

Chapter 4

Leveling

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Content

4.1 Introduction

4.2 Basic definitions

4.3 Basic principle of a level

4.7 Measuring elevation difference using a level

4.8 Procedure in differential leveling

4.9 General notes

4.14 Applications of leveling

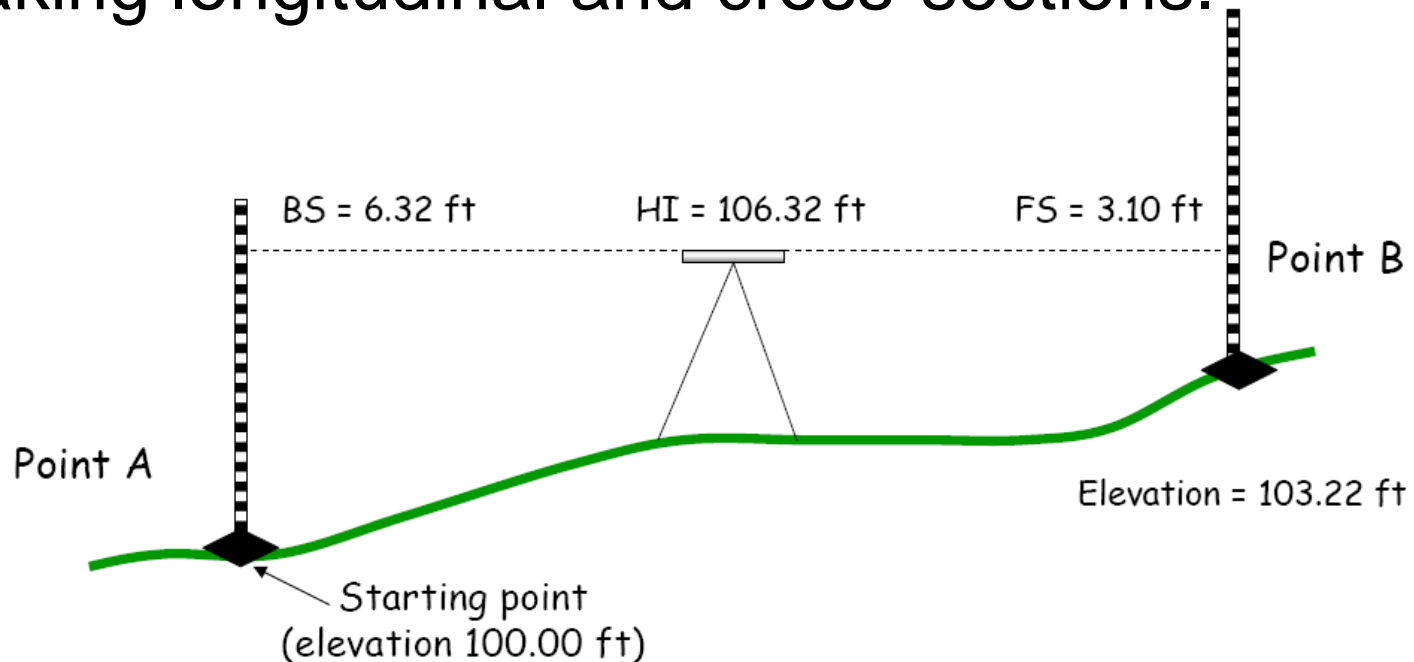
4.14.1 Longitudinal sections (profiles)

4.1 Introduction

- **The elevation of a point:** vertical distance between point and a reference level surface called datum.
- **Datum:** If a whole series of heights is given relative to a plane, this plane is called a datum. In topographical work the used datum is the mean sea level (MSL)
- +ve if above MSL such as Jerusalem
- -ve if below MSL such as Jericho.

4.1 Introduction

Leveling: is the operation required in the comparison of heights of points on the surface of the earth. Its purpose to provide spot heights or contour lines on a map, to provide data for making longitudinal and cross-sections.



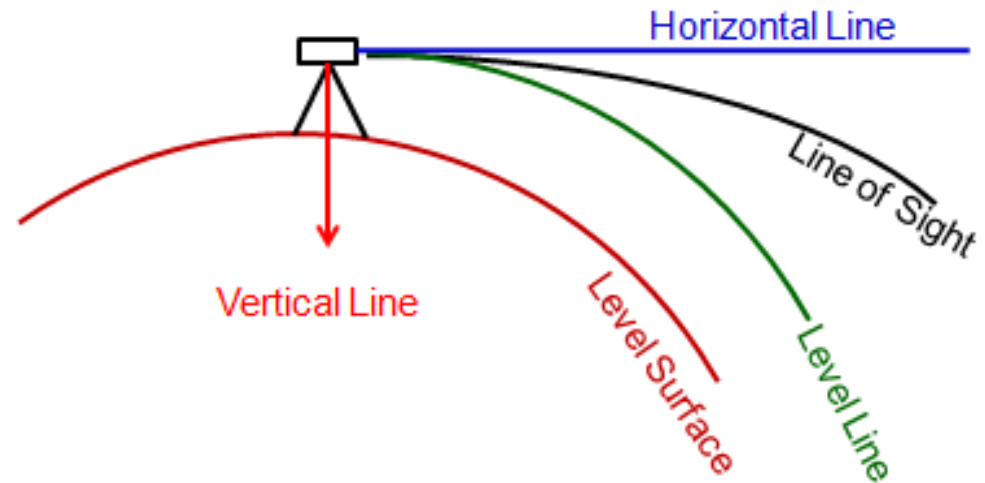
4.1 Introduction

Leveling can be done in several ways:

- Chain surveying
- **Barometric leveling:** using barometer to measure the atm. Pressure to determine elevation
- **Trigonometric leveling:** using Theodolite
- **Photogrammetric leveling:** using Camera
- GPS leveling
- **Differential leveling:** using level and staff

4.2 Basic Definitions

- Vertical Line
- Horizontal Line
- Horizontal Plane
- Level Surface
- Level Line: A line that lies on the level surface.
- Difference in elevation b/w 2 points: is the vertical distance b/w 2 level surfaces.
- Actual Line of Sight or Collimation: Neither horizontal nor level. Affected by atmospheric refraction.



4.2 Basic Definitions

- **Bench Mark:** A marked point whose elevation has been accurately measured.
- **Height of Instrument:** The line of Collimation above the datum after setting up the level above a certain point.

4.3 Basic Principles of a Level

Differential Leveling Requires:

- a) a device which gives a truly horizontal line (**the Level**),
- b) a suitably graduated staff for reading vertical heights (**the Leveling Staff**).

Level consists mainly of:

- a) Telescope for sighting and
- b) A leveling device for maintaining the line of sight in horizontal position.

4.3 Basic Principles of a Level

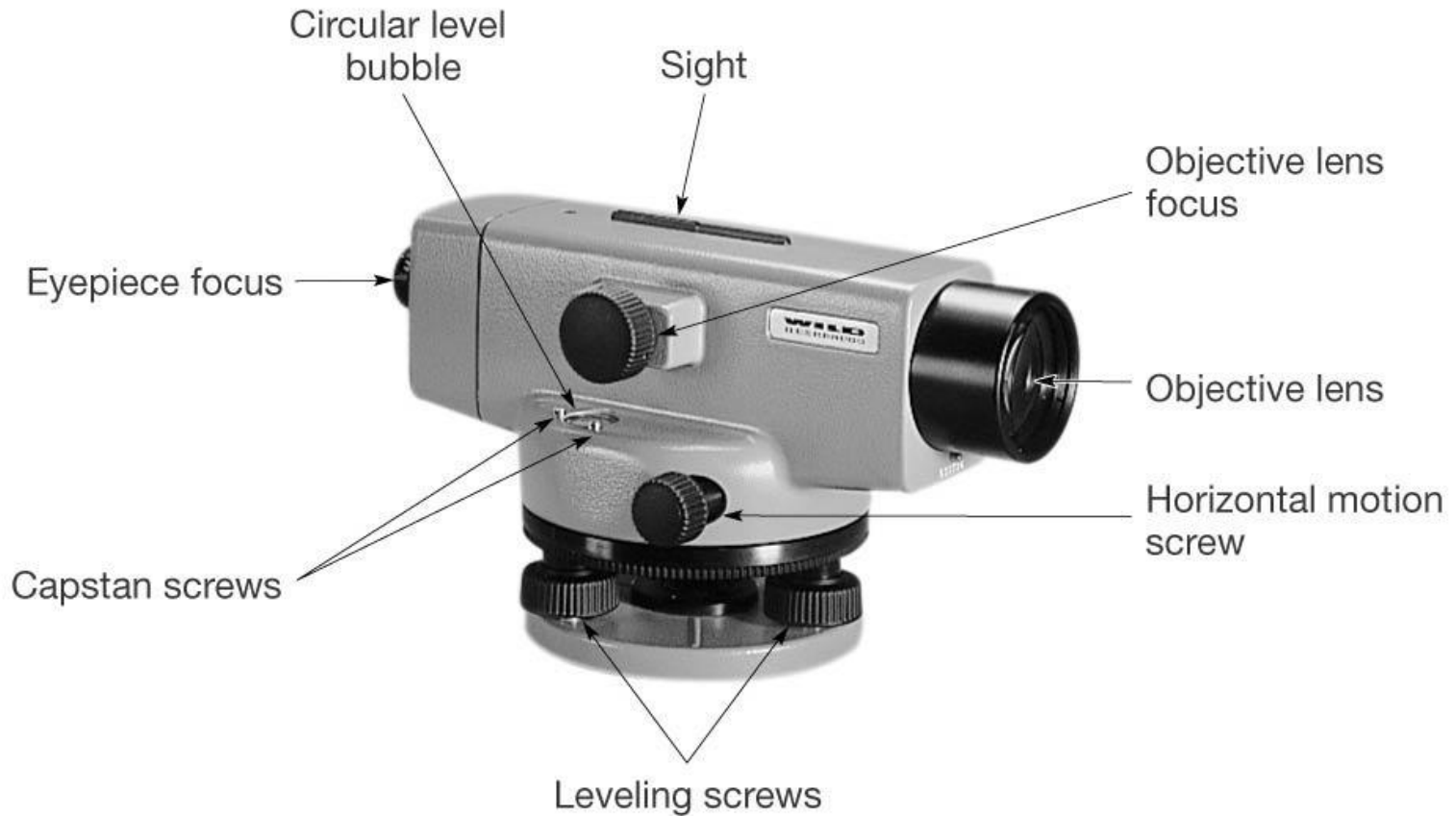
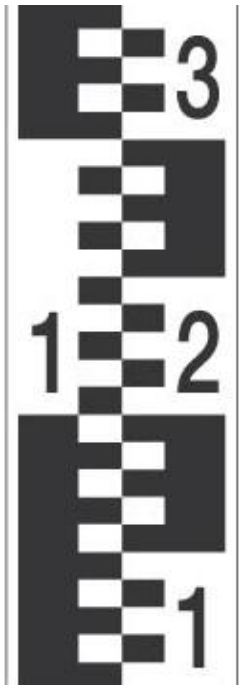


