevations referenced to level lines (surfaces), line of sight is almost horizontal line
- All rod readings contain convergence error, c, at distance d
- Amount: for d = 1,000', divergence = 0.024', for 300' distance, divergence is 0.002'

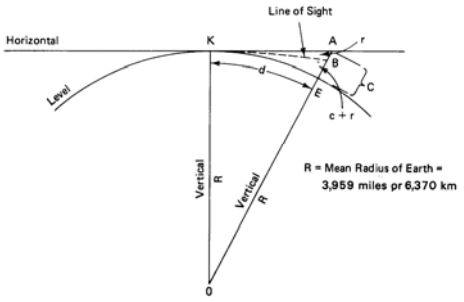


Level Observations Near Pittsburg, TX, circa 1902

Level Setup on Motor Velocipede

CURVATURE AND REFRACTION

- Curvature error also must account for refraction
- Lines of sight refracted downward by earth's atmosphere
  - Magnitude about 1/7 of curvature error
  - Partially compensates for curvature error



CURVATURE AND REFRACTION

- Curvature error

$$(R+C)^2 = R_2 + KA^2$$

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

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

$$C = \frac{KA^2}{2R+C}$$

$$\approx \frac{KA^2}{2R}$$

- Ignore c because small w.r.t. R
- Take R = 6,370 km,

$$C = \frac{KA^2 \times 10^3}{2 \times 6370}$$

$$= 0.0785\,KA^2$$

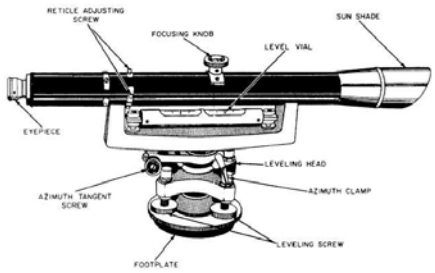
CURVATURE AND REFRACTION

- Refraction, r, affected by atmospheric pressure, temperature, geographic location
- Combined effects of curvature and refraction (c + r) are:

$(c+r)_m = 0.0675K^2$	$(c+r)_m$ in meters	K in kilometers
$(c+r)_{ft} = 0.574K^2$	$(c+r)_{ft}$ in feet	K in miles
$(c+r)_{ft} = 0.0206M^2$	$(c+r)_{ft}$ in feet	M in thousands of feet

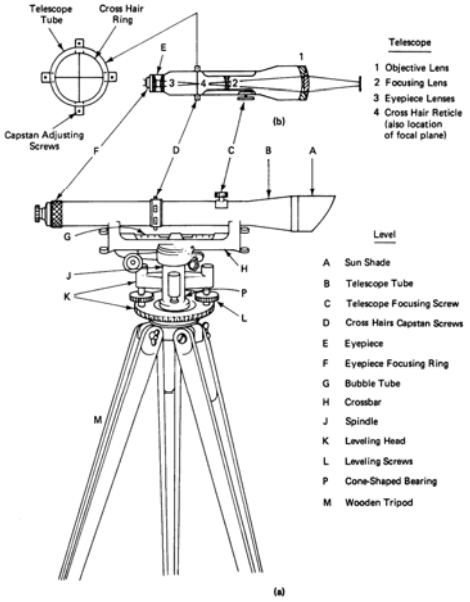
DUMPY LEVEL

- Three main parts: telescope, leveling tube, leveling head
- Line of collimation (line of sight) joins center of objective lens to intersection of cross hairs
- Optical axis – line through center of objective lens and perpendicular to vertical lens axis



DUMPY LEVEL

- Cross hairs – thin wires attached to cross-hair ring, or lines etched on glass plate that is enclosed by cross-hair ring
- 4 adjustable capstan screws used to adjust cross hairs up and down or left and right by loosening and tightening cross hair capstan screws



