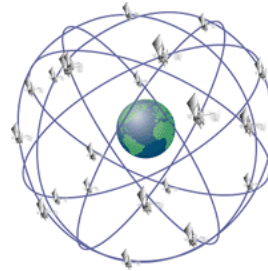
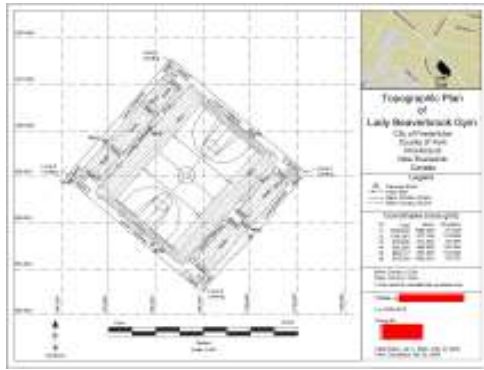


1. Control Surveys: Intro. 2. Leveling

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1/00

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Control Surveys

◆ Methods of Control Surveying

● Traversing

: distances (magnitude), angles (direction)

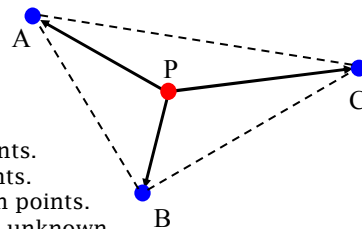
- Total Station, GPS or GNSS system
- open or closed type

: most fundamental → a closed traverse (controlled)

● Resection

: three directions are measured to three known features to determine unknown

1. Instrument needs to be set up on unknown points.
2. Not necessary to physically occupy known points.
3. Need to be able to sight to three or more known points.
4. Clear lines of sight needed between known and unknown points. There is no need to physically travel between the target and reference points.
5. Accuracy dependant upon the precision of instrument used.



<http://www.sli.unimelb.edu.au/>

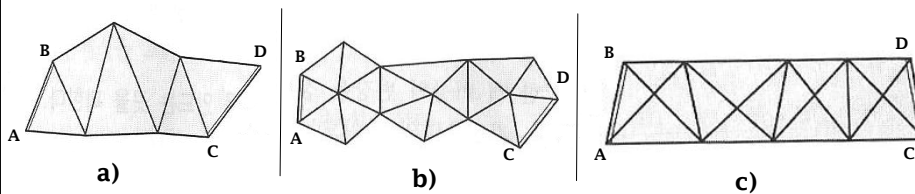
2/00

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Control Surveys

◆ Methods of Control Surveys (cont')

- Intersection
- Triangulation & Triangulation Network
 - a framework of linked triangles: connecting triangles, center point polygon, & braced quadrilaterals
 - measuring angles, from Willebrord Snell in 1615-17
 - GPS (or GNSS)

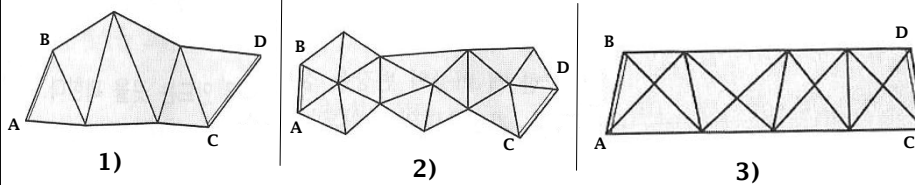


3/00

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Control Surveys

◆ Methods of Control Surveys (cont')



- Type 1
 - : appropriate of an area where the width is small, but the length is long; roads, tunnels, rivers etc.
 - : very fast, cost effective.
 - : not many measurements compared to the length; lowest precision
- Type 2
 - : appropriate of large area; flat area such as farm.
 - : better precision than type 1
- Type 3
 - : difficult to be adjusted, expensive, and time-consuming
 - : most precise than any other types; and largest number of conditions

4/00

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Control Surveys

◆ Procedures of Control Surveys

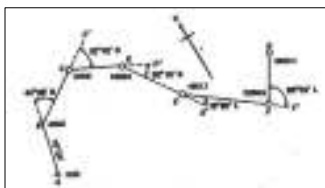
- Planning
 - specifications, field trip, method, equipment
 - control must be self-checking
- Selecting Station (control points)
 - convenience for detail surveying
 - inter-visible between stations for measurements
 - accessible and free from risk of disturbances
- Measurement
 - linear and angular measurements, and leveling
 - regular check and calibration of equipment
 - applying all necessary corrections
- Calculating Coordinates
- Plotting Control