Figure 4.9

4.3 Basic Principles of a Level



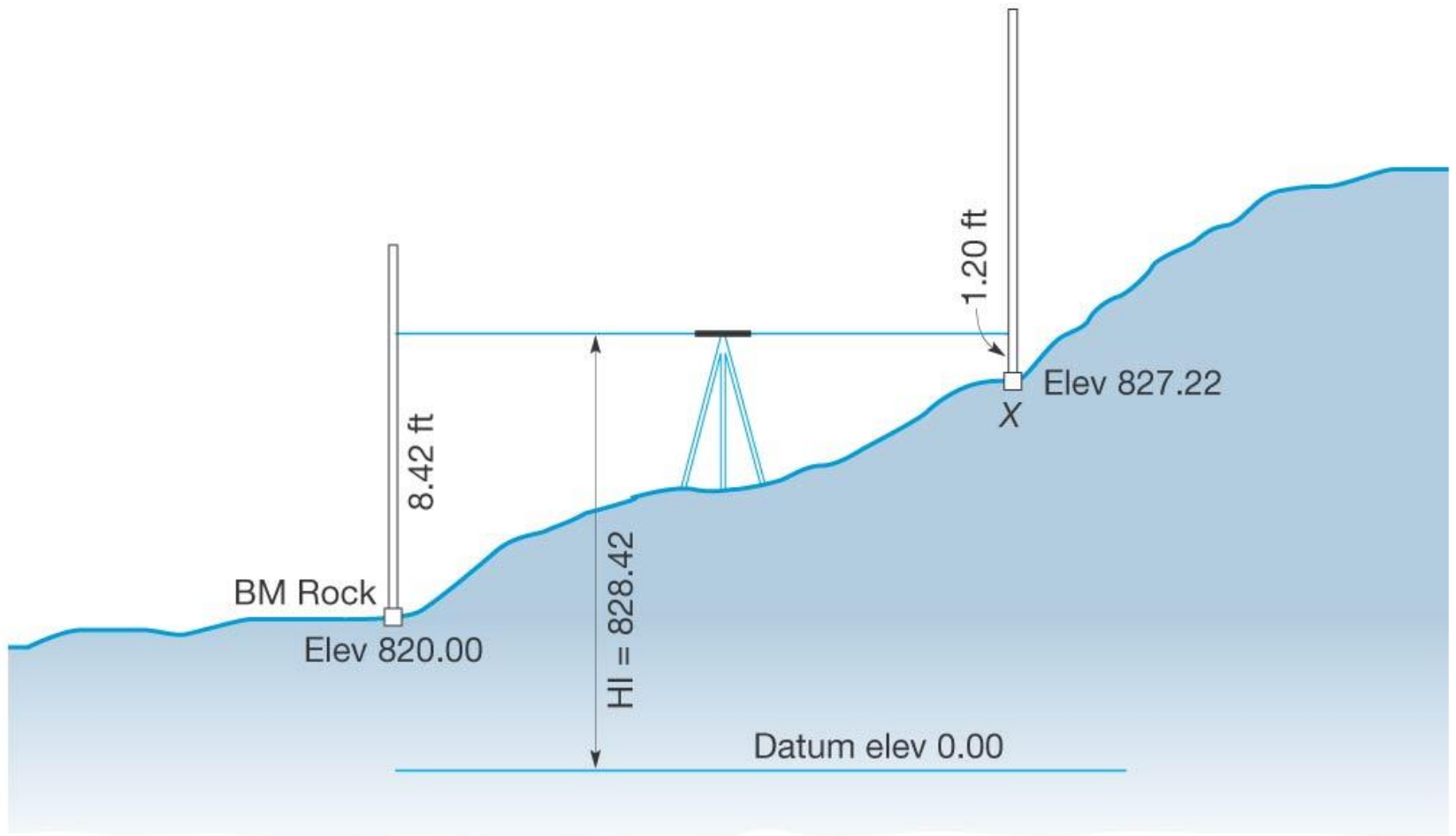
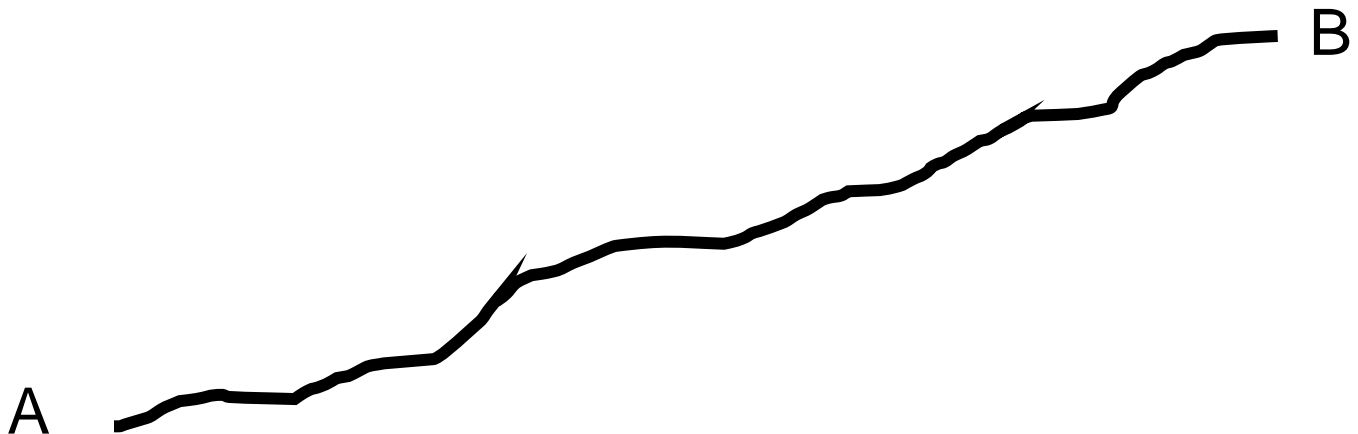