Blattner Wye Level

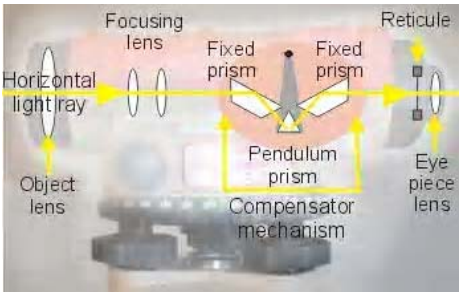
Mahn Dumpy Level

Level Survey Party

Zeiss level instrument, 1946

AUTOMATIC LEVEL

- Employs gravity-referenced prism or mirror compensator to orient line of collimation (line of sight) automatically
  - Compensator takes over once bubble in circular spirit level nearly leveled
- Advantages
  - Easy to set up and use
  - Can be used for almost any required precision



AUTOMATIC LEVEL

- Most levels equipped with three-screw leveling base
  - Four-screw base – center bearing while three-screw instruments supported entirely by foot screws themselves
  - Adjustment of foot screws effectively raises or lowers height of instrument line of sight
  - Adjustment of foot crews of four-screw instrument does not affect height of instrument line of sight – instrument supported by center bearing

AUTOMATIC LEVEL

Nikon AX-2s
Automatic Level

Zeiss Ni 2

DIGITAL LEVEL

- Uses digital electronic image-processor using a charge-coupled device (CCD) for determining heights and distances
- Automatic level (pendulum compensator) capable of normal optical leveling
- With press of button, can capture and process image of bar-code rod for distance from 0.5m to about 100m
- Processed image of rod compared with image of whole rod, stored in level's memory module

DIGITAL LEVEL

Leica DNA03 Digital Level

Trimble DiNi Digital Level

TILTING LEVEL

- Instrument roughly leveled with circular spirit level
- Just before reading rod, telescope precisely leveled by raising/lowering eyepiece end of telescope using tilting screw
  - Tubular level used for final leveling operation
  - bubble usually split in two longitudinally and two half ends are brought into coincidence – here telescope is precisely leveled

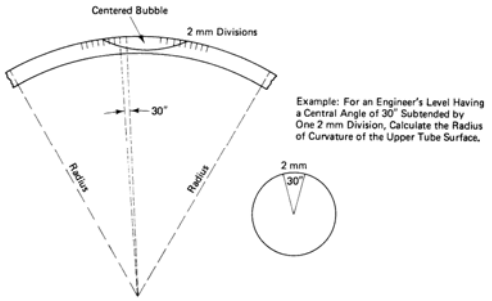
TILTING LEVEL

- Accuracy of center level bubble with tubular scale graduate at 2 mm
  - 1/5 division or 0.4 mm
  - With split bubble: 1/40 division or 0.05 mm
- Level tube
  - Filled with alcohol or other liquid with low freezing point
  - Upper surface ground to form circular arc
  - Sensitivity of bubble directly related to radius of curvature of bubble tube
    - Larger radius – more sensitive is level tube

Watts Tilting Level

LEVEL BUBBLE SENSITIVITY

- Sensitivity – central angle subtending one division (usually 2 mm)
- For many engineers' levels – sensitivity is 30"
- For precise levels, sensitivity usually 10"

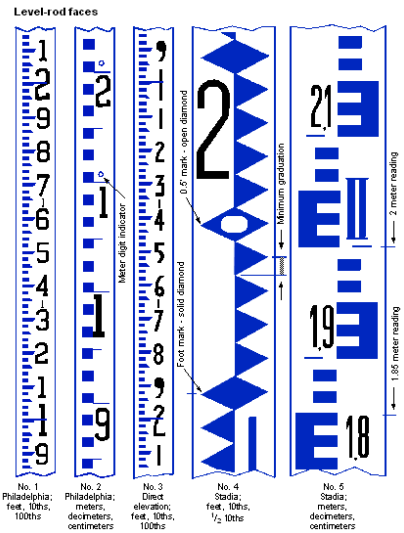


$$\frac{30''}{360^\circ} = \frac{0.002\,\text{m}}{2\pi R}$$

$$R = \frac{360^\circ}{0.00833^\circ} \times \frac{0.002\,\text{m}}{2\pi} = 13.75\,\text{m}$$

