Leveling: the art of determining relative altitudes of points on the surface of the earth. This branch of surveying deals with measurements in vertical planes.

By this process the elevations and depressions of the terrain are determined relative to a specific level known as the benchmark (reference surface), providing a natural representation of the topography of a particular area."

TECHNICAL TERMS USED IN LEVELLING

Elevation: the distance measured along a vertical line from a vertical datum to a point or object.

Bench mark (B.M): A relatively permanent and fixed reference point of known elevation above the datum.

Station: the point where levelling staff is help, it is the point whose elevation is to be determined or the point that is to be established at a given elevation

Height of instrument (H.I): the elevation of the line of sight with respect to the assumed datum is known as height of instrument.

Datum surface: the imaginary level surface with reference to which vertical distances of the points (above or below) are measured.

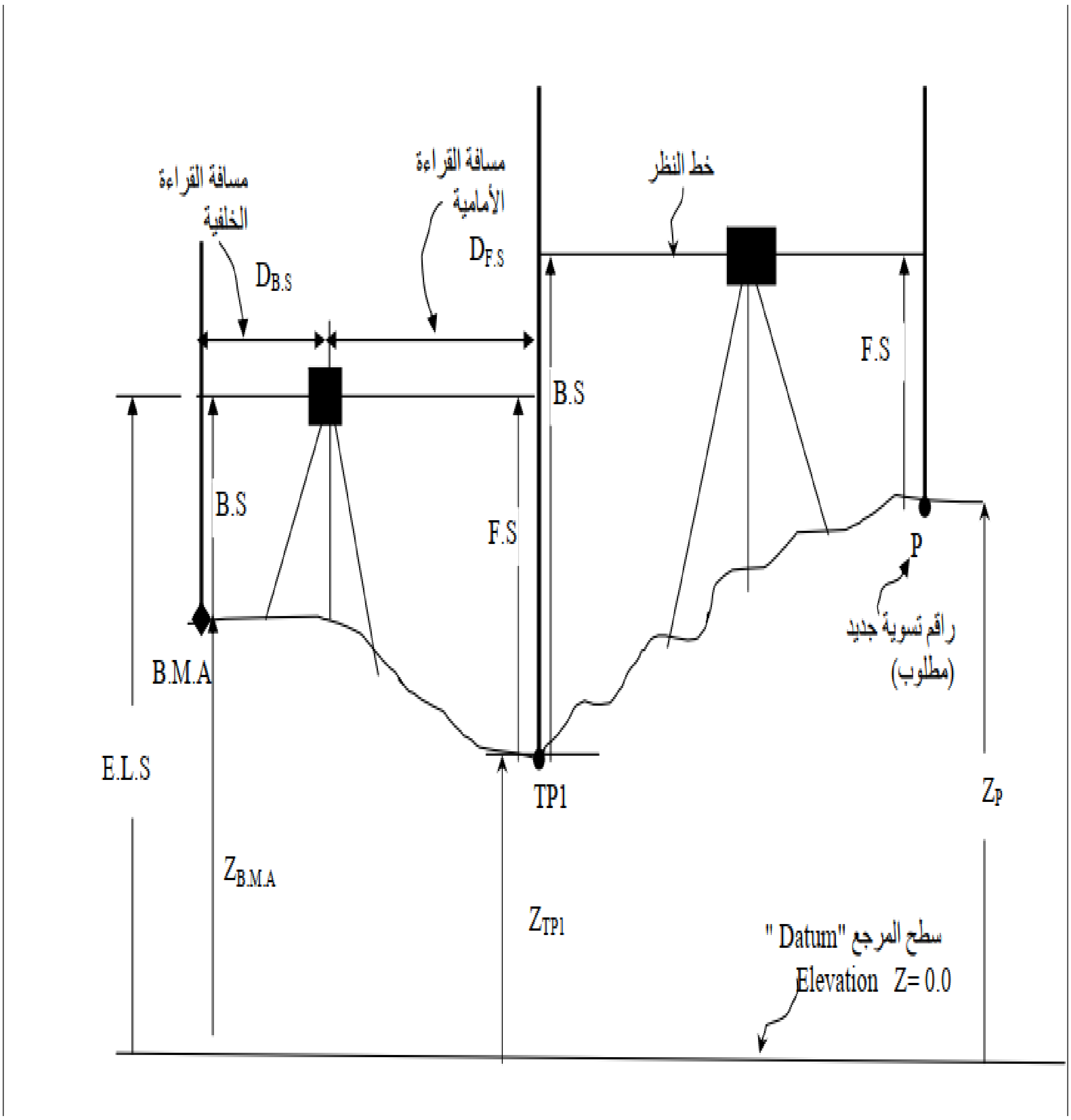
Line of sight: the line passing through the optical center of the objective, traversing the eye-piece and entering the eye.

