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Surveying Manual

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INTRODUCTION TO LAB PROCEDURES

- **FIELD NOTES**

Most of the assignments in this lab will be carried out in the field. A record of each field assignment shall be kept in your field book. Your field book shall be kept neat and orderly as it will be collected and graded periodically throughout the quarter.

Your field book shall include your name and group information on the first single page and a table of contents on the first double page.

PENCIL ONLY, PREFERABLY 2H DRAFTING PENCIL.

Each field book entry shall include, at minimum, the following information:
- page numbers
- lab title
- field measurements
- calculations
- weather conditions & ground cover
- date of field work
- crew number
- crew members
- crew member assignments
- procedure
- list of equipment used
- sketch (including, at min.: north arrow, scale or indicate not to scale, use straight edge for lines, adequate information to show the location of work)
- your signature
- indication of whether the notes are original or a copy

- **Your final grade in this class is largely based on the quality, completeness and correctness of your field book.**

- **FIELD CREWS**

  Each student will be assigned to a 4 or 5 people crew. A crew chief should be appointed for each lab assignment. The Crew Chief will be in charge of that particular lab and will be responsible for checking out and returning the equipment at the end of the lab session.

- **SURVEY EQUIPMENT**

  Equipment for each lab assignment will be checked out at the beginning of the lab and checked back in when the assignment is finished. Some important things to remember about the use and care of the equipment are as follows:
  1. Much of the equipment we will use is very expensive and quite sensitive, great care should be taken to protect the equipment from damage.

2. Instruments should be transported in their cases when taken to and from the field. These instruments may be carried on the tripod from station to station as long as they are held vertically at all times.
3. Steel tapes should be straightened out prior to being wound onto their reels. Care should be taken so that the tapes do not kink, bend or snap.
4. Malfunctioning equipment should be reported to the instructor.

LAB #1: DETERMINATION OF PACE

- **Objectives:**

  1. To determine the average length of your own pace
  2. To become familiar with using a steel tape to measure approximate horizontal distances.
  3. To become familiar with keeping notes in a field book.

- **Equipments:**

  Steel tape, chaining pins

- **Instructions:**

  1. The location for this lab shall be determined by your instructor.
  2. Place chaining pins in the ground at 0m, 20m, 40m, and 60m stations.
  3. Use ranging rods to insure that all 4 pins are in a straight line.
  4. Use your normal walk to pace off each distance (i.e.: 0 to 20, 0 to 40 and 0 to 60) a total of 3 times each.
  5. Record the number of paces for each trial in your field book.
  6. Calculate the average number of paces for each distance.
  7. Calculate the average length of your pace.
  8. Write up the lab in your field book, refer to the following example.

- **Field book example** *(please remember that you can use additional pages to clearly show all necessary information)*

	# OF PACES					
TRIAL	20M	40M	60M			
1	30	58	90			
2	30	57	89			
3	31	57	90			
AVG.	30.33	57.33	89.67			

PACE = 20/30.33 = 0.66M/PACE

40/57.33 = 0.70M/PACE

60/89.66 = 0.67M/PACE

AVERAGE PACE = 0.68M/PACE

LAB #2: CHAINING / TAPING ON LEVEL GROUND

- **Objectives:**

  1. Use a steel tape & plumb bob to measure horizontal distances.
  2. Practice making measurements in decimal feet.

- **Equipments:**

  Steel tape, plumb bob and pins

- **Instructions:**

  1. Locate the polygon that is to be measured (as directed by your instructor).
  2. One crew member shall be responsible for taking notes in the field book. Refer to the following page for a sample field book entry.
  3. Record distance between points by pacing only.
  4. Record distance between points by using steel tape only
  5. Record distance between points by using steel tape, plumb bob and pins.
  6. The tape must be held as close to level as you can and on line while making measurements.
  7. The temperature must be recorded.
  8. If the line is longer than the tape, an intermediate point or points must be set on line and two or more measurements must be made and recorded separately in the field book.
  9. Record all raw data; draw a detailed sketch of the polygon and surrounding area with each point of the polygon labeled.

- **Field book example** *(please remember that you can use additional pages to clearly show all necessary information)*

CHAINING ON

| | DISTANCE | | |
LINE	PACE ONLY	CHAIN ONLY	TAPE, PINS PLUMB BOB
A-B	62.39'	56.28'	56.30'
B-C	124.35'	100+25.50'	100+25.50'
C-D	12.90'	13.85'	13.68'
D-E	98.75'	98.25'	98.35'
E-F	...	"	"
F-A	...	"	"

LEVEL GROUND

WEATHER: MILD   DATE: ...
TEMP.: 72°   CREW #1
GROUND COVER: GRASS   CHIEF: ...
                                    NOTES: ...
PROCEDURE: CHAINMAN: ...
USE STEEL TAPE ....   CHAINMAN: ...
                              EQUIPMENT USED:
                              -STEEL TAPE, PLUMB BOB
                              AND PINS

BUILDING 17

CONCRETE WALK

N
N.T.S.

A .NG
"COPY"

LAB #3: SURVEY OF AN AREA BY CHAIN SURVEY (CLOSED TRAVERSE)

- **Objective:**

  To survey an open field by chain survey in order to calculate the area of the open field.

- **Equipments:**

  Chain, Tape, Ranging Rods, Arrows, Cross Staff.

- **Procedure for surveying the given open field (Closed Traverse):**

  Note: This procedure is general procedure only. This procedure varies with the experiment given to students. Therefore students are required to write the procedure according to the experiment given to them.

  Example 1:

  1. ABCDEF is the required closed traverse open field to be surveyed for calculating the area as shown in Fig 1.
  2. From the station A the length of all the opposite corners such as AC, AD and AE are measured with a chain and the longest distance is considered for laying off the main chain line. In this case AD is the longest and a chain line running from A to D is laid.
  3. Offsets to corner points B, C, E and F are now laid from the chain line AD either by tape or cross-staff and their foot of offsets are G, I, J, H respectively.
  4. All the offset lengths GB, HF, IC and JE are measured either by chain or tape depending on the length of offsets.
  5. The distances between all the points AG, GH, HI, IJ and JD are also measured along the chain line.
  6. Area Calculations: (Note: Areas of all triangles and trapeziums are calculated and added together to calculate the total area of open field (Closed Traverse) as described in class).
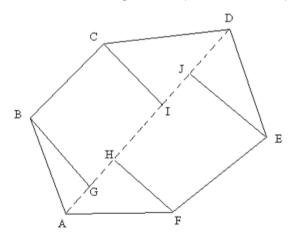

Figure 1: Survey of an Open Field (Closed Traverse)

Example 2:

1. Let ABCDE be the given field whose area is to be measured, fix the pegs at A, B, C, D & E.
2. Divide area into three triangles ADE, ABD and BCD by joining AD and BD.
3. Measure the lengths AB, BC, CD, DE, EA, AD and BD.
4. Calculate the area of the triangles.
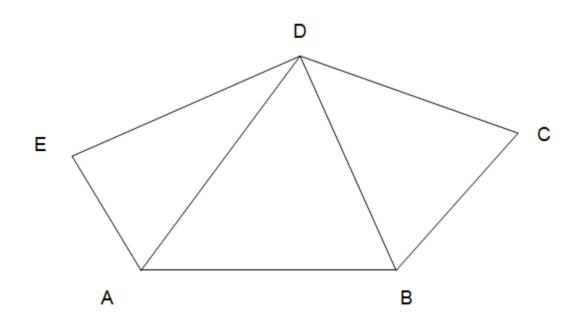5. The sum of the areas of the three triangles is the area of the given field.

FORMULA:

Area of the triangle $\Delta = \sqrt{s\,(s-a)\,(s-b)\,(s-c)}$

Where $S = (a + b + c) / 2$

a, b, c, are the sides of the triangle.

SKETCH:

LAB #4: CHAINING ACROSS OBSTACLES

- **Objective:**

  To survey an area by chain survey across obstacles and to calculate the obstructed lengths by using different methods.

- **Equipments:**

  Chain, Tape, Ranging Rods, Arrows, Cross Staff.