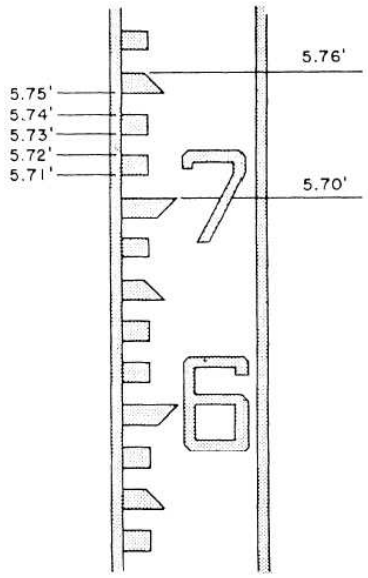
LEVEL RODS

- Wood, metal, fiberglass
- Graduated in feet or meters
- Variety of patterns
- One-piece rods used for more precise work
- Precise rods – face is invar strip held in place under temperature-compensating spring tension



LEVEL ROD

- A point on the face that is upwards indicates a whole tenth of a foot (0.1)
- A point on the face that is downwards indicates a whole 0.05’



DIFFERENTIAL LEVELING DEFINITIONS

- Benchmark (BM) – permanent point of know elevation
  - Placed in structure with substantial footings (below minimum frost dept penetration) to resist vertical movement due to settling & upheaval
- Temporary Benchmark (TBM) – semi-permanent point of know elevation
- Turning Point (TP) – temporary point used to transfer elevation
- Backsight (BS) rod reading on point of known elevation
- Height of Instrument (HI) – elevation of line of sight through level
- Foresight (FS) rod reading on point to determine its elevation
- Intermediate Sight (IS) rod reading on any other point

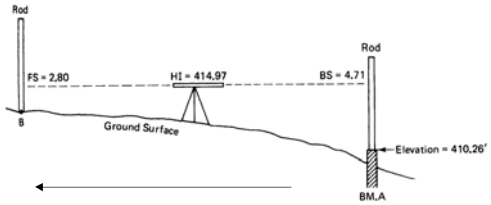
TECHNIQUE OF LEVELING

- Instrument usually set up in relatively convenient location
- Tripod legs snugly tightened
  - Leg, when raised, will fall back only under force of its own weight
  - Under tightening – can cause unsteady setup
  - Over tightening – can cause unsteady setup due to torque strain
- Tripod legs – rigid or collapsible (adjustable)
  - Rigid recommended for more stable setup
  - Adjustable gives more flexibility in instrument setup

TECHNIQUE OF LEVELING

- Eyepiece lens focus on crosshairs
  - Sharp as possible
  - Light colored background helpful
- Telescope focusing screw used to focus on level rod
- Both focuses in same plane
- Parallax – one or both focus adjustments improperly made
  - As observer's head moves slightly up/down, crosshairs appear to move slightly

TECHNIQUE OF LEVELING



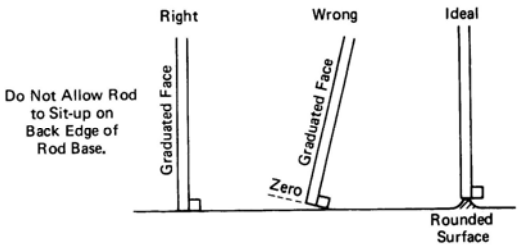
- Leveling commences on BS, ends on FS, with IS between
- Height of Instrument and Elevation of B found as:

$$HI = Elev_A + BS_A = 410.26' + 4.71' = 414.97'$$

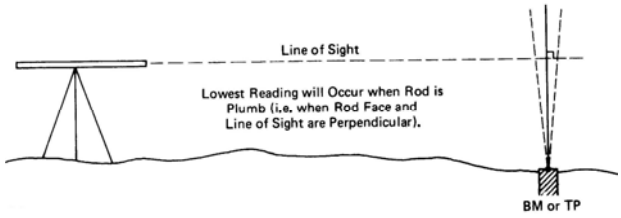
$$Elev_B = HI - FS_B = 414.97' - 2.80' = 412.17'$$

TECHNIQUE OF LEVELING

- Leveling between benchmarks/turning points
  - Level set up midway – eliminates/minimizes
    - Curvature & refraction errors
    - Faulty line of sight
- Careful in placement of rod