5/00

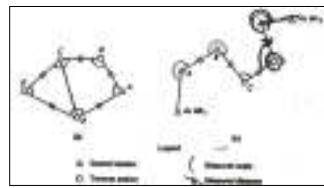
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Traverse

◆ Types of Traverse

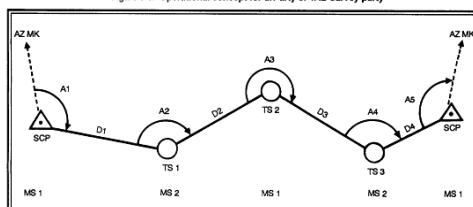


open or hanging traverse



closed loop and open "controlled" traverse (balancing)

Figure 5-6. Operational concept for div arty or TAB survey party



open "controlled" traverse (balancing)

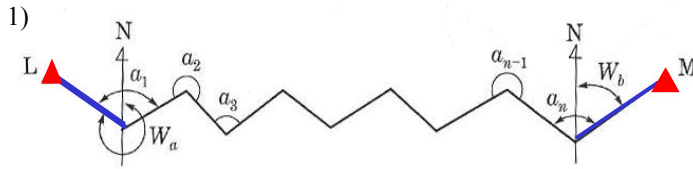
<http://www.globalsecurity.org/military/library/policy/army/fm/6-2/Ch5.htm>

6/00

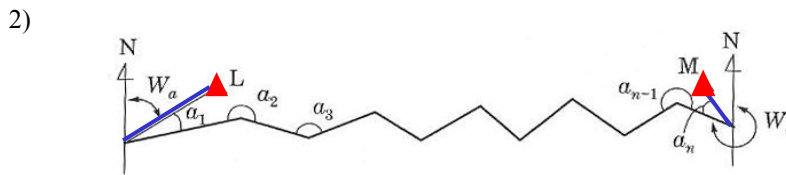
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Traverse

◆ Open “controlled” Traverse



$$E = W_a + \sum a - 180^\circ (n+1) - W_b$$



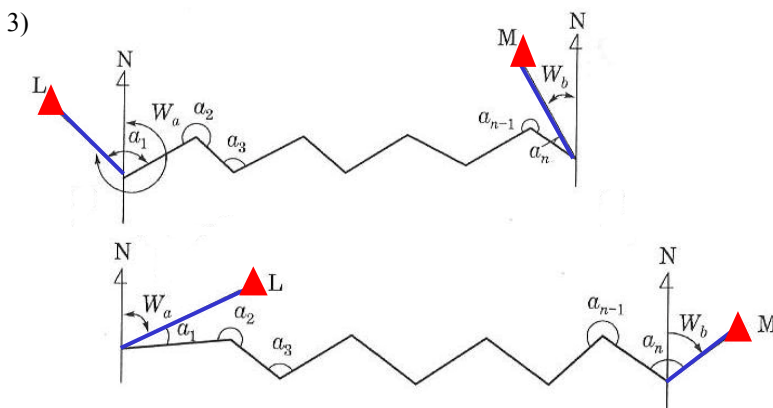
$$E = W_a + \sum a - 180^\circ (n-3) - W_b$$

7/00

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Traverse

◆ Open “controlled” Traverse



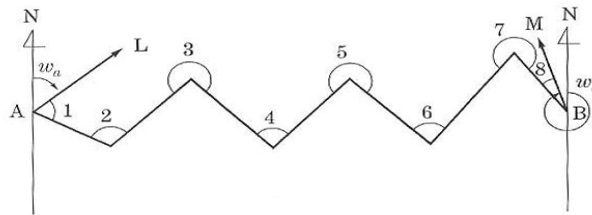
$$E = W_a + \sum a - 180^\circ (n-1) - W_b$$

8/00

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Traverse

- ◆ **Example)** When the azimuth of AL is $29^{\circ}40'15''$ and azimuth of BM $320^{\circ}27'12''$, and the total angles summed up from the first point to the end is $1190^{\circ}47'32''$, how much of the traverse error is?