- **Obstacles to Chaining:**

  During measurements, it is impossible to set out all the chain lines in a straightforward method because of a variety of obstacles to chaining and ranging in the field.

  1) *Obstacles to measurement:*

     The obstacles which do not obstruct the ranging (view) like ponds, rivers are known as Obstacles to Measurement.

  2) *Obstacles to alignment:*

     The obstacles which we cannot see across, i.e. both the chaining and ranging are obstructed, e.g. houses, stacks, etc. are known as Obstacles to Alignment.

- **Procedures to find out Obstructed Length:**

1) **Obstacles to measurement:**

 A) First Method:

  Let ABCD be a chain line obstructed by a pond (Fig 1). Let BC be the obstructed length. Two offsets BE and CF of equal lengths are made at B and C and chaining is done along EF to measure the distance EF.

Now the required obstructed length BC is equal to the measured distance EF.

Therefore,   BC = EF

B) Second Method:

Let AB be the obstructed length across the river (Fig 2). AC is laid off, of any convenient length, perpendicular to the required distance AB.

Now a perpendicular is laid off from C such that it meets the extended line of AB at D.

Triangles ABC and ADC are similar triangles.

From the principle of similar triangles,

$$AB / AC = AC / AD$$

Therefore, obstructed length $AB = AC^2 / AD$

C) Third Method:

Let AB be a chain line obstructed by a river (Fig 3). A point I is assumed anywhere in line with the required distance AB. A point H is taken in such a way that HJ = HI and HK = HB.

Now a point L is established in line AH and at the same time in the line JK produced.

Triangles KHL and ABH are similar triangles and their corresponding sides are equal to each other as the points K, B and I, J are equidistant either side from H.

Therefore, the obstructed length AB = KL

D

C ---- F

B

E

A

Fig 1

B

River

A

D

C

Fig 2

River

J

K - - - H - - - B

I

L

Fig 3

2) Obstacles to alignment:

A) First Method:

Let DE be the obstructed length across the building (Fig 4). A point C is assumed arbitrarily. E and C are joined such that EC = CB. Now D and C are also joined such that DC = CA.

Triangles CDE and CBA are similar triangles and their corresponding sides are equal to each other as points BE and AD are equidistant either side from C.

Therefore, obstructed length DE = BA

B) Second Method:

Let DE be the obstructed length across the building (Fig 5). A point F is established at equal distances from D and E at any convenient distance. Points H and G are established such that FH = FG.

Triangles FDE and FHG are similar triangles.

From the principle of similar triangles,

$$DE / DF = HG / HF$$

Therefore, obstructed length DE = (HG X DF) / HF

Fig 4

Fig 5

- **Calculations:**

Note: All calculations of all methods to find obstructed lengths should be shown here.

- **Results:**

1) *Obstacles to measurement:*

Obstructed length from First Method   =   m

Obstructed length from Second Method =   m

Obstructed length from Third Method   =   m

2) *Obstacles to alignment:*

Obstructed length from First Method   =   m

Obstructed length from Second Method =   m

- **Instructions to students:**

  Students are required to draw all the diagrams of all methods to scale with all dimensions on the left pages of lab record.

LAB #5: CHAIN SURVEYING (MAPPING BY TAPE)

- **Objective:**

Chain (Tape) surveying is the simplest form of detail surveying. In this method the lengths of lines marked on the field are measured, while the details are measured by offsets and ties from these lines. So, this field work aimed to train the student on the following process:

1. Selection of a frame work (chain or base lines) and control points.
2. Direct method of linear measurements (horizontal distance measurement).
3. Setting out right angles (offsets).
4. Determining the direction of any line in the field with respect to magnetic north "bearing".
5. Booking Method.
6. Plotting Method.

- **Equipments:**

2 Tapes, 3 Ranging rods, Arrows/Marker paint, Prism Square, Prismatic Compass Booking Board

- **Procedure:**

1. Make a reconnaissance of the area and select a suitable framework (chain lines) and stations based on the criterion given in Note 1.
2. Measure all the chain (based) lines once in each direction using the direct measurement method.
3. Measure the offsets/or ties from every necessary point on the details to the corresponding base line. Use the procedure explained in Note 2.
4. You may need some measurements on the details (on the building sides…).
5. Measure the bearing of one of the chain lines by using the prismatic compass. See Note 3.
6. Record all the information and measurements properly in the booking papers as explained in Note 4.
7. Make the necessary calculations and corrections.
8. Draw the details in a suitable scale to produce a detailed map of the area. See Note 5.

Note 1: CHAIN LINES & STATIONS SELECTION

To locate a suitable stations and chain lines, a reconnaissance of the area should be undertaken by walking around the area required to be surveyed. Any obstacles should be noticed. The selected stations should produce well formed linked triangles or braced quadrilaterals.

The principles to be considered are:

1. Few long lines should be used.
2. Avoid any obstacles to ranging or chaining.
3. Angles should be > 30° & <120°.
4. Make check lines when possible to detect errors when plotting.
5. The lines should be closed to the details (Avoid long offsets (>10m) and ties.

After selection of the framework you should draw sketch of the area and mark the stations by wooden pegs or marker paints, and give a number for each station.

Note 2: SETTING THE OFFSET

Any point on the details can be related to the chain line by offset or ties:

➢ The pair of ties method depends on taking the measurement of two distances from the point to be surveyed to a traverse line (base line).
➢ The offset method is based on taking a perpendicular distance from the point to the survey line (base line).

To set out offsets, a prism square can be used. To locate the point at which a perpendicular from any point on the feature would meet the chain line (say AB) you can follow the following steps:

1. One man should hold the ranging pole at the given point, while the other pole is placed at any point on the chain line AB.
2. The observer holds the instrument and walk along the line AB until he sees both poles coincide in each other. Then the distance to this point along the chain line can be measured beside the length of the perpendicular.

Another method can be used by holding the zero point of the tape at the given point and swinging tape over the chain line and mark the point on the chain line at minimum reading.

NOTE 3: MEASURING THE BEARING OF A LINE

To measure the angle that any line (say AB) makes with the magnetic direction, you can use a prismatic compass. The procedure is as follow:

1. Place the ranging pole vertically at point B.

2. Place the prismatic compass over its tripod at point A and level it using the bubble and screws.
3. Rotate the compass until it is directed to the pole and read the angle.
4. Repeat the whole procedure for point B.

NOTE 4: BOOKING

The field book should be neat and consistent:

1. Each chain line is represented by double line drawn through the corner of the page.
2. Entries start at the bottom of the page.
3. Detail that is on the right-hand side of the line is booked on the right-hand side of the page and vice versa.
4. The lengths from the beginning of the line are written inside the double lines while the offset lengths outside.

NOTE 5: PLOTTING

A. Plot the framework of chain lines by:

1. Draw the longest line according to its bearing.
2. Build up the other chain lines by using beam compasses.
3. Draw the check lines, and if there are any errors, check the drawn lines in the incorrect triangles. (You may need to measure them in the field).

B. Draw the details for each chain line based on offsets and ties information. Then connect these points to get the details.

LAB #6: STUDY OF LEVEL AND LEVELLING STAFF

- **Objective:**

  Study of components of dumpy level and leveling staff.

- **Equipments:**

  Level, Leveling staff, Tripod, Staff bubble.

1. **Levels**

   A level is basically a telescope attached to an accurate leveling device, set upon a tripod so that it can rotate horizontally through 360°. The following figure shows the level and its components.
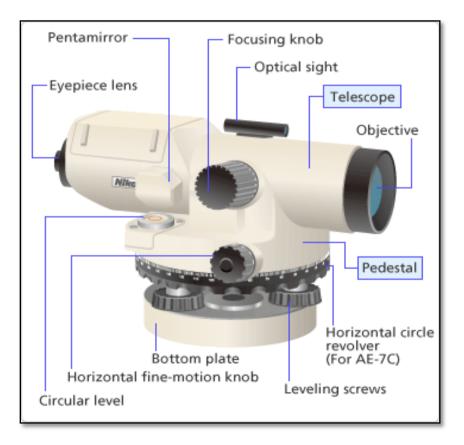

Figure 1: Level

2. Tripod

The tripod consists of three legs and a head where the level instrument is mounted. The tripod could be of aluminum or wood material. When leveling the level instrument, the tripod head must be set approximately level beforehand by adjusting the tripod legs.