TECHNIQUE OF LEVELING

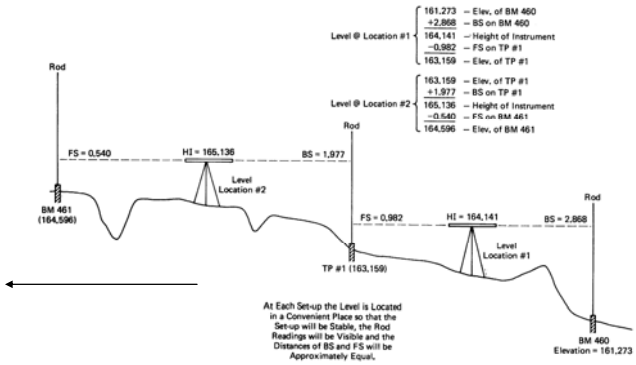


- Hold rod plumb
  - Rod level
  - "rock the rod" or "wave the rod"
    - Lowest reading correct reading

TECHNIQUE OF LEVELING

- When distance between 2 benchmarks too long, need to set turning point(s)
- Level loop – once elevations of 2nd point found
  - Go back to beginning
  - Continue leveling until another BM of known elevation is encountered

TECHNIQUE OF LEVELING



Arithmetic check

•Sum FS and BS readings separately

$$\text{Elev}_{\text{Last}} - \text{Elev}_{\text{First}} = \sum \text{BS} - \sum \text{FS}$$

$$164.596 - 161.273 = (2.868 + 1.977) - (0.982 + 0.540)$$

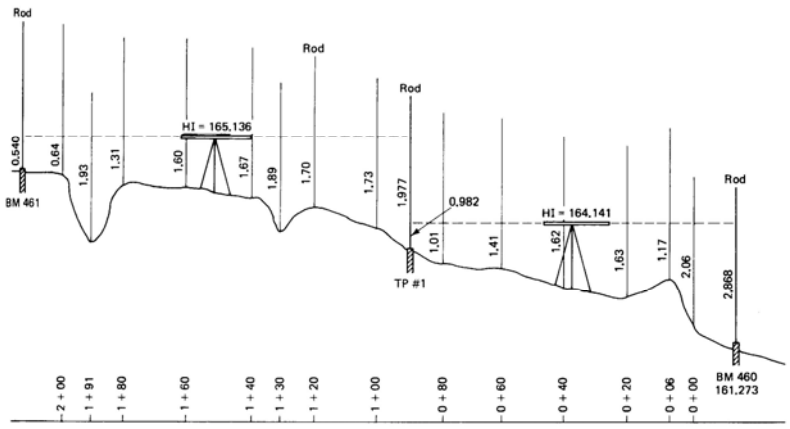
$$3.323 = 4.845 - 1.522$$

$$= 3.323 \quad \textit{check}$$

PROFILE LEVELING

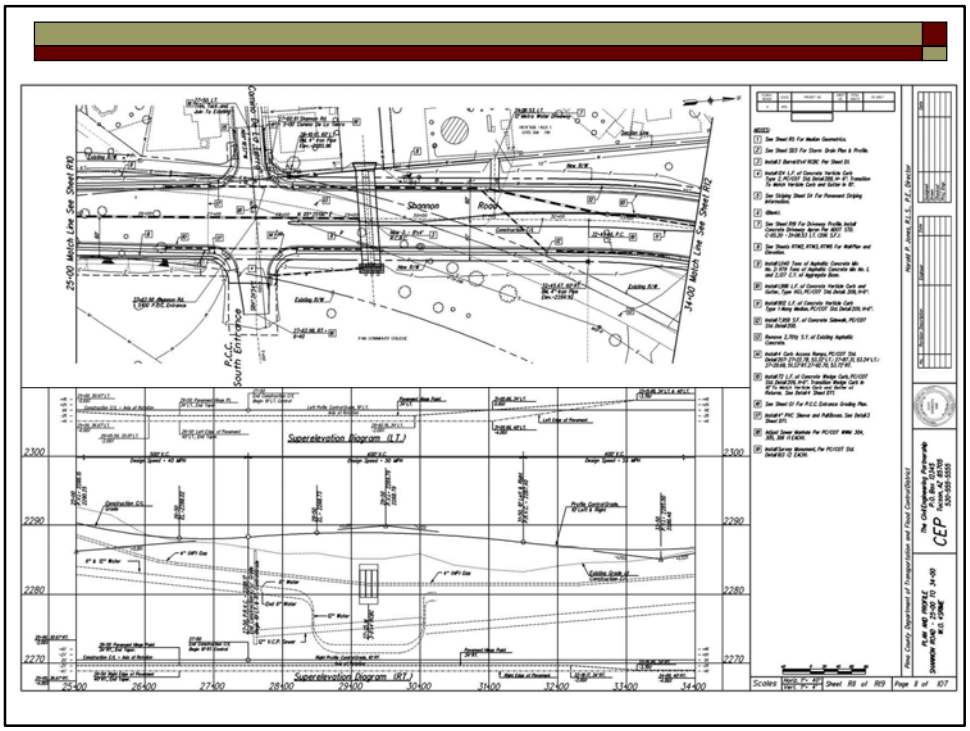
- Plan view – look down on area from above
- Profile view – side view or elevation where longitudinal surfaces highlighted
- Cross-section – shows end view of section at a station and is at right angles to centerline