Figure 4.5

From *Elementary Surveying, An Introduction to Geomatics*, Eleventh Edition, by Paul R. Wolf and Charles D. Ghilani. ISBN 0-13-148189-4. © 2006 Pearson Education, Inc., Upper Saddle River, NJ. All rights reserved.

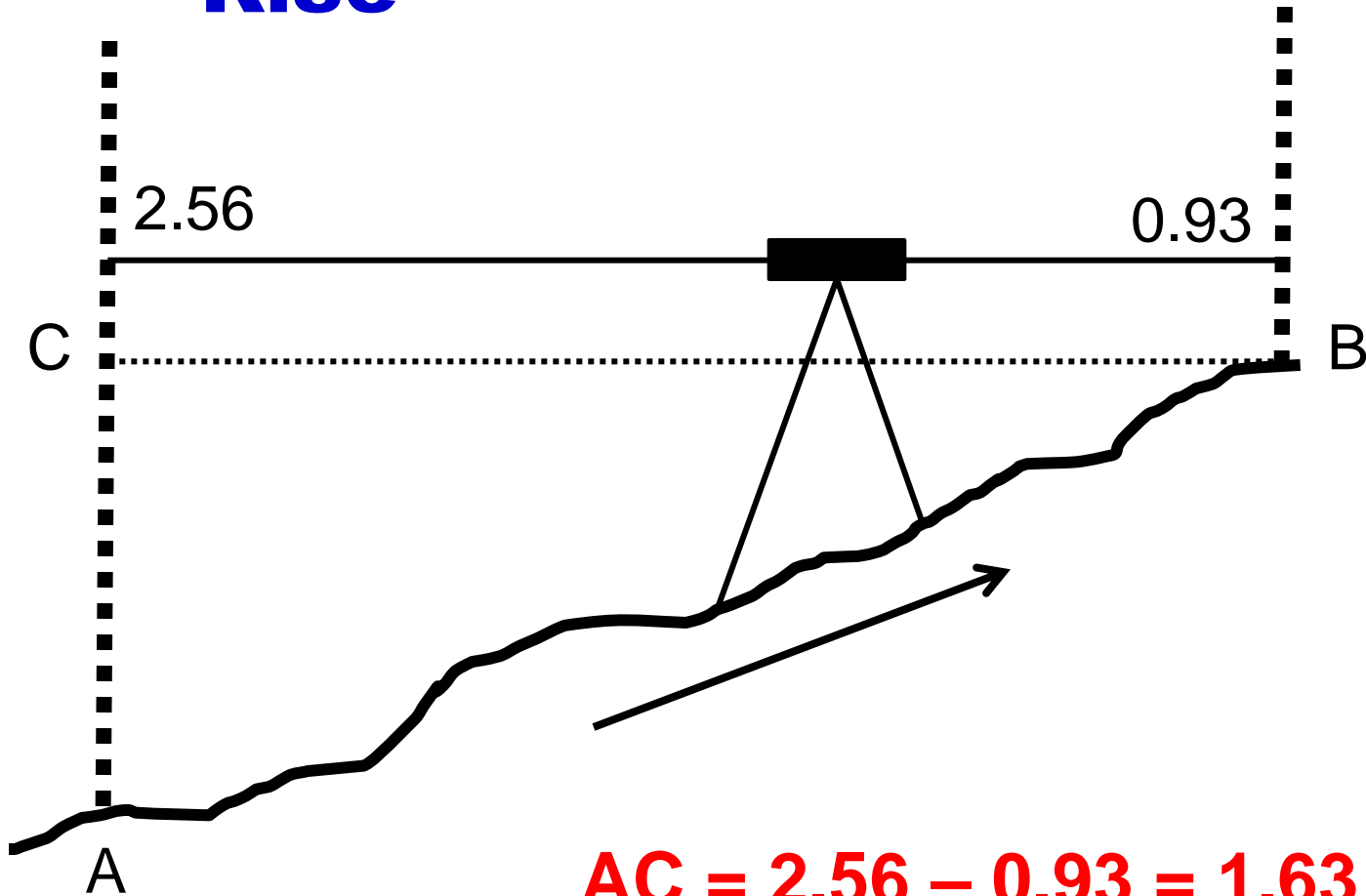
4.7 Measuring Elevation Difference

- The basic operation in differential leveling is the determination of elevation differences between two points.
- Consider two points A and B as shown below.
- Set up the level so that readings may be made on a staff held vertically at **A** and then at **B**.