Figure 2: Tripod

3. Leveling staff

The leveling staff is a box section of aluminum or wood, which will extend to 3 or 5 m in height by telescoping, hinging or addition of sections. One face has a graduated scale attached for reading with the cross-hairs of the level telescope.

4. Staff bubbles

These are generally a small circular bubble on an angle plate which is held against one corner of the staff to ensure that the staff is held in a vertical position. If the staff is not held vertical, the reading will be too large and may be significantly in error.
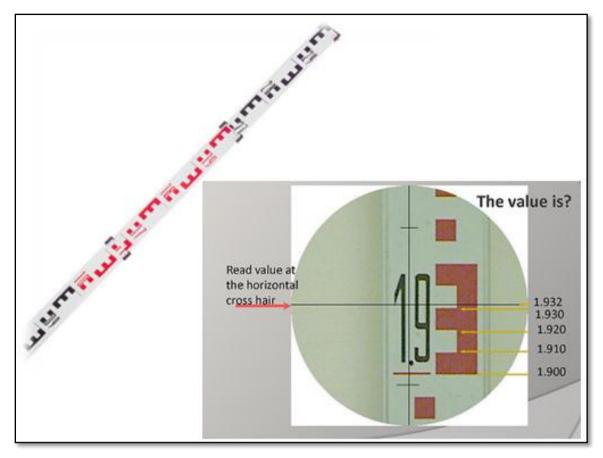
Figure 3: Leveling staff

Figure 4: Staff bubble

SETTING UP OF THE DUMPY LEVEL:

1. Release the clamp screw of the instrument
2. Hold the instrument in the right hand and fix it on the tripod by turning round only the lower part with the left hand.
3. Screw the instrument firmly and bring all the foot screws to the center of its run.
4. Spread the tripod legs well apart and fix any two legs firmly into the ground by pressing them with the hand.
5. Move the third leg to up or down until the main bubble is approximately in the center.
6. Then move the third leg in or out until the bubbles of the cross-level is approximately in the center.
7. Fix the third leg firmly when the bubbles are approximately in the centers of their run.

LEVELLING UP:

1. Place the telescope parallel to a pair of foot screws.
2. Bring the bubble to the center of its run by turning the foot screws equally either both inwards and both outwards.
3. Turn the telescope through 90°, so that it lies over the third foot screw.
4. Turn this third foot screw so that the bubble comes to the center of its run.
5. Turn the telescope through and check whether the bubble remains central.

ELIMINATION OF PARALLAX:

1. Remove the lid from the object glass.
2. Hold a sheet of white paper in front of the object glass.
3. Move the eyepiece right or left until the cross hairs are distinctly visible.
4. Direct the telescope towards the staff.
5. Turn the focusing screw until a clear and sharp image is formed in the plane of the cross hairs.

LAB #7: DIFFERENTIAL OR FLY LEVELLING – REDUCE LEVELS BY H.I METHOD

- **Objective:**

To find the difference in elevation and calculate the reduced levels of various points by H.I method.

- **Equipments:**

Dumpy level, Tripod, Leveling staff, staff bubble.

- **General procedure for measuring elevations using a level:**

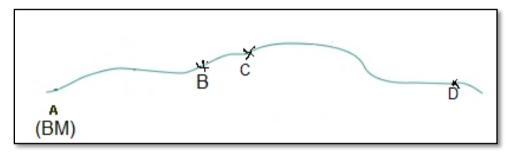Suppose that B, C and D are points whose reduced level is to be determined as in Figure 1:

Figure 1: points whose reduced level is to be determined

1. Place the staff over a bench mark (BM), whose reduced level is known, and set up the instrument in convenient and safe location where the BM (point A) is visible. Take a sight on the staff, that reading is called backsight (B.S). See Figure 2

2. Place staff over B. Take a sight on the staff, that reading is called Intermediate sight (I.S). See figure 2

3. Place staff over C. Since the distance between the level and D is long, so it is not possible to read the staff over D from the current level position (pos 1). So take the last reading over C for this position, this will be a foresight (F.S). See figure 2

4. Now, move the instrument to a new position (position 2) and take the reading on the previous position of the staff (over C). This position of staff is known as Turning Point (T.P) and this reading will be backsight (BS). See figure 2

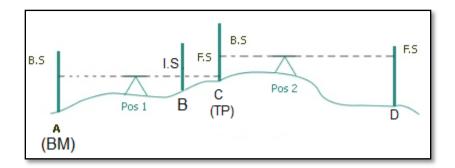5. Now, shift the staff to the point D and take reading, this reading will be foresight (F.S). See figure 2

Figure 2: Leveling procedure

- **Tabulation:**

STATION	READINGS			HEIGHT OF INSTRUMENT	REDUCED LEVEL	REMARKS
	B.S	I.S	F.S			

- **Calculations**

1. The height of instrument position(1) can be calculated as:

    HI of position 1 = Elevation of BM + BS at BM

2. The reduced level of any point (i) taken from position 1, can be calculated as:

    R.L of point i = HI of position 1 – staff reading at point i

3. The height of instrument position(2) can be calculated as:

    HI of position 2 = Reduced level of TP1 + BS at TP1

4. The reduced level of any point (i) taken from position 2, can be calculated as:

    R.L of point i = HI of position 2 – staff reading at point i

5. And so on….

6. **Checks:** The following checks on the booking and arithmetic calculations are performed:

    A) Number of BS readings = Number of FS readings

    B) $\sum BS - \sum FS = $ RL of last point – RL of first point

LAB # 8: DIFFERENTIAL OR FLY LEVELLING – REDUCE LEVELS BY RISE AND FALL METHOD

- **Objective:**

  To find the difference in elevation and to calculate the reduced level of various points by Rise and Fall method.

- **Equipments:**

  Dumpy level, Leveling staff.

- **Procedure:**

  The field procedure and booking of staff reading is done in the same way as explained in the height of instrument method (each reading is entered on a different line in the appropriate column, except at a change point, where a FS and BS occupy the same line). However the data booking is performed as shown in the Table below.

- **Tabulation:**

STATION	READINGS			RISE	FALL	REDUCED LEVEL	REMARKS
	B.S	I.S	F.S				

- **Calculations:**

  1. The difference in elevation between any two successive points (say A and B) can be calculated as:

Elevation difference between A and B = first reading at A – second reading at B

2. <u>NOTE, for any two successive staff readings</u>:

   ➢ Second reading smaller than first reading represents a Rise (The sign of elevation difference is positive).

   ➢ Second reading greater than first reading represents a Fall (The sign of elevation difference is negative).

3. If the <u>elevation of the first point is known</u>, then <u>the elevation of the second point</u> can be calculated as:

   Height of B = height of A + rise   (in rise case)

   or

   Height of B = Height of A – fall   (in fall case)

4. **Checks:** The following checks on the booking and arithmetic calculations are performed:

   A) Number of BS readings = Number of FS readings

   B) $\sum$BS - $\sum$FS = $\sum$Rise - $\sum$Fall = RL of last point – RL of first point

LAB # 9: CLOSED LOOP LEVELING

- **Objective:**

To calculate the misclosure for a line of levels and distribute the error.

- **Equipments:**

Dumpy level, Leveling staff, Tripod, Staff bubble.