Back sight [B.S]: This is the first reading of the leveling rod taken after the instrument is set up. It is always taken at a point with a known elevation.

Fore sight [F.S]: This is the final reading of the instrument after its setup, the reading that the device raises immediately after taking it. Often, this reading is taken at a point with an unknown elevation

Intermediate sight [I.S]: An intermediate sight is any staff reading taken on a point of unknown elevation after the back sight and before the fore sight.

Turning Point [T.P]: This is a point that is established when it is desired to move the instrument to another location. Two readings, the first one in front (fore-sight) and the other one behind (back-sight), are taken on this point after the instrument has been relocated, and its elevation is determined from these readings.


مسافة القراءة
الخلفية
مسافة القراءة
الأمامية
خط النظر
D B.S
D F.S
B.S
F.S
B.S
F.S
B.M.A
E.L.S
TP1
P
راقم تسوية جديد
(مطلوب)
Z B.M.A
Z TP1
Zp
سطح المرجع "Datum"
Elevation Z= 0.0

Leveling instrument: It is a mechanical device consisting of a mounted telescope on a metal base. It also has screws for horizontal adjustment and an air bubble for leveling. Inside it, there is a glass disk with three horizontal lines and one vertical line, which are called stadia hairs.

Basic Components

1- Telescope: the primary purpose of a telescope is to stabilize the line of sight and give enlarged image of the visible object (level rod).

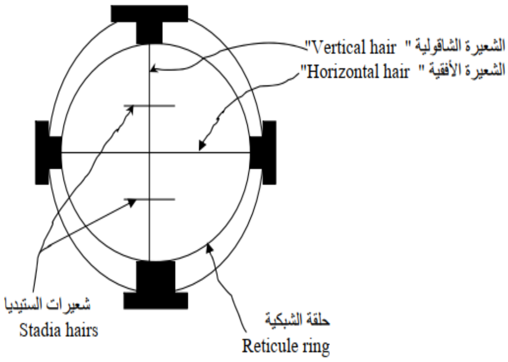
In reference to the shape, the telescope consists of three main parts

a- Objective lens: The purpose of the objective lens is to create a real image of the visible object. This image is small and inverted. This image is located at the level of the **reticule**.

b- Eye piece lens: The main purpose of the eyepiece is to magnify the image of the visible object (ruler leveling and retinal filaments)

c- Reticule: The purpose of the reticule in a telescope is to clarify the image for both the eyepiece lens and the objective lens.