PROFILE LEVELING



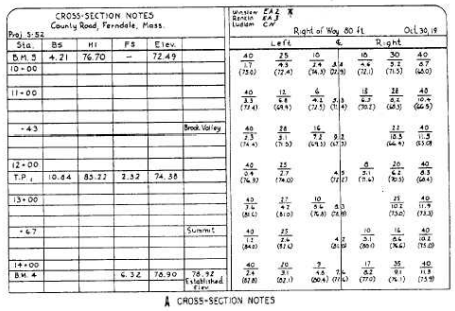
PROFILE LEVELING

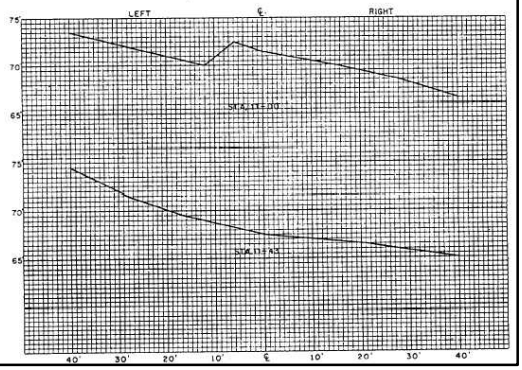
- Profile levels – taken along paths of interest to designer
  - In road work, often centerline (℄)
- Intermediate sights taken usually at some predefined interval
  - Rod readings taken to 0.1’ (0.01m)
- Turning points taken on solid, well-defined points
  - Rod readings taken to 0.01’ (0.003m)



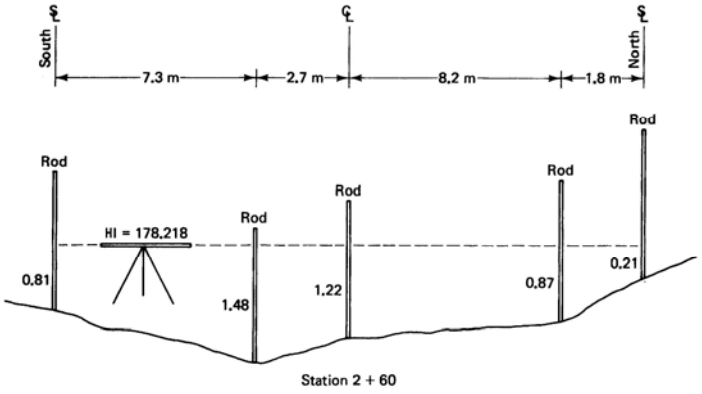
CROSS SECTION

- Taken at all even station
- Rod readings along line perpendicular to ℄
  - At significant change in surface slope
  - At limits of job