- **Procedure**

    1. The survey begins at the specified benchmark (BM) and finishes at the same benchmark (See Figure 1). (follow the same procedure for leveling, booking and calculation as explained before).
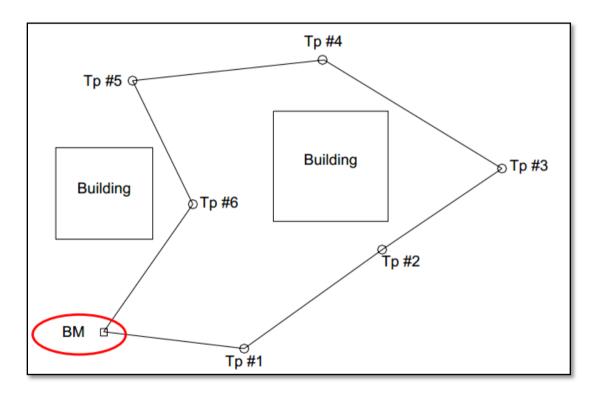

Figure 1: Closed loop leveling

    2. Compare the reduced level of the closing bench mark with the level obtained for it by calculation from the staff readings. If we completed our level loop with complete accuracy, our computed benchmark elevation would be exactly the same as the benchmark elevation

used to initiate the survey. <u>This comparison of the starting elevation and the computed ending elevation is termed closure</u>.

3. The closure error can be simply calculates as:

Error of Closure = Given benchmark elevation - Observed benchmark elevation

4. Compute the allowable misclosure. The allowable misclosure for a line of levels is given by:

$$\text{Allowable misclosure} = \pm \, m \, \sqrt{n}$$

Where, m is a constant and n is the number of instrument positions used. The value most often used for m is 5mm.

5. Compare the error of closure with the allowable misclosure.
   - ➢ If the error of closure is greater than the allowable value, the leveling is rejected and must be repeated.
   - ➢ If the error of closure is less than the allowable value the leveling is accepted and the leveling is adjusted.

6. Adjust the elevations according to the following equations:

Correction = Error of Closure X <u>distance from the starting benchmark</u>

Total length of level run

Adjusted Elevation = Observed elevation + Correction

LAB # 10: PROFILE LEVELING (LONGITUDINAL SECTIONING & CROSS SECTIONING)

- **Objective:**

  To determine the configuration of ground survey by conducting – Longitudinal & Cross Sectional leveling.

- **Equipments:**

  Dumpy Level, Levelling Staff, Tripod, Staff bubble, Chain or Tape.

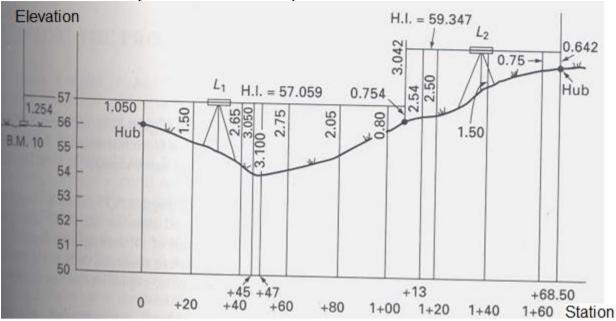- **Procedure**

  A) Profile Leveling

  Profile leveling is one of the most common applications of running levels and vertical distance measurement for the surveyor. The results are plotted in the form of a profile, which is a drawing that shows a vertical cross section. Profiles are required for the design and construction of roads, curbs, sidewalks, pipelines etc. In short, profile leveling refers to the process of determining the elevation of points on the ground at mostly uniform intervals along continuous line.

  Field Procedure:

  Profile leveling is essentially the same as benchmark leveling, with one basic difference. At each instrument position, where an HI is determined by a back sight rod reading on a benchmark or turning point, several additional foresight readings may be taken on as many points as desired. These additional readings are called rod shots, and the elevation of all those points is determined by subtracting the rod shot from the HI at that instrument location. (See figure 1)

  Plotting the Profile:

  The profile drawing is basically a graph of elevations, plotted on the vertical axis, as a function of stations, plotted on horizontal axis. A gridded sheet called profile paper is used to plot the profile data from the field book. All profile drawings must have a proper title block, and both axes must be fully labeled with stations and elevations. The elevation or elevation scale is typically exaggerated; that is, it is 'stretched' in comparison to the horizontal

scale. For example the vertical scale might be 10 times larger. The horizontal line at the bottom of the profile does not necessary have to start at zero elevation

Figure 1: Profile leveling

B) Cross-Section Leveling

The term cross-section generally refers to a relatively short profile view of the ground, which is drawn perpendicular to the route centerline of a highway or other types of linear projects. Cross-sectional drawings are particularly important for estimating the earthwork volumes needed to construct a roadway; they show the existing ground elevations, the proposed cut or fill side slopes, and the grade elevation for the road base.

There is really no difference in procedure between profile and cross-section leveling except for the form of the field notes. Cross-section rod shots are usually taken during the route profile survey from the same instrument positions used to take rod shots along the centerline. Cross-section data are obtained at the same locations along the route that are used for the profile rod-shot stations. (See figure 2 a and b).
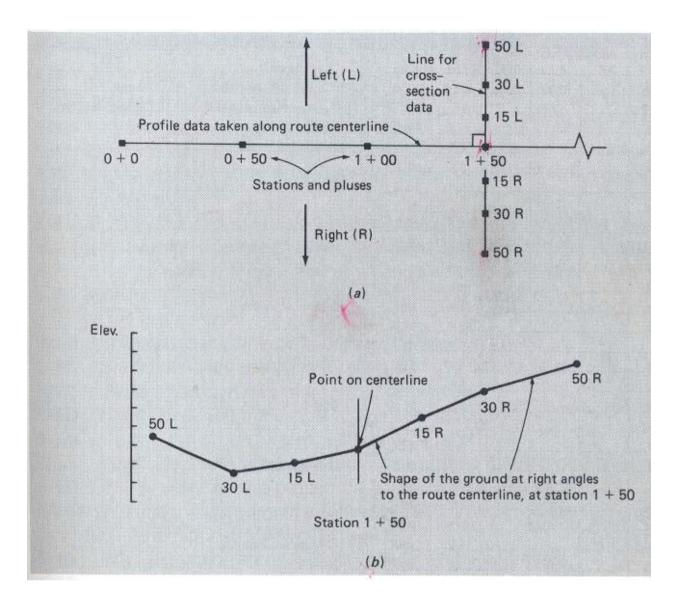
Figure 2:
(a) Top view showing the route center line and the line for cross-section leveling at station 1+ 50.
(b) The cross-section showing ground elevations at points left and right of the center line.

- **Result:** The longitudinal sectioning & cross sectioning is carried out and the profile and cross sections are plotted on Graph sheet.

LAB # 11: CONTOURING – GRID METHOD

- **Objective:**

To plot the contour map for a given land by direct method.

- **Eqipments:**

Dumpy Level, Levelling Staff, Tripod, Staff bubble, Chain or Tape.

- **Procedure:**

1. First, ensure that an appropriate bench mark (BM) is available near the site of the survey. If a B.M is not available, then one should be located near the site by fly leveling.
2. Once a benchmark is available, set up the instrument (level) at a suitable position covering a large part of the area to be surveyed.
3. The area is divided into a number of squares and all grid points are marked (Ref. Fig. 1). Commonly used size of square varies from 5 m × 5 m to 20 m × 20 m.
4. Levels of all grid points are established by leveling.
5. Then **grid square** is plotted on the drawing sheet. Reduced levels of grid points marked and contour lines are drawn by interpolation [Ref. Fig. 1].
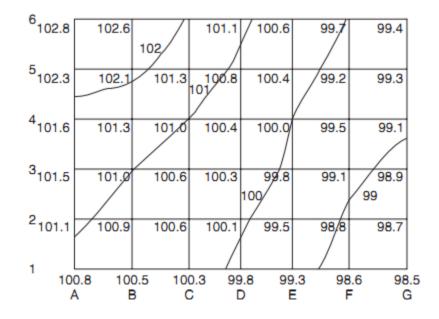

Figure 1: Grid Contouring

LAB # 12: STUDY OF THEODOLITE

- **Objective:**

  To study different parts of Theodolite and temporary adjustments.