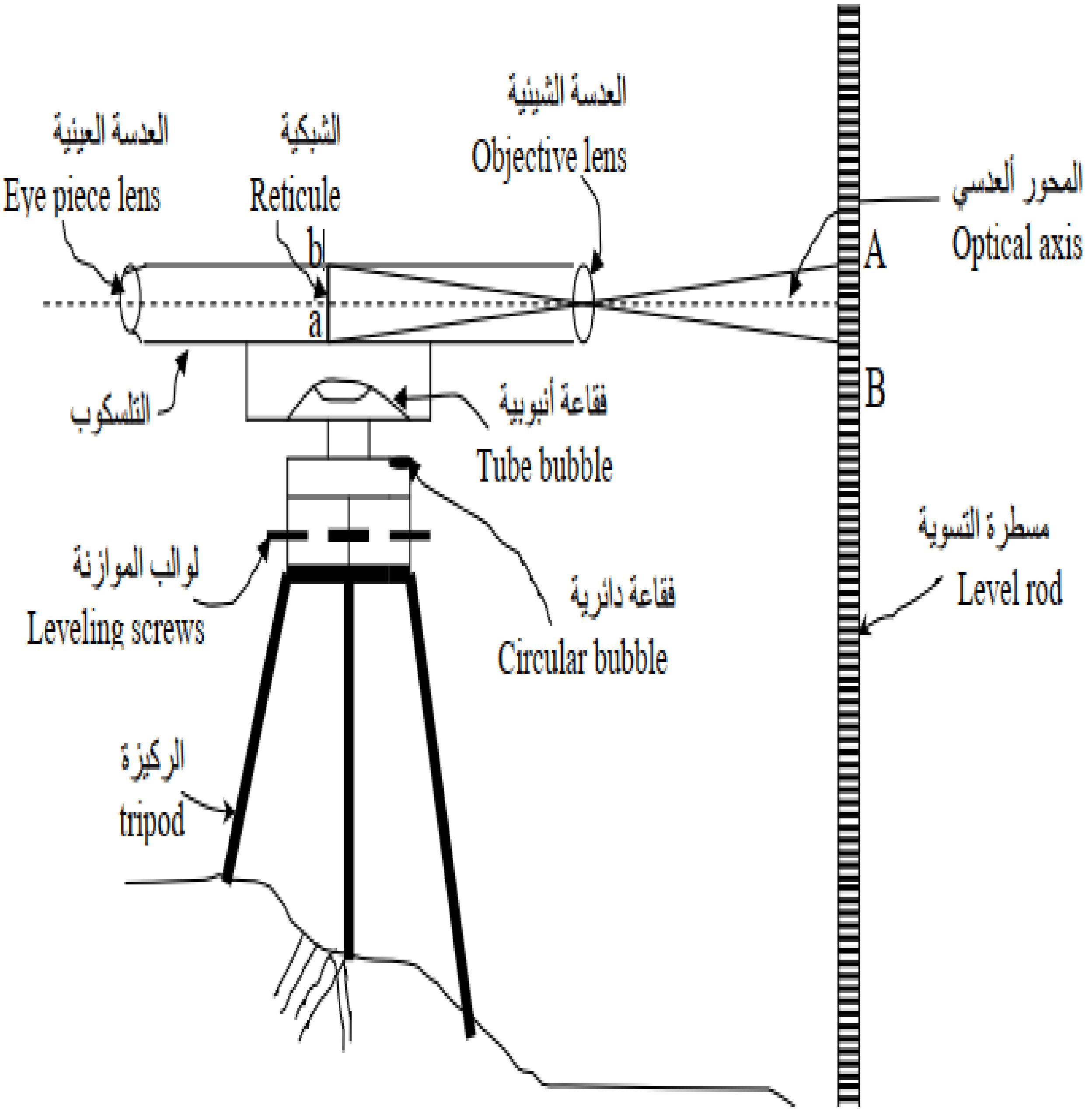
The reticule mainly consists of two types of filament, one of which is horizontal, and the other is called the Vertical filament, representing the center of the device and located on the optical axis of the device. In most leveling devices, the retina contains two additional horizontal hairs called (staidia filament).



5- Circular bubble: used in a leveling device to obtain a horizontal line. The accuracy achieved from the leveling device largely relies on the Circular bubble.

7- Leveling screws: There are three of them in general. They are used to weigh the leveling device, which is done by making the level axis is a horizontal line that is obtained by moving the bubble, (using the c screws) until it is position in the center .

6- Tripod: It is a three-legged tripod used to support a leveling device.



The process of leveling using a leveling instrument:

There are two methods for finding the difference in elevation and the elevations of points, which are:

1. **Direct Leveling (Height of Instrument Method):** In this method, a leveling instrument is set up, and a series of readings are taken on a graduated leveling rod held at different points. The difference in elevation between the instrument and each point is calculated directly from the readings.
2. **Differential Leveling (Rise and Fall Method):** This method involves taking readings on both a back sight (a point with a known elevation) and a foresight (a point whose elevation needs to be determined). The difference in elevation between the back sight and the foresight is computed to find the elevation of the foresight point.