CROSS-SECTION SURVEYING



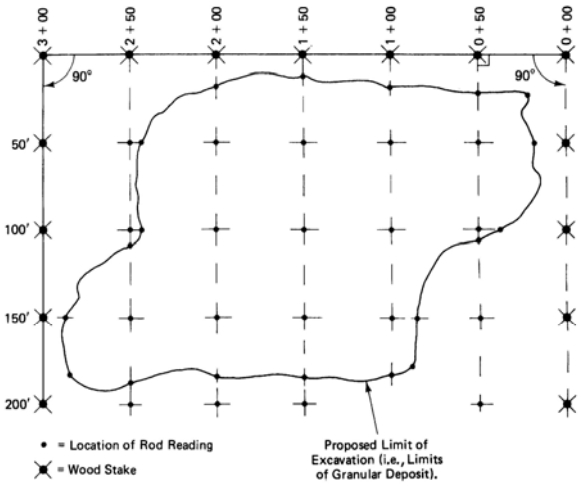
Observing from Level Mounted on Velocipede, California, 1920

Level Rod Operation Circa 1900

BORROW PITS (GRAVEL PITS)

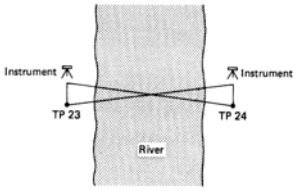
- Surveyed to determine volume of material "borrowed" and transported to site
- Before excavation, 1 or more reference baselines established
- Benchmarks (at least 2) located in convenient locations
- Cross section taken over (and beyond) area of proposed excavation
- Original cross section used as basis
- Subsequent cross sections taken after excavation

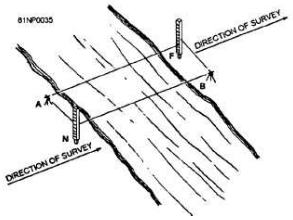
BASELINE CONTROL FOR BORROW PIT SURVEY



RECIPROCAL LEVELING

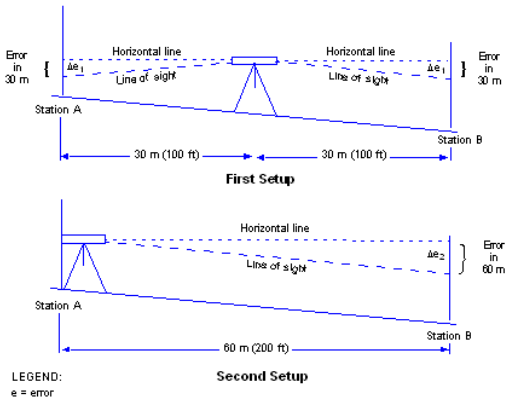
- Level set up near TP 23 and rod read at TP 23 and TP 24
- Level moved to other side and rod readings taken on both TPs again
  - Precision improved by taking multiple rod readings on pointings across river
- Differences in elevations averaged
  - Eliminate instrument and natural errors like curvature
  - Refraction errors minimized by keeping elapsed time to minimum





COLLIMATION TEST (PEG TEST)

- Check line of sight is horizontal (parallel to axis of bubble tube)
- In middle, difference in elevation will be true difference
- At A, no collimation error on rod reading on rod at A but will be present in reading on B if the error exists



COLLIMATION TEST

First Set-up	**Rod Reading at A**	**1.075 m**
	Rod Reading at B	**1.247 m**
	True Difference in Elevation	**0.172 m**
Second Set-up	**Rod Reading at A**	**1.783 m**
	Rod Reading at B	**1.946 m**
	Apparent Difference in Elevation	**0.163 m**

Collimation Error = Apparent Difference – True Difference

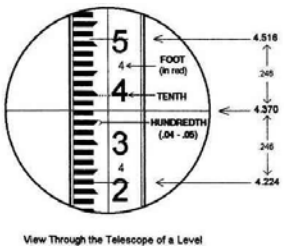
= 0.163m – 0.172m = -0.009m

Error in 60m

C-factor – collimation correction

$$\text{C} - \text{Factor} = -\frac{\text{Collimation Error}}{\text{Distance}} = -\frac{-0.009\,\text{m}}{60\,\text{m}} = 0.00015\,{}^{\text{m}}\!/_{\text{m}}$$