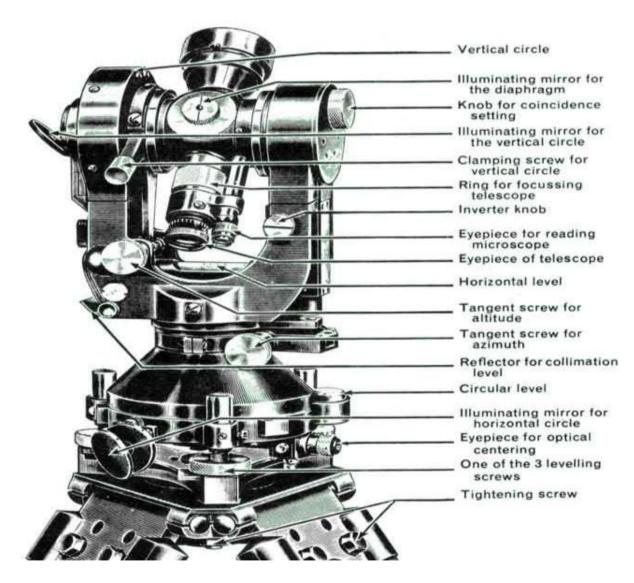- **Equipment:** Theodolite.

SKETCH:

Figure 1: Transit theodolite (optical theodolite)

Figure 2: Example of Digital Theodolite

- ➢ *VERTICAL AXIS:* It is the axis about which the telescope can be rotated in a horizontal plane.
- ➢ *HORIZONTAL AXIS*: It is the axis about which the telescope can be rotated in a vertical plane.
- ➢ *LINE OF COLLINATION:* It is the imaginary line joining the intersection of the cross hairs of the diaphragm to the optical center of the object glass and its continuation.
- ➢ *AXIS OF THE TELESCOPE*: It is the line joining the optical center of the object glass to the center of the eye-piece.
- ➢ *AXIS OF THE LEVEL TUBE*: It is the straight line tangential to the longitudinal curve of the level tube at the center of the tube.
- ➢ *CENTERING*: The process of setting the theodolite exactly over the station mark.

- **Equipment Description:**
  - ➢ *TELESCOPE*: It consists of eye-piece, object glass and focusing screw and it is used to sight the object.
  - ➢ *VERTICAL CIRCLE*: It is used to measure vertical angles.
  - ➢ *LEVELLING HEAD:* It consists of two parallel triangular plates called tribrach plates. Its uses are: 1) To support the main part of the instrument, 2) To attach the theodolite to the tripod.
  - ➢ *LOWER PLATE*: It consists of lower clamp screw and tangent screw.
  - ➢ *UPPER PLATE*: The upper plate is attached to the inner axis and it carries two verniers. It consists of an upper clamp screw and tangent screws. These screws are used to fix upper plate with lower plate accurately.
  - ➢ *FOOT SCREWS*: These are used to level the instrument.
  - ➢ *PLUMB BOB:* It is used to center theodolite exactly over the ground station mark.
  - ➢ *SWINGING THE TELESCOPE*: It means turning the telescope about its vertical axis in the horizontal plane. A swing is called right or left according as the telescope is rotated clockwise or counter clockwise.
  - ➢ *FACE LEFT*: If face of the vertical circle is to the left side of the observer, then the observation of the angles taken is known as face left observation.
  - ➢ *FACE RIGHT*: If the face of the vertical circle is to the right side of the observation, then the observation of the angles taken is known as face right observation.

➤ *CHANGING FACE*: It is an operation of bringing the face of the telescope from left to right and vice-versa.

Note: Face left and face right are the terms used in optical theodolite, While Direct mode and Reverse mode terms are used in the digital theodolite.
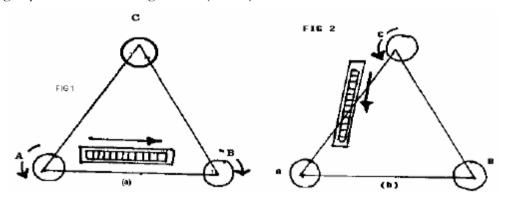
- **Temporary Adjustments:**

There are three temporary adjustments of a theodolite. These are

1. Setting up the theodolite over a station.
2. Leveling up.
3. Elimination of parallax.

1. *SETTING UP:* It includes two operations

   1. Centering a theodolite over a station: Done by means of plumb bob.
   2. Approximately leveling it by tripod legs only: Done by moving tripod legs.

2. *LEVELING UP:* Having centered and approximately leveled the instrument, accurate leveling is done with the help of foot screws with reference to the plate levels, so that the vertical axis shall be truly vertical.

To level the instrument the following operations have to be done.

1. Turn the upper plate until the longitudinal axis of the plate level is roughly parallel to a line joining any two of the leveling screws (A & B).

2. Hold these two leveling screws between the thumb and first finger of each hand uniformly so that the thumb moves either towards each other or away from each other until the bubble comes to the center.

3. Turn the upper plate through 90º (i.e until the axes of the level passes over the position of the third leveling screw 'C').

4. Turn this leveling screw until the bubble comes to the center.

5. Rotate the upper plate through 90º to its original position fig (a) and repeat step (2) till the bubble comes to the center.

6. Turn back again through 90º and repeat step 4 .

7. Repeat the steps 2 and 4 till the bubble is central in both the positions.

8. Now rotate the instrument through 180º. The bubble should be remaining in the center of its run, provided it is in correct adjustment. The vertical axis will then be truly vertical.

- **Elimination of Parallax:**

Parallax is a condition arising when the image formed by the objective is not in the plane of the cross hairs. Unless parallax is eliminated, accurate sighting is not possible. Parallax can be eliminated in two steps.

a) FOCUSSING THE EYE-PIECE:

Point the telescope to the sky or hold a piece of white paper in front of the telescope. Move the eyepiece in and out until a distant and sharp black image of the cross-hairs is seen.

b) FOCUSSING THE OBJECT:

Telescope is now turned towards object to be sighted and the focusing screw is turned until image appears clear and sharp.

LAB # 13: HORIZONTAL ANGLE MEASUREMENT
"CLOSING THE HORIZON"

- **Objectives:**

  1. Use a theodolite to measure horizontal angles.

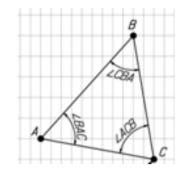 2. To become familiar working with angles in degrees, minutes & seconds format.

- **Equipments:**

  Theodolite, Tripod, range pole.

- **Instructions:**

  The following instructions make reference to the sample field book shown below.

HORIZONTAL ANGLE   MEASUREMENT

PG. #

STATION: A

POINT SIGHTED	HA-DIRECT READ	HA-REVERSE READ	MEAN HA	ANGLE
B	0°00'00"	0°00'00"	0°00'00"	—
C	31°01'02"	31°01'06"	31°01'04"	31°01'04"
B	359°59'56"	359°59'50"	359°59'53"	328°58'49"

SUM = 359°59'53"

ERROR: 360°00'00" – 359°59'53" = 0°00'07"

STATION: B

POINT SIGHTED	HA-DIRECT READ	HA-REVERSE READ	MEAN HA	ANGLE
C	0°00'00"	0°00'00"	0°00'00"	—
A	##	##	##	##
C	##	##	##	##

SUM = ##

ERROR: 360°00'00" – ## = ##

STATION: C

POINT SIGHTED	HA-DIRECT READ	HA-REVERSE READ	MEAN HA	ANGLE
A	0°00'00"	0°00'00"	0°00'00"	—
B	##	##	##	##
A	##	##	##	##

SUM = ##

ERROR: 360°00'00" – ## = ##

WEATHER: DATE:
TEMP: CREW #
PRESSURE: CHIEF:
                             INST.:
PROCEDURE: ROD:
                             NOTES:

                             EQUIPMENT USED:

BLDG. 17

CONC. WALK

BLDG. 9   CONC. WALK

B

NTS

ANGLES
BAC = 31°01'04"
CBA =
ACB =

SET HUB &
TACK (TYP.)