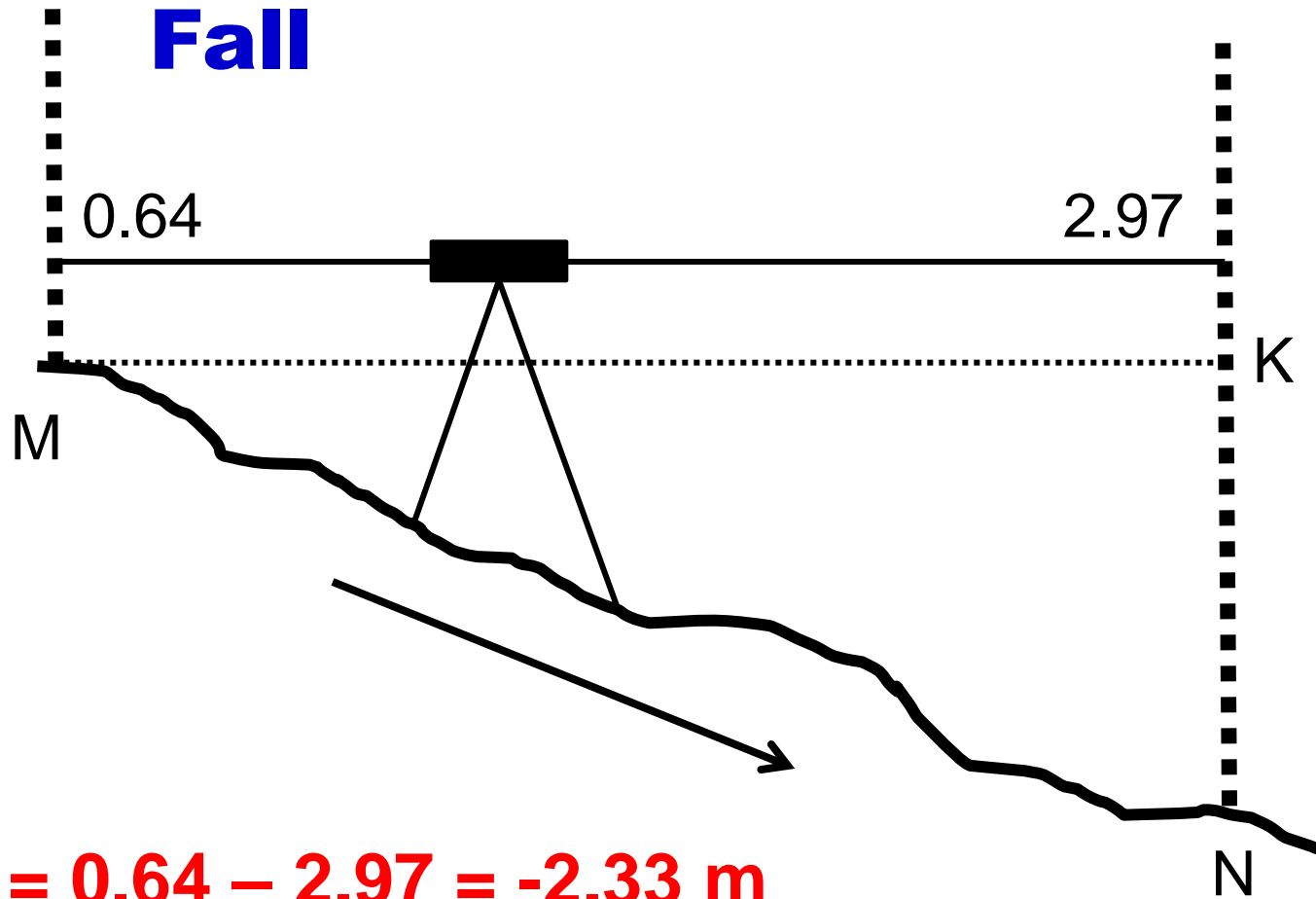
4.7 Measuring Elevation Difference

Rise



$$AC = 2.56 - 0.93 = 1.63 \text{ m}$$

4.7 Measuring Elevation Difference



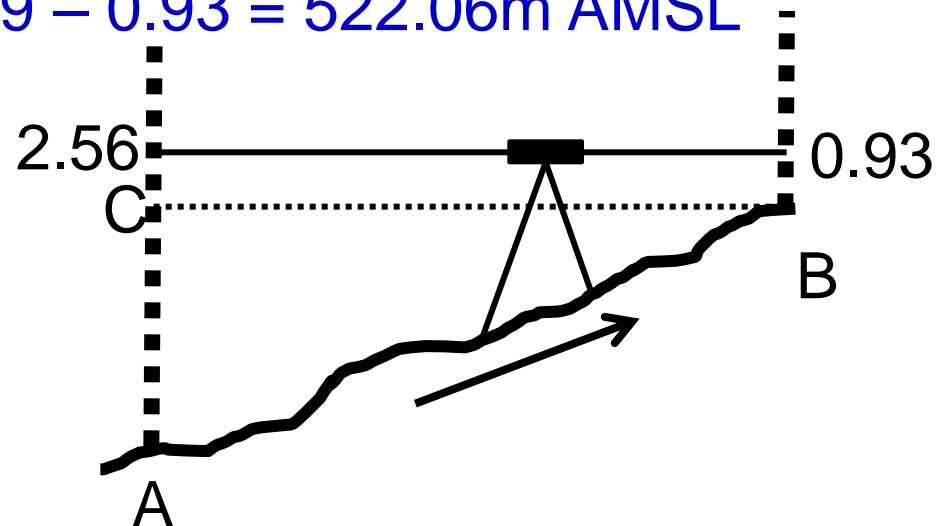
4.7 Measuring Elevation Difference

Calculation of Elevation

1. The height of instrument method

Elevation of Point A = 520.43m AMSL

- a. Height of Instrument HI = Elevation of A + Staff Reading
= 520.43 + 2.56 = 522.99m AMSL