These methods are commonly used in surveying and construction to determine the elevations and levelness of various points on the ground.

Direct Leveling (Height of Instrument Method):

In this method, height of the instrument (H.I.) is calculated for each setting of the instrument by adding the back sight (B.S.) to the elevation of the B.M. The reduced level of the first station is obtained by subtracting its fore sight from the instrument height (H.I.). For the second setting of the instrument, the height of the instrument is calculated by adding the back sight taken on the first station to its reduced level. The reduced level of the last point is obtained by subtracting the fore sight of the last point from the height of instrument at the last setting.

$H.I_{(i)} = Elev.\ B.M + B.S_{(i)}$

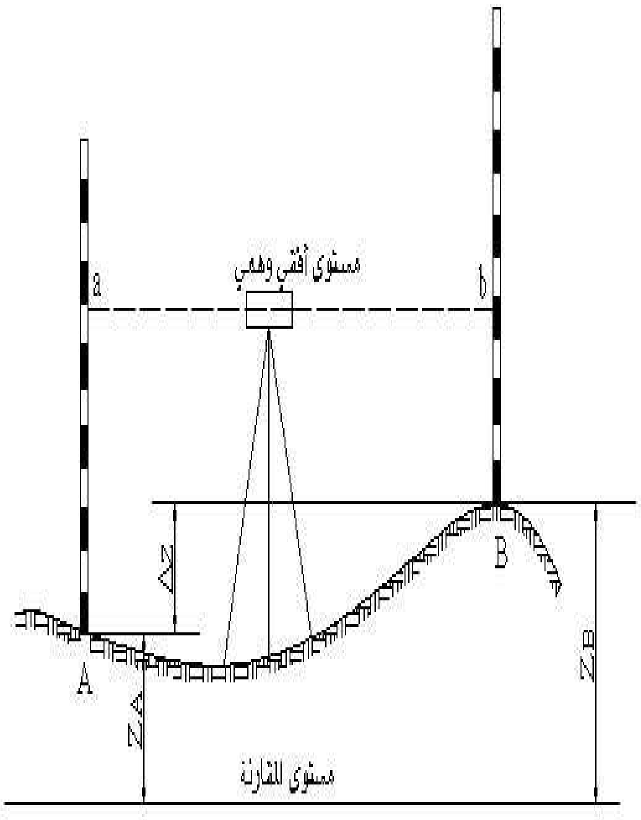
$Elev\ of\ point = H.I - I.S$

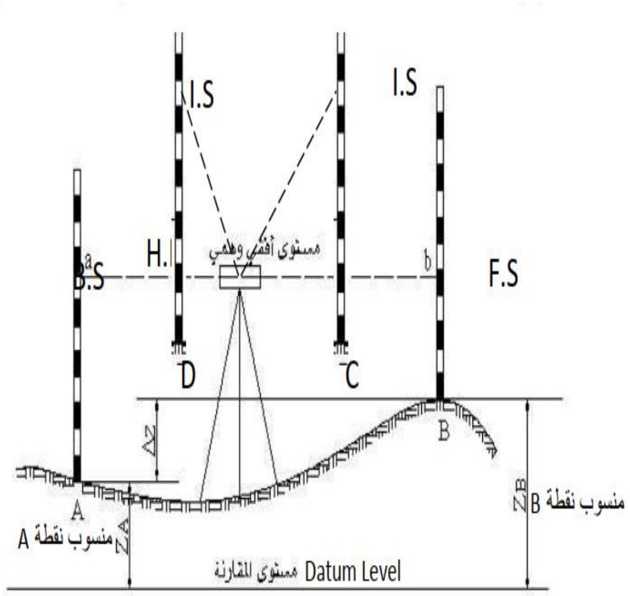
Or

$Elev\ .\ of\ point = H.I - F.S$

FOR CHECK

$B.S - \sum F.S = last\ Elev - first\ Elev$





$$Elev.\ D = Elev.\ A + B.S - I.S_{(D)} = H.I - I.S_{(D)}$$

$$Elev.\ C = Elev.\ A + B.S - I.S_{(C)} = H.I - I.S_{(C)}$$

$$Elev.\ B = Elev.\ A + B.S - F.S = H.I - F.S$$

For each station there is its own H.I and it does not change unless the location of the device changes