A. L. Blee
"COPY"

1. Locate the angles to be measured (as directed by your instructor). Suppose that angles of triangle ABC shown in the figure are to be measured:

2. Set up the instrument at point A.
3. Take a backsight on point B by setting the instrument's horizontal angle to 0° 00' 00" while sighting point B:
   ✓ If any point cannot be sighted directly, the rod (range pole) must be set up on the point and held plumb so that it can be sighted by the instrument.
   ✓ Refer to the figure 1 below for proper sighting methods.
4. Turn the instrument to point C and record the horiz. angle in your field book
5. Turn the instrument back to point B and record the horiz. angle in your field book, this measurement will provide a check.
6. Perform the necessary calculations before moving the instrument to the next point:
   ✓ Calculate the mean direction to each point using the direct and reverse measurements for each point sighted.
   ✓ Calculate the horizontal angles between lines using the mean directions.
7. Repeat steps 3 through 6 for second set of data.
8. Set the instrument up on point B and follow the same routine to measure angle CBA.
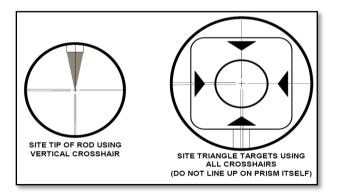9. Set the instrument up on point C and follow the same routine to measure angle ACB.

Figure 2: Proper sighting methods

- **Calculations**:

  1) Sum the angle to check your precision, as follow:

     ➤ Theoretical sum of included angles of a closed traverse = $(2n - 4) \times 90^0$
     Where; n = Number of sides of closed traverse.

     ➤ The Error in the actual included angles can be calculated by,

     Error = (Theoretical Sum of Included Angles – Total Actual Included Angles) / n

     ➤ If the Error is positive, add this error to each actual included angle and if the Error is negative, deduct this error from each actual included angle.

        Therefore, Corrected Included Angle = Actual Included Angle + Error, if positive.

        Corrected Included Angle = Actual Included Angle – Error, if negative

  2) If the error is greater than 30", then measurements must be repeated.

LAB #14: MEASUREMENT OF THE LENGTH (WIDTH) OF AN OBSTRUCTED BUILDING USING THE THEODOLITE
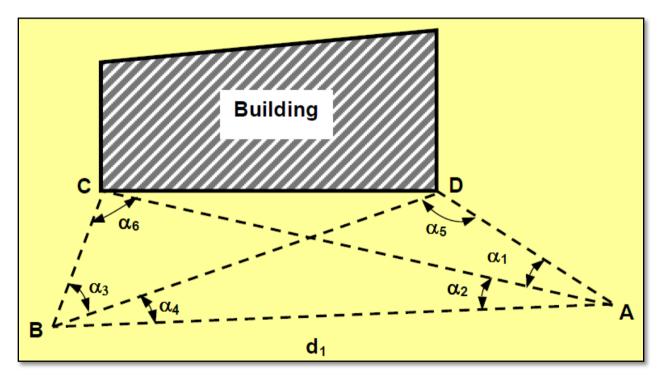
- **Objective:**

  To obtain the length of a building without direct measurement using the theodolite.

- **Equipments:**

  Theodolite, Chain / Tape, Ranging rods, Plumb bob, Tripod

SKETCH:

- **Procedure:**

  1. Select a base line AB and measure AB accurately (d_1).
  2. Setup the theodolite at A and level it accurately.
  3. Measure the horizontal angles α_1 and α_2 each on both faces of the instrument and take their respective mean values.
  4. Setup the theodolite at B and level it accurately.

5. Measure the horizontal angles α_3 and α_4 each on both faces of the instrument and take their respective mean values.

6. Compute α_5 and α_6 as follow:

$$\alpha_5 = 180° - (\alpha_1 + \alpha_2 + \alpha_4)$$

$$\alpha_6 = 180° - (\alpha_2 + \alpha_3 + \alpha_4)$$

7. Using the sine law, the distances AC and AD can be calculated as follow:

$$AC = AB\,\frac{sin\,(\alpha 3 + \alpha 4)}{sin\,(\alpha 6)}$$

$$AD = AB\,\frac{sin\,(\alpha 4)}{sin\,(\alpha 5)}$$

8. The distance CD can be calculated using the cosine law as follow:

$$CD = \sqrt{AC^2 + AD^2 - 2(AC)(AD)\cos(\alpha_1)}$$

9. **NOTE:** The Horizontal distance CD can also be calculated by plotting the angles and obtaining the intersection points C and D.

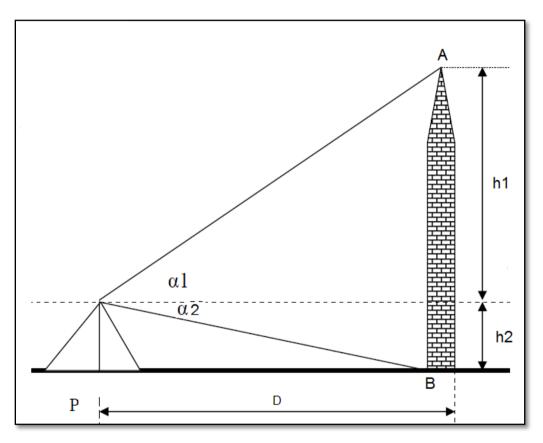# LAB #15: MEASURING AN OBJECT HEIGHT BY MEASURING VERTICAL ANGLE

- **Objective:**

  Determining a height of an object by measuring vertical angle.

- **Equipments**:

  Theodolite, Leveling Stop, Tape or Chain, Pegs, Plumb bob

SKETCH

- **Procedure:**
  1. Setup the instrument at station P.
  2. Perform all temporary adjustments.
  3. Bring the line of collimation horizontal (vertical angle reading is zero).

4. Sight the top of the object (A), and read the vertical angle α1.

5. Sight the bottom of the object B, and read the vertical angle α2.

6. Measure the Horizontal distance between the instrument station and the object (D).

7. Calculate the height of the object as follow:

$$h1 = D \tan \alpha1$$

$$h2 = D \tan \alpha2$$

$$\text{The object height} = h1 + h2$$

LAB #16: STUDY OF TOTAL STATION

- **Objective:** study of total station

- **Equipments:** Total station (Leica TS02 Total Station)

- **Instrument Setup Procedure (Leica TS02 Total Station):**

TRIPOD:
1. Set up the tripod at the appropriate height.
2. Visually check that the tripod is level and centered over the ground point.
3. Press the tripod legs into the ground to guarantee a firm foothold.
4. Attach the instrument to the tripod and "center" the foot screws.

PLUMB:
5. Turn on the instrument. The laser plummet will be activated automatically, and the Level/Plummet screen appears. If this screen does not appear, press user key 1.
6. IF NECESSARY Move the **position of the tripod legs** to make **large adjustments** to center the plummet over the ground point.
7. Use the **footscrews** to make **small adjustments** to center the plummet over the ground point.

ROUGH LEVELING:
8. Adjust the **height of the tripod legs** to level the circular level bubble. Note: Do not move the legs from their position just lengthen or shorten them, one at a time, as necessary to bring the bubble into center.

FINE PLUMB & LEVEL:
9. At this time your instrument should be very close to level and very close to the ground point, check the plummet & circular level bubble to verify this. If this is not the case you must repeat the Plumb & Rough Leveling steps above, otherwise, continue on to the next step.
10. Turn the instrument until it is parallel to two footscrews.
11. Center the electronic level of the first axis by turning the two footscrews. Arrows show the direction of rotation required. When the electronic level is centered the arrows are replaced by checkmarks.
12. Center the electronic level for the second axis by turning the last footscrew. An arrow shows the direction of rotation required. When the electronic level is centered the arrow is replaced by a checkmark.
13. When the electronic level is centered and three checkmarks are shown, the instrument has been perfectly leveled up.
14. IF REQUIRED, Center the instrument precisely over the ground point. Loosen the instrument from the tripod (loosen only) and slide the instrument over the point while sighting.

- **Instruments Procedure (LEICA TS02 TOTAL STATION):**

1. Set up and level the instrument so that it is precisely over the control point. Press OK to exit the Level/Plummet Screen

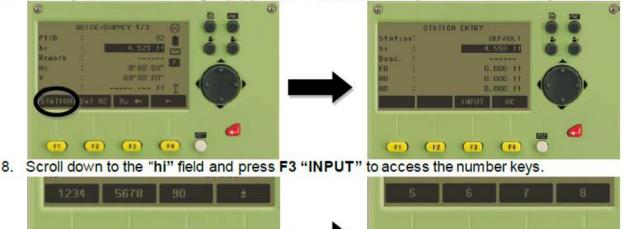2. Navigate to the Q-Survey (quick survey) Program from the Main Menu and press ◢ .