- ◆ **Answer)**

$$\begin{aligned}
 E &= W_a + \sum a - 180^{\circ}(n-3) - W_b \\
 &= 29^{\circ}40'15'' + 1190^{\circ}47'32'' - 180^{\circ}(8-3) - 320^{\circ}27'12'' \\
 &= 35''
 \end{aligned}$$

9/00

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Traverse

◆ Procedures of Traverse

- Planning
 - accuracy, density & location of points, time and resources
- Reconnaissance
 - nature of terrain, access, location of points (length & angle)
- Station marking
 - type of marks, reference and protection
- Angular measurement:
 - target, reading and booking
- Linear Distance
 - correction and booking
- Computations

(Dare, 2007)

10/00

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Traverse

◆ Errors of Traverse

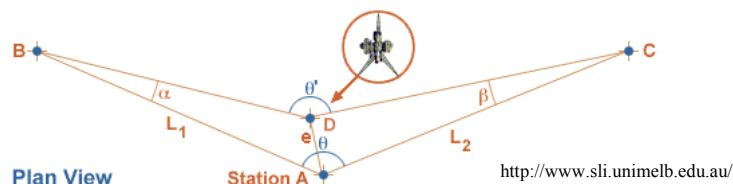
- Errors due to:
 - Angles and distances
- Additional concerns:
 - Poor selection of stations (e.g., unclear line of sight, observing too close to the ground), Wrong station names.
 - Observing wrong station, Setup at incorrect station.
 - Internal or external angles?
- Surveying Errors
 - no measurement is exact;
 - every measurement contains errors;
 - the true value of a measurement is never known
 - the exact error present is always unknown
- Sources of error: instruments, environments and operators (people), e.g.:
 - instruments: imprecision and calibration
 - environment: refraction of the earth, wind
 - people: observation habit, judgment, or condition

(Dare, 2007)

Traverse

◆ cf. Miscentring Stations ?

: the error caused by the theodolite not being correctly plumbed over the reference mark. It is caused by a combination of operator carelessness and either the optical plummet or plumb bob. It effects horizontal angles. As the theodolite has not been centred properly over the station position, it is actually vertically above Point D. Angle BAC is the "correct" angle, that is the angle observed if we were set up above the mark at Station A. Due to miscentring, the angle actually read is BDC, the measured angle.



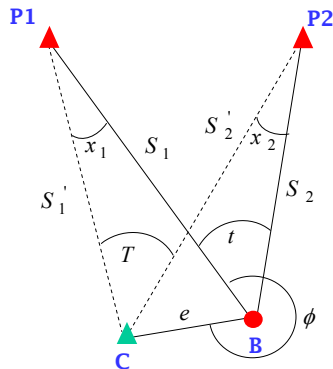
$$\theta' - \theta = \alpha + \beta \approx \frac{e}{L_1} + \frac{e}{L_2}$$

Assume $L_1 = L_2 = L$ $\theta' - \theta \approx 2e/L$

Traverse

◆ cf. Eccentric Stations

: It happens in a certain situation in trigonometry survey work when a survey point over which an instrument is centered and which is not positioned in a vertical line with the station it is representing. In the case of the situation, you may want to make them consistent at one point.



$$T + x_1 = t + x_2$$

$$T = t + x_2 - x_1$$

For x_1 , from sine law

$$\frac{e}{\sin x_1} = \frac{S_1'}{\sin(360^\circ - \phi)}$$

$$\sin x_1 = \frac{e}{S_1'} \sin(360^\circ - \phi)$$

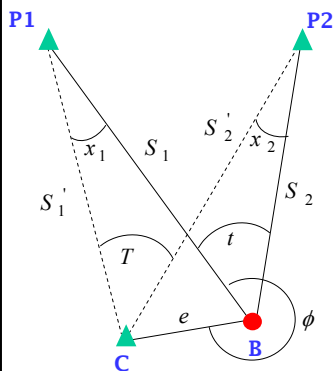
For x_2 , from sine law

$$\frac{e}{\sin x_2} = \frac{S_2'}{\sin(360^\circ - \phi + t)}$$

$$\sin x_2 = \frac{e}{S_2'} \sin(360^\circ - \phi + t)$$

Traverse

◆ Examples) Eccentric Stations



1) Due to some reason, we could not set up a EDM on point C. Instead, it was installed on the point B. We got the angle $t = 31^\circ 15' 40''$. How about angle T in this case?