Example 1: In the leveling process, the following readings were taken, starting from benchmark A with an elevation of 23.157 meters, and they were as follows

➔ 1.237, 1.315, 2.28, 1.953, 0.87, 1.42, 2.213, 2.104, 1.313, 0.976, 1.512, 1.915, 0.854, 1.506 m

Considering that the leveling instrument was moved after the fourth, seventh, ninth, and twelfth readings, calculate the elevations of the remaining survey points and verify the accuracy of the calculations.

Solution:

When it is mentioned that the instrument was moved after the fourth reading, it means that the fourth reading is a foresight reading (F.S) , and likewise, the reading following it (the fifth) is a second back-sight reading ($B.S_2$), and the same applies to the seventh, ninth, and twelfth readings.

For the purpose of organizing the solution, we arrange the data in the form of a table as shown below:

$H.I_1 = 23.157 + B.S_A = 23.157 + 1.237 = 24.394$ m
Elev. $B = H.I – I.S_B = 24.394 – 1.315$ m
Elev. $C = H.I – I.S_C = 24.394 – 2.280 = 22.114$ m
Elev. $D = H.I – F.S_D = 24.394 – 1.953 = 22.441$ m

In this stage, the instrument was moved to the second station; therefore, a new H.I. (Height of Instrument) value needs to be determined

$H.I_2 =$ Elev. $D + B.S_D = 22.441 + 0.87 = 23.311$ m
Elev. $E = H.I_2 – I.S_E = 23.311 – 1.42 = 21.891$ m
Elev. $F = H.I_2 – F.S_F = 21.891 – 2.213 = 21.098$ m

In this stage, the instrument was moved to the second station; therefore, a new H.I. (Height of Instrument) value needs to be determined

$H.I_3 =$ Elev. $F + B.S_F = 21.098 + 2.104 = 23.202$ m
Elev. $G = H.I_3 – F.S_G = 23.202 – 1.313 = 21.889$ m

In this stage, the instrument was moved to the second station; therefore, a new H.I. (Height of Instrument) value needs to be determined

$H.I_4 =$ Elev. $G + B.S_G = 21.889 + 0.976 = 22.865$ m
Elev. $H = H.I_4 – I.S_H = 22.865 – 1.512 = 21.353$ m
Elev. $I = H.I_4 – F.S_I = 22.865 – 1.915 = 20.950$ m

In this stage, the instrument was moved to the second station; therefore, a new H.I. (Height of Instrument) value needs to be determined

H.I5 = Elev. I + B.SI = 20.950 + 0.854 = 21.804 m
Elev. J = H.I5 – F.SJ = 21.804 – 1.506 = 20.298 m

Point	B.S	I.S	F.S	H.I	Elevation	Remarks
A	1.237			24.394	23.157	B.M
B		1.315			23.079	
C		2.28			22.114	
D	0.87		1.953	23.311	22.441	T.P
E		1.42			21.891	
F	2.104		2.213	23.202	21.098	T.P
G	0.976		1.313	22.865	21.889	T.P
H		1.512			21.353	
I	0.854		1.915	21.804	20.950	T.P
J			1.506		20.298	
	∑=6.041		∑=8.90			

Up to this point, the process of determining the elevations of the survey points has been completed. For the purpose of verifying the calculations, we use the following formula or law

∑B.S - ∑F.S = *Last Elev. – First Elev*

6.041 – 8.900 = 20.298 – 23.157
-2.859 = -2.859 OK

Example 2:

Using a leveling instrument and a level rod, readings were taken at various points A, B, C, D, E, F, to determine their elevations above sea level from two setups of the level. Given the elevation of point A is 30.00 m as a reference, calculate the elevations of the other points and verify the accuracy of the calculations using the provided data in the table.