3. To set your horizontal angle backsight press **F4** twice to make the **"Set Hz"** softkey available.
4. Press **F2 "Set Hz"** to open the **"Set Horizontal Angle"** menu.

5. Aim at the back sight point then press **F1 "Hz=0"**. Press **F4 "OK"** to set the back sight angle. (**Note: Press the button lightly so as not to change the alignment of the instrument!**)

6. The instrument is now ready to measure horizontal angles.
   - As you turn the instrument to the right (clockwise), the horizontal angle measurement (Hz) will increase.
   - As you turn the instrument to the left, (counter clockwise) Hz will decrease.
   - If this is not the case, see your instructor.

7. To set your Instrument Height (hi) press F1 "STATION" to open the Station Entry menu.

8. Scroll down to the "**hi**" field and press **F3 "INPUT"** to access the number keys.

9. Use the **F#** keys to select the appropriate numbers and the navigation key to move from digit to digit. The following keystrokes are useful when entering data:

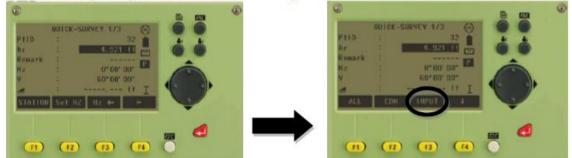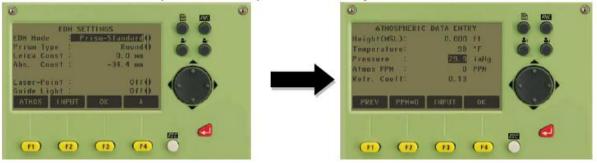| Edit fields | ☞ | ESC Deletes any change and restores the previous value. |
	◄	Moves the cursor to the left.
	►	Moves the cursor to the right.
	▲	Inserts a character at the cursor position.
	▼	Deletes the character at the cursor position.

☞ In edit mode the position of the decimal place cannot be changed. The decimal place is skipped.

10. Once you have the correct instrument height in place, press **Enter**. Press **F4 "OK"** to return to page one of the Quick Survey Program.
11. To set the height of your reflector use the navigation button to select the "**hr**" field.

12. If the "**INPUT**" softkey is unavailable, press **F4** to toggle until it is available.
13. Press F3 "INPUT" and use the **F#** keys to select the appropriate numbers and the navigation key to move from digit to digit.
14. Once you have the correct reflector height in place, press **Enter**.
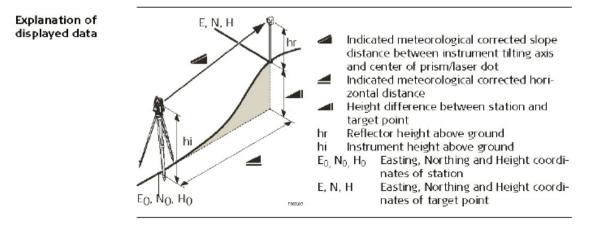15. To set the current temperature and pressure press **F2 "EDM"**.

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16. Press **F1 "ATMOS"** to open the Atmospheric Data Entry Menu.

17. Scroll to the Temperature field and use the **"INPUT"** and number softkeys to insert the appropriate temperature. Once the field is correct, press **Enter**.
18. Scroll to the Pressure field and enter the current pressure using the same routine.
19. Press "OK" twice to return to page one of the Q-Survey program.
20. Now you are ready to begin measuring horizontal angles, horizontal distances & vertical distances.
21. To make a measurement, aim the Total Station at the prism and press **"ALL"** or use the black Trigger Key located on the right hand side of the instrument.
22. The instrument will display the Horizontal Angle (hz), Vertical Angle (V), and the Horizontal Distance (◢) on the first page of data.

23. Press the **Page Button** to display the hz, Slope Distance (◢), and Vertical Distance (◢).
24. Pressing the **Page Button** again will display Northing, Easting, and Elevation.
25. Pressing the Page Button once again will return the display to the first page showing hz, V and Horizontal Distance again.
26. The following page shows a graphic explanation of the measurements that the instrument will make.

Explanation of displayed data

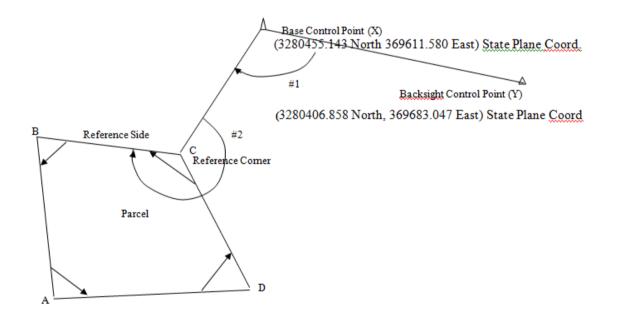|	
◢	Indicated meteorological corrected slope distance between instrument tilting axis and center of prism/laser dot
◢	Indicated meteorological corrected horizontal distance
◢	Height difference between station and target point
hr	Reflector height above ground
hi	Instrument height above ground
E_0, N_0, H_0	Easting, Northing and Height coordinates of station
E, N, H	Easting, Northing and Height coordinates of target point

LAB #17: MEASUREMENT OF A CLOSED TRAVERSE

- **Objectives:**

    1. To become familiar with using a total station to measure horizontal angles, horizontal distances and height differences.
    2. To become familiar working with angles expressed in degrees, minutes, seconds format.
    3. To apply a compass rule adjustment to the traverse (polygon) measured in the previous lab session.
    4. To balance the traverse with respect to elevation and reference it to a know bench mark.

- **Equipments:**

    Total station, tripod, prism & rod, tape.

- **Sample layout**

- **Instructions:**

    1. There will be 4 or 5 points polygon for this lab (In the shown figure, the closed traverse ABCDA). Locate the figure to be measured (as directed by your instructor).
    2. Prepare your field book for recording horizontal angles, horizontal distances and height differences.

3. Draw a sketch to show the location of the figure to be measured and label the vertices.

4. Begin your measurements by setting up on one of the points; this becomes your instrument station for the first set of measurements.

5. Enter the current temperature and barometric pressure on the instrument.

6. Measure the heights of the total station and the prism and then enter them on the instrument.

7. The interior angles of the figure are to be measured as "angles to the right."

8. Set your horizontal angle to zero while sighting the rod on the backsight point.

9. Measure the horizontal distance of the line from the instrument station to the backsight point and record it in your field book.

10. Measure the height difference to the backsight point and record it in your field book.

11. Turn the total station to the foresight point and record the horizontal angle. This is the interior horizontal angle (measured to the right, clockwise) for that vertex of the figure as measured with the instrument in the direct position.

12. While sighting the foresight point measure the horizontal distance of the line from the instrument station to the foresight point and record it in your field book.

13. Measure the height difference to the foresight point and record it in your field book

14. Plunge the telescope and reset the backsight (zero) to measure the interior horizontal angle again with the instrument in reverse position.

15. Move the total station to each point in the figure and repeat the process as described above to obtain 2 sets of angle measurement for each interior angle, two distance measurements and two height differences for each side of the figure.

16. Measure two "geo-referencing" angles:

    A. From your "Base Control Point" geodetic station, sight your "Backsight Control Point" and turn the clockwise angle to your nearest parcel corner (we'll call this the "reference corner" of your parcel.) Turn this angle twice and take the mean.

    B. Set up on the "reference corner", backsight the "Base Control Point" geodetic station and turn the angle to the first station in your traverse. This line is termed the "reference side". Double the angle and take the mean.

17. Calculate the mean interior angles and record them in your field book.

18. Calculate the angular misclosure of your traverse and show the calculation and result in your field book.

19. Calculate the mean distance for each side and record it in your field book.

20. Calculate the mean height difference for each side and record it in your field book.

21. Calculate elevation of traverse by adding the height difference (Δh) from the initial traverse point (first point your group set up).