- b. Elevation of B = HI – Staff Reading at B
= 522.99 – 0.93 = 522.06m AMSL

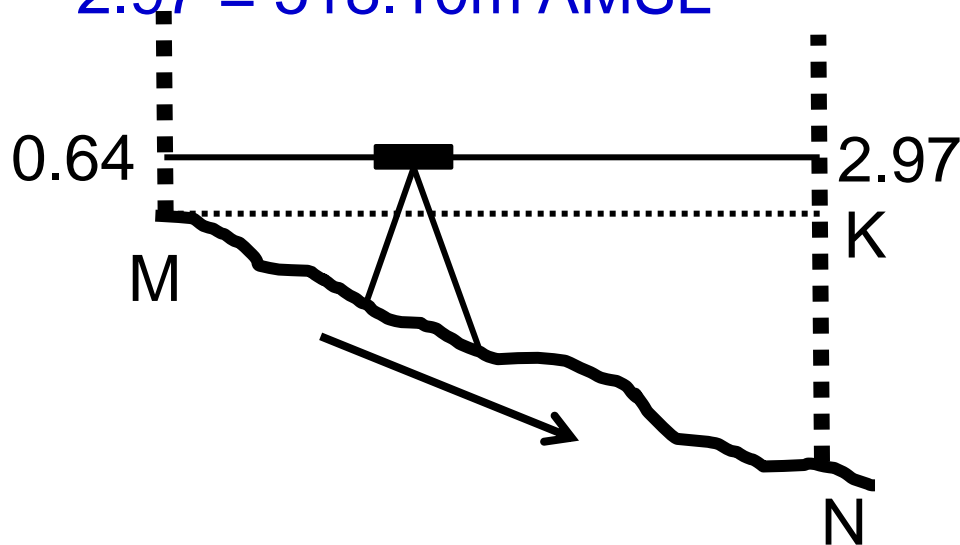


4.7 Measuring Elevation Difference

1. The height of instrument method

Elevation of Point M = 520.43m AMSL

- a. Height of Instrument HI = Elevation of M + Staff Reading
= 520.43 + 0.64 = 521.07m AMSL
- b. Elevation of N = HI – Staff Reading at N
= 521.07 – 2.97 = 518.10m AMSL