Point	B.S	I.S	F.S	H.I	Elevation	Remarks
A	1.54				30.00	B.M
B		1.45				
C		1.38				
D	1.61		1.52			T.P
E		1.55				
F		1.48				
G			1.73			

Solution

Point	B.S	I.S	F.S	H.I	Elevation	Remarks
A	1.54			31.54	30.00	B.M
B		1.45			30.09	
C		1.38			30.16	
D	1.61		1.52	31.63	30.02	T.P
E		1.55			30.08	
F		1.48			30.15	
G			1.73		29.90	
	∑=3.15		∑=3.25			

∑B.S - ∑F.S = Last Elev. – First Elev.
3.15 – 3.25 = 29.90 – 30.00
-0.10 = -0.10 ok

Rise and Fall Method

It relies on finding the difference between a previous reading and a subsequent reading, and when this difference is positive, it means that the subsequent point is higher in elevation than the previous point, indicating an increase in elevation (Rise), however, when the subsequent point is lower than the previous point, it indicates a decrease in elevation (Full)

The process of finding the resulting difference is performed with readings within each coterie separately, and calculations between coteries are not allowed

(ΔH) = Last reading – Next reading = → Rise (+) / Full (-) **(Within the same coterie)**

And therefore, to determine the elevations of the other points

Next Elev. = Last Elev. + R   or   Next Elev. = Last Elev. – F

Example 1: In the leveling process, the following readings were taken, starting from benchmark A with an elevation of 23.157 meters, and they were as follows

➔ 1.237, 1.315, 2.28, 1.953, 0.87, 1.42, 2.213, 2.104, 1.313, 0.976, 1.512, 1.915, 0.854, 1.506 m Considering that the leveling instrument was moved after the fourth, seventh, ninth, and twelfth readings, calculate the elevations of the remaining survey points and verify the accuracy of the calculations (used full & rise method)

Solution:

Point	B.S	I.S	F.S	Rise (+)	Fall (-)	Elev. (m)	Rem.
A	1.237			فارغ دائماً في هذه الطريقة		23.157	B.M
B		1.315			0.078	23.079	
C		2.28			0.965	22.114	
D	0.87		1.953	0.327		22.441	T.P
E		1.42			0.55	21.891	
F	2.104		2.213		0.793	21.098	T.P
G	0.976		1.313	0.791		21.889	T.P
H		1.512			0.536	21.353	
I	0.854		1.915		0.403	20.950	T.P
J			1.506		0.652	20.298	
Σ=6.041		Σ=8.90		Σ=1.118	Σ=3.977		

حلقة واحدة أو محطة واحدة

$\sum B.S - \sum F.S = \sum Rise - \sum Fall = Last\ Elev. - First\ Elev.$

6.041 – 8.90 = 1.118 – 3.977 = 20.298 – 23.157

- 2.859 = - 2.859 = - 2.859 ➔ **ok**

Example 2:

A leveling instrument and leveling rod were used to determine the elevations of points located on a street center for a planned project. The reading on the first rod (known elevation) was recorded as 1.45 m, the subsequent readings are 1.54 m , 1.63 m and reading of the last rod, before instrument was moved 1.75 meters. After moving the instrument, the first reading was 1.37 meters, and the subsequent points are 1.46 m , 1.51 m and the last reading is 1.25 m, If you know that the elevation of the first point where the rod was placed is 20.00 m Calculate the elevations of the remaining points.