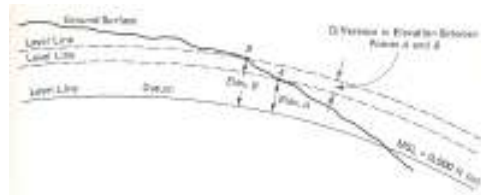
(Assumption:

$$e = 2.5m, \phi = 295^\circ 20', S_1' = 1.5km, S_2' = 2km)$$

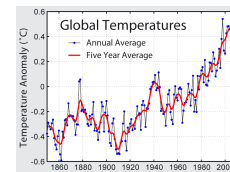
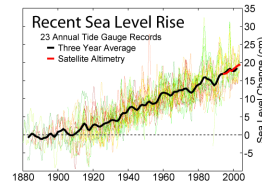
Leveling

◆ Leveling

: procedure for determining difference in elevation between points (vertical distance via *reference datum*)



(Kavanagh, 2006)



● MSL

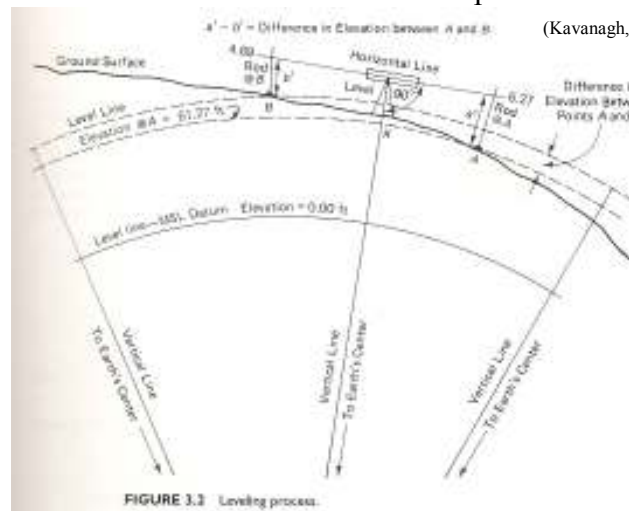
- mean sea level, mean height of the sea
- measured by tide gauge
- coincide with the Geoid with no external forces are employed (geoid: equipotential surface of Earth's gravitational field) varies globally in a range of $\pm 2\text{m}$

<http://en.wikipedia.org>

Leveling

◆ Differential Leveling

: determine differences in elevation between points with measuring rod

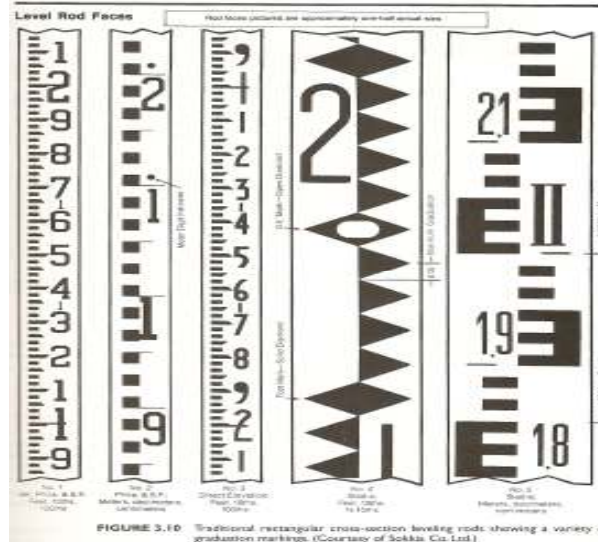


(Kavanagh, 2006)

FIGURE 3.3 Leveling process.

Leveling

◆ Leveling rods



(Kavanagh, 2006)

17/00

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Leveling

◆ Definition for differential leveling - review

- BM (benchmark): permanent point of known elevation. determined by precise leveling technique
- TBM (temporary benchmark): semi-permanent, e.g. firehydrants, nails in the roots of tree, etc.
- TP (turning point): temporary point for transferring an elevation
- BS (back sight): rod reading at known elevation point
- FS (fore sight): rod reading on TP, BM, TBM etc to determine its elevation
- HI (height of instrument): elevation of the LOS through the level

18/00

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Leveling

◆ Field Procedures

1. Preliminary test for our instrument

- : test for collimation error which is a leading systematic error in leveling.
- : collimation error arises due to the de-correlation between the optical axis of a level and horizontal axis.