THREE-WIRE LEVELING

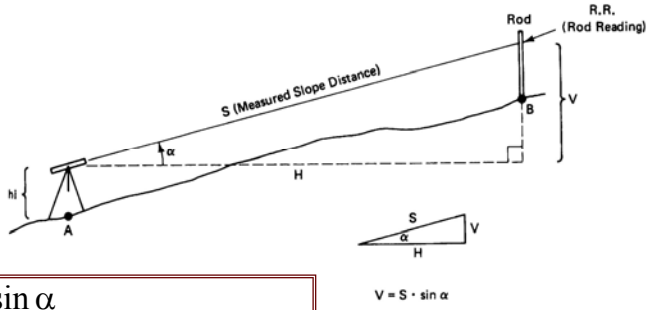


View Through the Telescope of a Level

- Utilizes the stadia cross hairs plus the horizontal cross hair
- Three readings averaged
- Stadia wires equal distance above/below horizontal wire
  - Gives 1.00 ft (m) of interval per 100 ft (m) of horizontal distance

TRIGONOMETRIC LEVELING

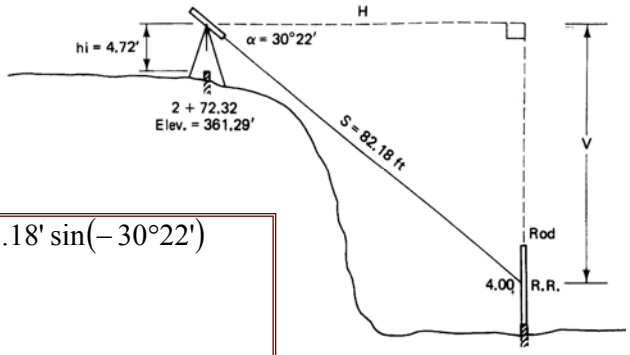
- Difference in elevation computed from vertical angle and slope distance



$$V = S\sin\alpha$$

$$Elev_B = Elev_A + hi \pm V - RR$$

TRIGONOMETRIC LEVELING EXAMPLE

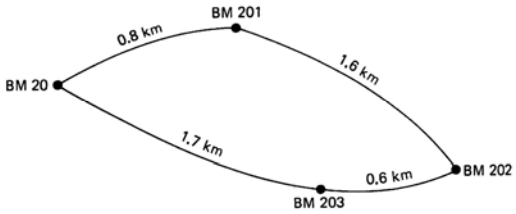


$$V = S\sin\alpha = 82.18'\sin(-30°22')$$
$$= -41.54'$$

$$Elev_{Rod} = Elev_{Inst} + hi + V - RR$$
$$= 361.29' + 4.72' + (-41.52') - 4.00'$$
$$= 320.47'$$

If hi = RR, simplifies the calculations

LEVEL LOOP



- Error proportional to distance traveled
- Can also be performed based on number of setups if the distances are unknown

SUGGESTIONS FOR ROD WORK

- Rod should be properly extended and clamped
- Make sure bottom of sole plate does not become encrusted with mud, dirt, etc.
- Rod targets, if used, should be properly positioned
- Hold rod plumb – use rod level or “rock rod”
- Make sure turning points are suitable
- FS and BS distances should be equal
- Hold rod in same place for both foresight and backsight readings
- Make sure rod is facing correct direction during observation

SUGGESTIONS FOR INSTRUMENT WORK

- Use rigid tripod if possible
- Tripod legs should be properly tightened
- Instrument should be cradled under one arm with instrument forward when moving to new setup position
- Make sure tripod is set into ground by gently applying weight on shoe spurs
- Spread tripod legs further apart when setting up on rigid surfaces
- When setting instrument up in hill, two legs should be placed downhill and the third uphill – roughly level using the uphill tripod leg
- Instrument location chosen to "see' maximum number of rod locations, particularly BS and FS locations

SUGGESTIONS FOR INSTRUMENT WORK

- Focus cross hairs sharply to eliminate parallax
- If parallax exists, check both cross hair and objective lens focus
- Read rod consistently, either top or bottom of cross hair
- Never move level before foresight taken
- Check that level bubble remains centered or compensation device is operating
- Rod readings should not be taken below 18" above ground due to refraction