Solution:

Point	B.S	I.S	F.S	Rise (+)	Fall (-)	Elev. (m)	Rem.
A	1.45			فارغ دائماً في هذه الطريقة		20.00	B.M
B		1.54			0.09	19.91	
C		1.63			0.09	19.82	
D	1.37		1.75		0.12	19.70	T.P
E		1.46			0.09	19.61	
F		1.51			0.05	19.56	
G			1.25	0.26		19.82	
∑=2.82		∑=3.00		∑=0.26	∑=0.44		

حلقة واحدة او محطة واحدة

$\sum B.S - \sum F.S = \sum Rise - \sum Fall = Last\ Elev. - First\ Elev.$

2.82 – 3.00 = 0.26 – 0.44 = 19.82 – 20.00

- 0.18 = - 0.18 = - 0.18 ➔ ok

Longitudinal and cross profile

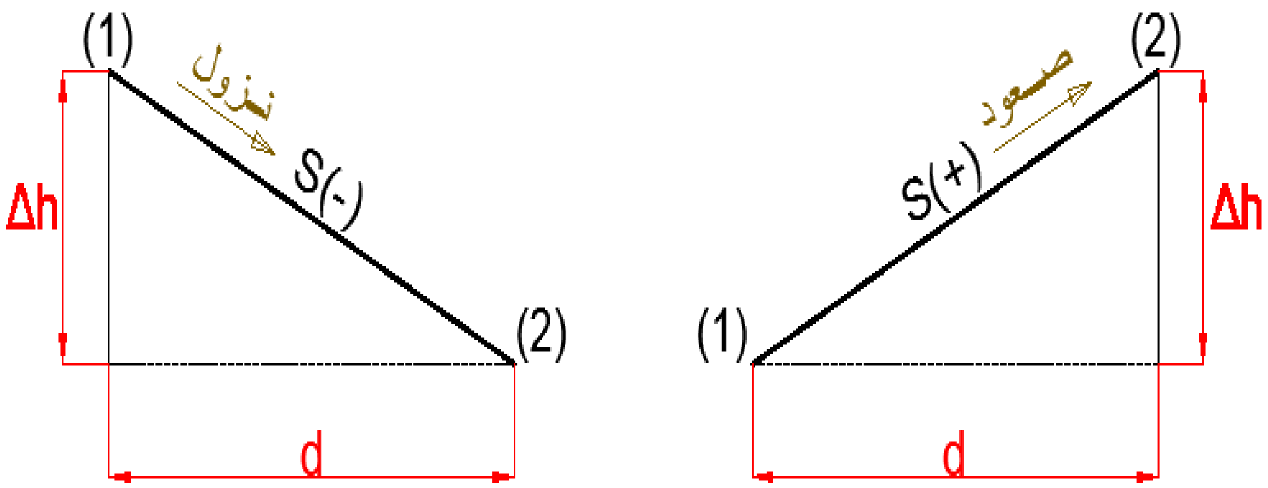
Longitudinal Profiles: Prior to the design of certain projects, taking a longitudinal section of the ground surface where these projects will be constructed is considered essential. The longitudinal section is taken along a predetermined and marked reference line in the field, such as the centerline of a road, railway track, canal, pathway along the road, or the alignment of electrical power poles.

The central line used for taking the longitudinal section can be either a straight line, a broken line, as in pipeline routes, or a series of straight segments connected by curves, as in roads, railways, or canals. When drawing the longitudinal section (in addition to drawing cross-sections), the nature of the ground surface along the proposed central line can be studied. The project's elevation is established in the most economical manner before the design. Typically, sections are taken along multiple proposed lines, and these lines are studied and compared to choose the best option.

Stations: The distance of points along the centerline of a project is expressed in a stationing system, where one station is equal to 100 meters. The starting point of the project is referred to as station (0) or (0+00). Points that are located at multiples of 100 meters from this station are called full stations, such as 100, 200, 300, etc. These are often denoted as 01+00, 02+00, 03+00, and so on. Points that fall between full stations are called plus stations, for example, 13+65.50

Steps for solving and drawing longitudinal sections

1- Finding natural ground line elevations and distances between points in the form of stations, and fixing them using a leveling table.



2- Designing (establishing) the proposed centerline, then determining its elevations using its slope as follows.

$$s = \frac{\Delta h}{d}$$

$$\Delta h = s \times d$$

$$Gread\ (2) = Gread\ (1) \pm s \times d$$

3- After extracting the actual ground elevation (natural ground) and the proposed elevation (construction elevation), it becomes possible to determine the depths of excavations and fills at each station of the project.