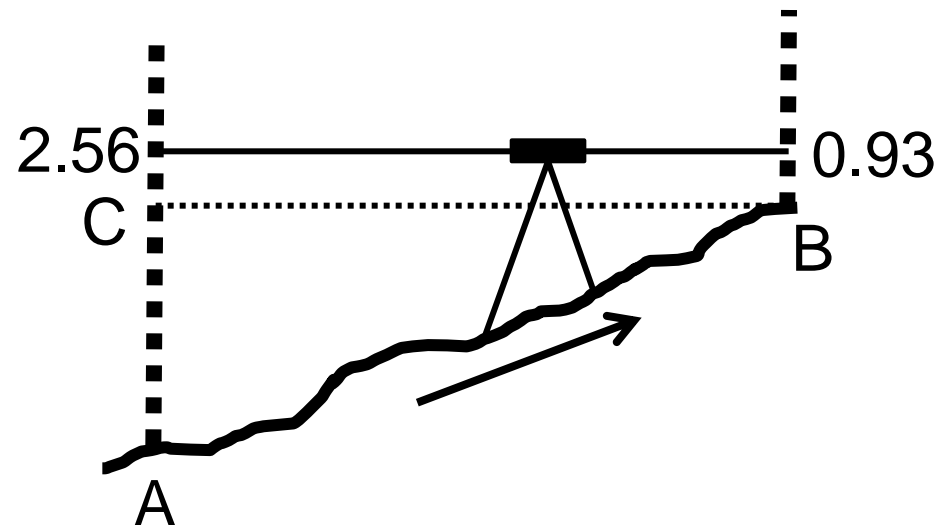
4.7 Measuring Elevation Difference

2. The rise and fall method

Elevation of Point A = 520.43m AMSL

a. Elevation Difference = Elevation of A - Elevation of B
= 2.56 - 0.93 = +1.63m (rise)

b. Elevation of B = Elevation at A + rise
= 520.43 + 1.63 = 522.06m AMSL



4.8 Procedure in differential leveling

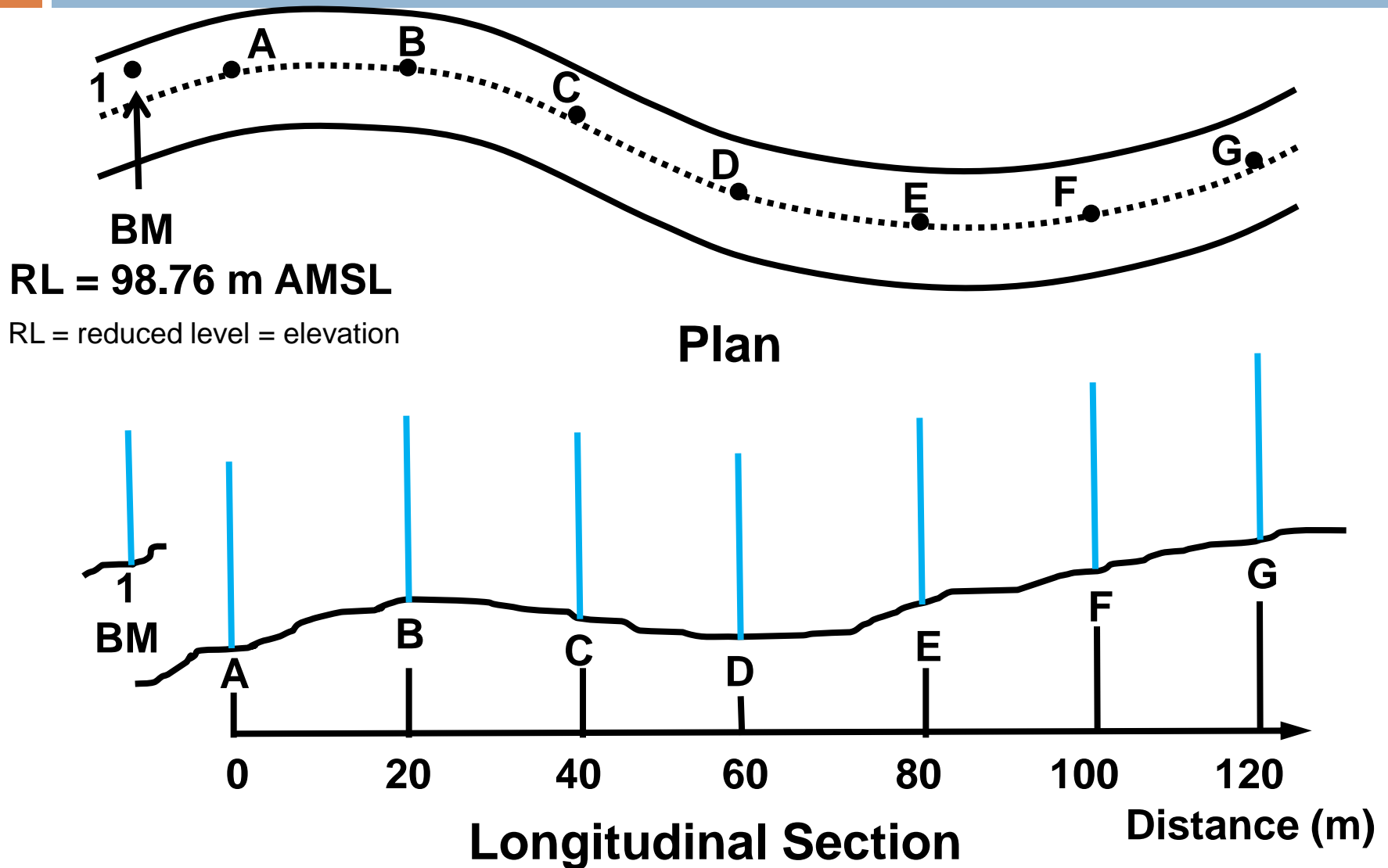
Backsight (BS): This is the first reading taken by the observer at every instrument station after setting up the level