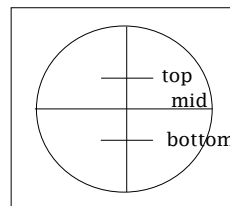
Collimation?

- : even if the instruments are leveled by bubble, the optical LOS is *not perfectly perpendicular to the direction of gravity*.
- : can be minimized the effect *by choosing the midway* between the targets.

: *Kukkamaki or Peg test*

3. Choose a method: ex.) 3-wire level

- : to improve accuracy and to minimize the blunders.
- : read “top-middle” and “middle-bottom” to check the consistency.



Leveling

◆ Kukkamaki Test

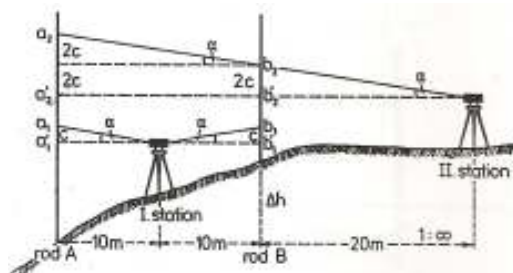


Fig. 9.1.8 Kukkamäki's modified method of level adjustment (GGE1001 Lecture note)

- : optical LOS and true horizontal differ by angle α (called “collimation angle”)
- : read backsight-foresight at station I $\rightarrow \Delta h_I = (bs + c) - (fs + c) = bs - fs$
- : move to station II at exactly twice than previous one \rightarrow now 4 times collimation at rod A, 2 times at rod B $\rightarrow \Delta h_{II} = (bs + 4c) - (fs + 2c) = bs - fs + 2c = \Delta h_I + 2c$

: collimation can be determined by: $\therefore c = \frac{\Delta h_{II} - \Delta h_I}{2}$

Leveling

◆ Peg tests (GGE1001 Lecture note)

: the effect of collimation error on a rod reading, e_{rc} , increases with the length of sight, s :

$$e_{rc} = \alpha \cdot s$$

: balancing the lengths of sight, in a set-up, removes the effect of collimation error

$$r' = r + e_{rc} = r + \alpha \cdot s$$

r' : rod reading contaminated by collimation error

r : correct rod reading

: at any one setup $r'_{bs} - r'_{fs} = r_{bs} + \alpha \cdot s_{bs} - (r_{fs} + \alpha \cdot s_{fs})$

$$= r_{bs} - r_{fs} + \alpha \cdot (s_{bs} - s_{fs}) \leftarrow \text{zero if } (s_{bs} = s_{fs})$$

$$\therefore \alpha = \frac{(r'_{bs} - r'_{fs}) - (r_{bs} - r_{fs})}{(s_{bs} - s_{fs})}$$

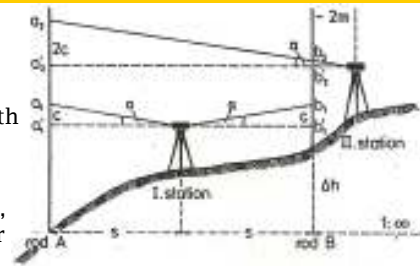


Fig. 9.1.7 Peg test

21/00

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Leveling

◆ Peg tests (GGE1001 Lecture note)

: In second setup, $s_{bs} \doteq 0$ relative to s_{fs}

$$\alpha = \frac{(r'_{bs} - r'_{fs}) - (r_{bs} - r_{fs})}{(-s_{fs})}$$

$$= \frac{(r_{bs} - r_{fs}) - (r'_{bs} - r'_{fs})}{(s_{fs})}$$

$$= \frac{\Delta h_{AB} - (r'_{bs} - r'_{fs})}{(s_{fs})}$$

$$[e_{rc} = \alpha \cdot s]$$

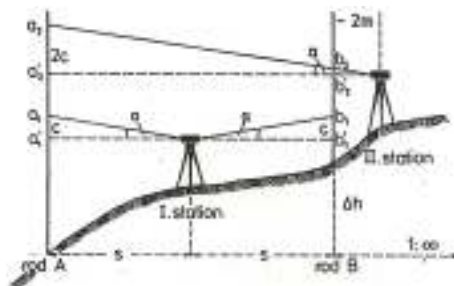


Fig. 9.1.7 Peg test

22/00

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Leveling

◆ Peg Leg test

● First Setup:

1. placed two stakes at a distance of 60~90m apart
2. *level is setup midway between them*
3. taken rod reading at both locations
4. if LOS through the level is not horizontal, then the errors in rod reading (Δe_1) at both point A and B will be identical because the level is half way between the points.
5. can be eliminated due to the differences and the final will be the "true" differences in elevation

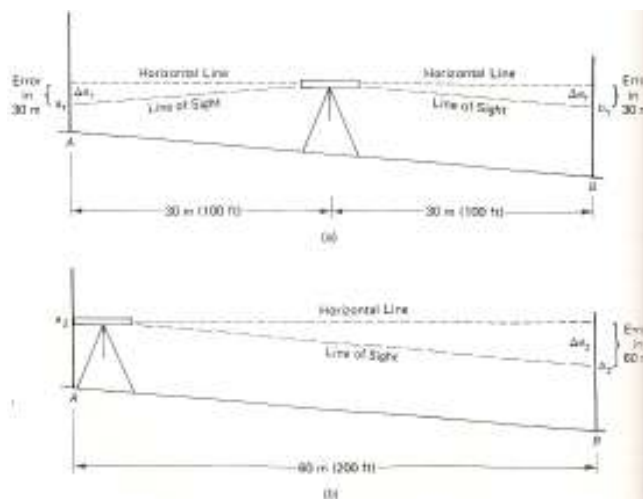
● Second Setup:

1. level moved one of the point
2. setup so that eyepiece of the telescope just touch the rod, but can be setup 2m from A with the rod reading
3. taken a2 rod reading
4. taken the reverse rod reading.

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Leveling

◆ Peg test example (Kavanagh, 2006)



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Leveling

◆ Peg test example (GGE1001 Lecture note)

$$\alpha = \frac{\Delta h_{AB} - (r'_B - r'_A)}{(s_B)} = \frac{\Delta h_{AB1} - \Delta h_{AB2}}{(s_B)}$$

$[e_c = \alpha \cdot s]$

[TWO] PEG TEST (KB) $\frac{1.783 - 1.247}{3.20} = 0.1675$
KT: 3.06

FIRST SETUP: $s_B = s_A$

$$\Delta h_{AB} = r'_B - r'_A = r_A - r_B$$

WHICH IS FREE OF COLLIMATION ERROR.

SECOND SETUP: $s_B \gg s_A$ TO EMPHASISE THE INFLUENCE OF COLLIMATION ERROR AT FA.

$$\Delta h'_{AB} = r'_B - r'_A = r'_A - r'_B = r_B + e_B - r'_A - e_A$$

↑ NOT SAME AS IN FIRST SETUP

SET $[r_B - r'_A] = \Delta h_{AB}$ FROM FIRST SETUP

$$\text{SO: } r'_B - r'_A = \Delta h_{AB} + e_B - e_A$$

$$= \Delta h_{AB} + \alpha \cdot s_B - \alpha \cdot s_A$$

$$\therefore \alpha = \frac{r'_B - r'_A - \Delta h_{AB}}{s_B - s_A} \quad ; \quad e_B = \alpha \cdot s_B$$

PEG TEST IN KB $\frac{1.783 - 1.247}{3.20} = 0.1675$ $s_B = 0$ RELATIVE TO s_A IN SECOND SETUP, SO:

$$\alpha = \frac{r'_B - r'_A - \Delta h_{AB}}{-s_B} = \frac{\Delta h_{AB} - (r'_B - r'_A)}{s_B}$$

KB example 32 $r'_B = 1.247$

$$1^{\text{st}}: \Delta h_{AB} = 1.075 - 1.247 = -0.172 \text{ m}$$

$$2^{\text{nd}}: \Delta h'_{AB} = r'_B - r'_A = 1.783 - 1.956 = -0.163 \text{ m}$$

$$\alpha = \frac{(-0.172) - (-0.163)}{60} = \frac{-0.009}{60}$$

$$= -0.000150 \text{ radian}$$

$$\rightarrow e_B = -0.000150 (60) = -0.009 \text{ m}$$

i.e. Lev was 9 mm lower than it should be at B in the 2nd setup.

THE CORRECTION WOULD BE $-e_B$, SO:

$$r'_B - e_B = 1.956 - (-0.009) = 1.965 = r_B$$

CHECK $1.783 - 1.965 = -0.172$ AS IN 1st SETUP.

$$\text{L } r'_B \text{ why not } r_B = r'_B - e_B ?$$