The process of finding the resulting difference is performed with readings within each coterie separately, and calculations between coteries are not allowed

Ground level– grade level = → Rise (+)
→ Full (-)

Note: The longitudinal section is drawn by representing elevations along the vertical axis (ordinate) and distances (stations) along the horizontal axis (abscissa) for the points on the centerline. The drawing is done using a scale for vertical elevations and another scale for horizontal distances.

Example 1: The readings below are taken in meters along the centerline of a proposed earth embankment, where the distance between each point is ten meters, and the readings are as follows:"

Start of project➔ 1.38, 1.34, 1.33, 1.59, 1.86, 2.09, 2.10, 1.18, 1.52, 1.50, 1.49

If you know that the leveling instrument was moved after the fourth, seventh, and ninth readings, If the requirement is for the surface to have regular slopes, with the full depth at the first point is 2 meters, at the middle points of the section is 3 meters, and at the last point is 2.5 meters above the ground surface, calculate the full depth at the remaining points

Station	B.S	I.S	F.S	H.I	Ground elevation	Grade Elevation
0+00	1.38			51.38	50.00	52.00
0+10		1.34			50.09	52.263
0+20		1.33			50.05	52.527
0+30	1.86		1.59		49.79	52.79
0+40		2.09			49.50	52.56
0+50	1.18		2.10		49.55	52.28
0+60	1.50		1.52		49.21	52.00
0+70			1.49		49.22	51.72

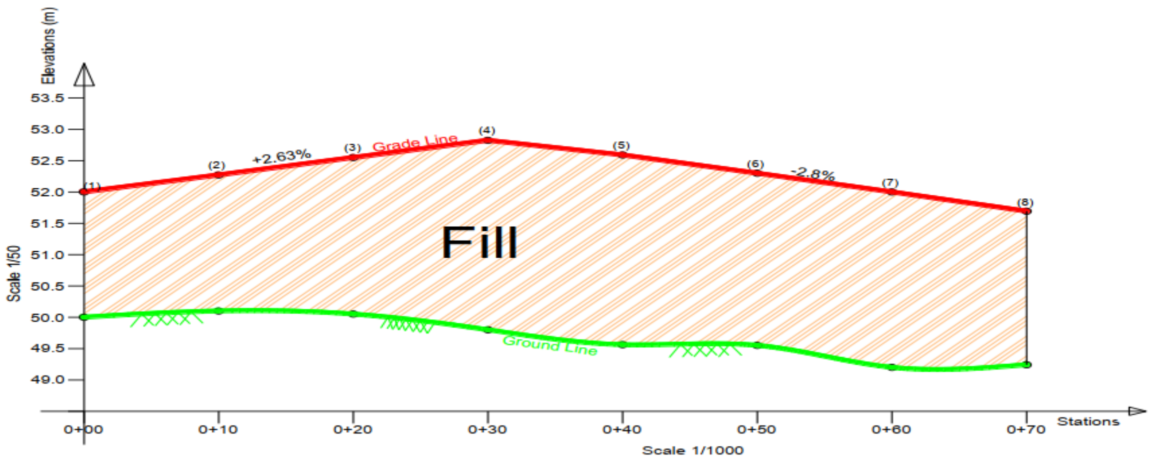
Full (-)	Cut (+)
2	
2.173	
2.477	
3	
3.06	
2.73	
2.79	
2.5	

$$Grade_{(1)} = slope = S = \frac{52.79 - 52.00}{30} = +0.0263 = +2.63\%$$

$$Grade_{(2)} = \frac{51.72 - 52.56}{30} = -0.028 = -2.8\%$$

$$\therefore Grade\ Elevation\ _{(2)} = Grade\ Elevation\ _{(1)} + S.d = 52.00 + 0.0263 \times 10 = 52.263\ m$$

$$\therefore Grade\ Elevation\ _{(6)} = Grade\ Elevation\ _{(5)} - S.d = 52.56 + 0.028 \times 10 = 52.28\ m$$



مخطط المقطع الطولي