- **Compass Rule Adjustment Instructions:**

  1. Draw a sketch of the traverse (does not have to be drawn in your field book, can be drawn on a separate sheet of paper).
      A. The sketch should be large enough so that you can add mathematical information to each leg and angle.
      B. The sketch should be drawn to scale or as near to scale as possible.
      C. Label the vertices.
      D. Label the mean distances measured* for each line.

  2. Adjust the measured interior measured angles:
      A. Divide the angular misclosure by the number of angles measured. This is the angular correction.
      B. Apply the angular correction to each of the measured angles.
      C. Check the adjusted angles by comparing their sum with the equation: $(n-2)180°$.
      D. Label the sketch with the adjusted angles.

  3. Calculate the azimuth of each line
      A. Determine the "control azimuth" – the direction from your "base control point (X)" to the "backsight control point (Y)."
      B. Calculate the azimuth of your parcel's "reference side" by applying your two measured georeferencing angles to the control azimuth.
      C. Calculate your traverse azimuths by applying your measured interior angles to the reference azimuth.
  4. Set up a compass rule adjustment table.
      A. Write in the lines, azimuths and mean distances from your sketch.
      B. Calculate the sum of the distances. This is the traverse perimeter.

  5. Calculate the latitude and departure of each leg and write them in the table including the sign.
  6. Calculate the sum of the latitudes to determine the error in latitude.
  7. Calculate the sum of the departures to determine the error in departure.
  8. Calculate the closure error for the entire traverse:

$$\text{Closure error} = \sqrt{\text{Dep. Error}^2 + \text{Lat. Error}^2}$$

9. Calculate the precision (ratio of error) of the traverse:

$$precision = closure\ error\ /\ traverse\ perimeter$$

10. Calculate the correction for each latitude and departure:

$$correction\ in\ departure = -\ (total\ Dep.\ Error)(length)/(traverse\ perimeter)$$

$$correction\ in\ latitude = -\ (total\ Lat.\ Error)\ (length)/\ (traverse\ perimeter)$$

11. Calculate the adjusted latitude and departure for each line by applying the appropriate correction.
12. Calculate the sum of the adjusted latitudes and departures as a check. The sums should now equal zero.
13. Calculate the new lengths and bearings for the adjusted traverse

$$length = \sqrt{Dep.^2 + Lat.^2}$$

$$bearing\ angle = Atan(departure\ /\ latitude)$$

- positive latitude indicates a NORTHERLY bearing
- negative latitude indicates a SOUTHERLY bearing
- positive departure indicates a EASTERLY bearing
- negative departure indicates a WESTERLY bearing

14. Calculate the adjusted coordinates for traverse points
15. Write the adjusted coordinates in your field book.

- **Vertical Adjustment Instructions:**

1. Calculate the vertical misclosure of the traverse by summing the mean height differences.
   A. Distribute the vertical misclosure evenly to each leg of the traverse to determine the adjusted height differences for each leg.
   B. Check your calculations by summing the adjusted height differences again, now the sum should equal zero.
2. Calculate the elevations of each point using the Temporary Bench Mark.
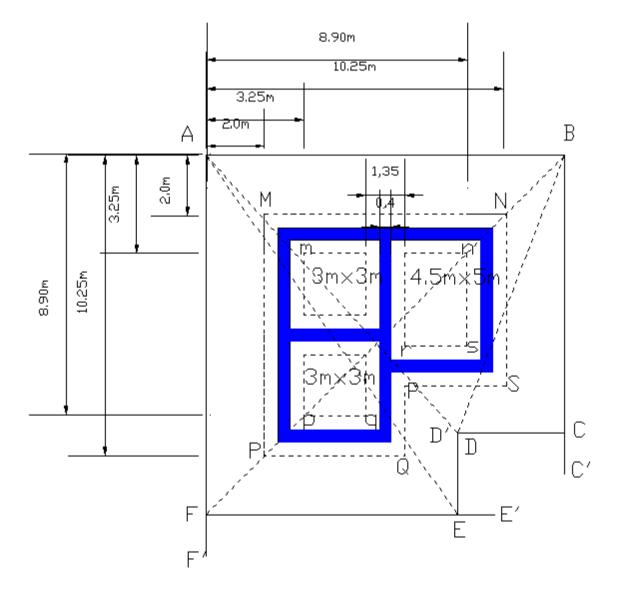
LAB #18: LAYOUT FOR GIVEN PLAN OF BUILDING

- **Objective:**

  To give layout for given plan of building.

- **Equipments:**

  Pegs, Nails, Lime, Wooden Mallet.

SKETCH: Plan figure.

- **Theory:**

When plans are ready for the works, the works are to be executed .To start with any structure first of all; trenches for the foundation are to be excavated. To excavate these trenches, the outline of excavation are defined on the ground, the process of defining the outlines of the excavation on the ground is known as setting out of works or lining out of works.

To set any structure or work whether it may be building, culvert, pipeline or sewer line, the plan showing the width of the foundation trench, for various walls, distance of the corners from some definite line etc. is required. This plan called foundation plan (Fig).The distances and they are with reference to lines AB and AF.

- **Procedure:**

1. To start with the setting out of building, first of all a point A is fixed and then line AB is oriented in the required direction .Thus having fixed the direction of the line AB, two pegs A and B are driven at distance of 12.25m apart (This distance calculated from the plan).
2. Wire nails are driven at the centers of the pegs. Again the distance between the wire nails is checked and which should be equal to12.25m. And a cord is stretched along AB and ends are secured to the wire nails at A and B.
3. Perpendiculars AF' and BC' are set out. Perpendicular may be set with a tape by 3-4-5 method or by swinging method. (Theodolite may be used to set a perpendicular if the work is important).
4. Along AF' and BC', points F and C are fixed at a calculated distance from A & B respectively.
5. The perpendicular are then set at C and F and point D and E are fixed along CD' and FE' at a calculated distance from C and F respectively.
6. The stakes are driven at these points C, D, E, and F and wire nails are driven at the centers of these stakes. A cord is stretched all along ABCDEF.
7. To check up the work, the diagonal AE, AD, BF, and BD are actually measured and these measured values should agree with their corresponding calculated lengths.

Otherwise the setting out work should be repeated and stakes should be refixed at their correct positions.

8. After fixing up all the pegs and stretching the cords, the corners M, N, P etc and m, n, p etc. are to be located. The point A is considered as the origin and the lines AB and AF as the axes of the coordinates. The coordinates of all the corners M, N, P etc., and m, n, p, etc. are calculated with reference to A as origin. For example Co-ordinates of M.N.P are (2 , 2) , (2 , 10.25) and (10.25 , 2) respectively and those for m, n, p are (3.35 , 3.35) , (3.35 , 8.90) and (8.90 , 3.35) respectively.

9. With these coordinates, point M, N, P, m, n, p etc., are set and pegs are driven at these points. The cord are stretched around the wire nails at M,N,P,Q,R,S and m, n, p, r, s indicating peripheries. The outlines of the peripheries are marked with lime spread.

10. Now the lime lines on the ground indicate the trenches for the various walls and the excavation may be started. During the progress of the work if the marked lines are disturbed, they may be checked or reset with help of reference line ABCDEF.

Appendix A: Field Report Preparation

- **Report Characteristics:**
    a) Font: Times New Roman
    b) Font size: 11
    c) Line spacing = 1.5 lines
    d) Margins: 1" all sides

- **The report shall take the following format and shall include all sections shown below:**
    A. **Title page:**
        - Include: Report title, University name, class name, class number, crew number, member names (first & last), date prepared.
    B. **Introduction:** (1 or 2 paragraphs)
        - This is an introduction to the report; it should summarize what the report is about and explain the purpose of the report.
    C. **Method & equipment used**
    D. **Procedure:** At minimum give a brief description of the field procedures followed. Include crew assignments & special methods used (if any). Discuss any problems that you encountered and the solutions to those problems.
    E. **Data and Calculation**
    F. **Results:** Discuss your raw results and any adjustments that were required (if any).
    G. **Conclusion:** Discuss important things that you learned. Discuss things you might do differently in the future or things that worked out well.
    H. **References**