Foresight (FS): This is the last reading taken at every instrument station before moving the level

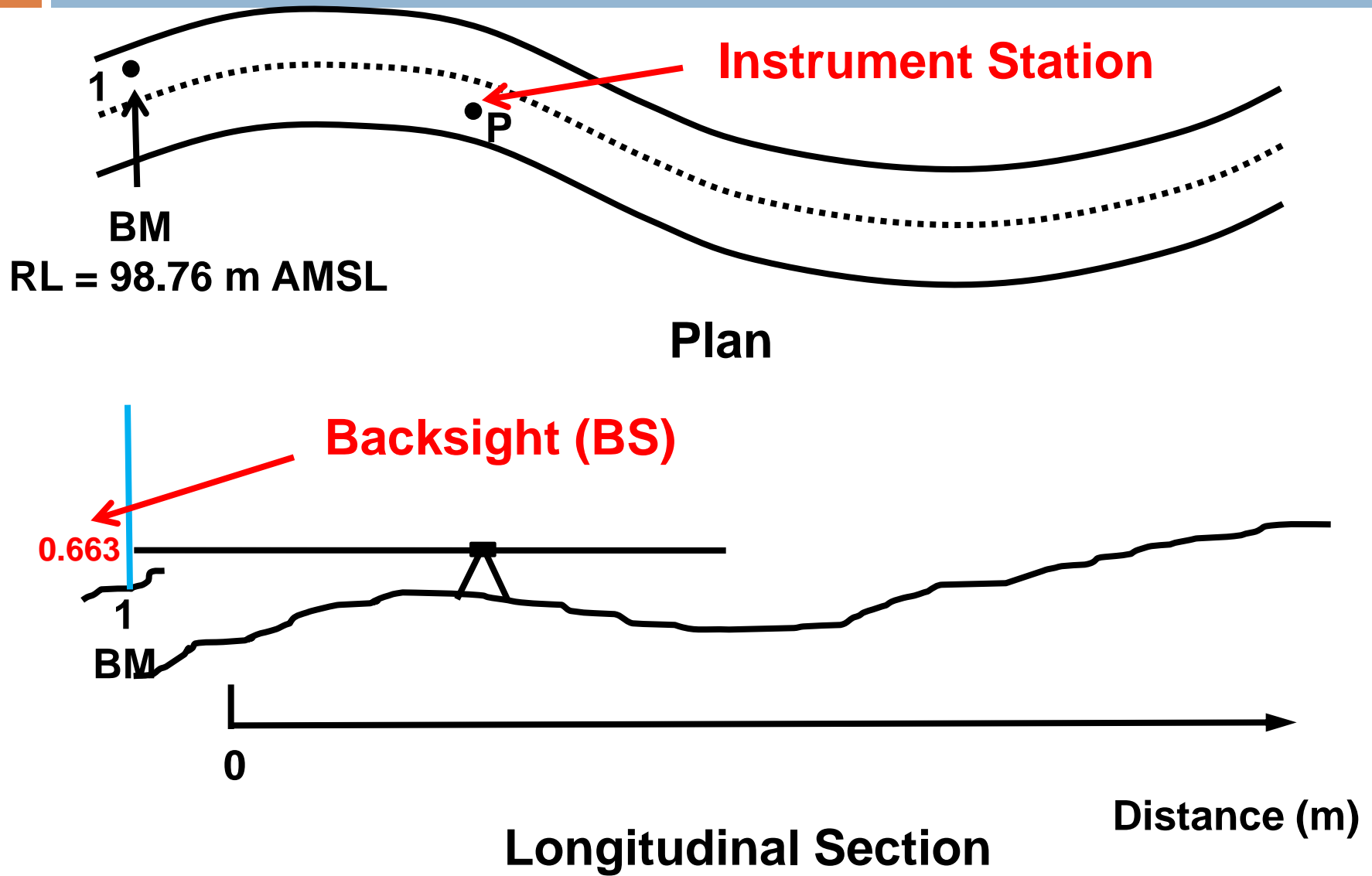
Intermediate Sight (IS): This is any reading taken at an instrument station between the backsight and the foresight

Turning point (TP): This point at which both a foresight and a backsight are taken before moving the staff

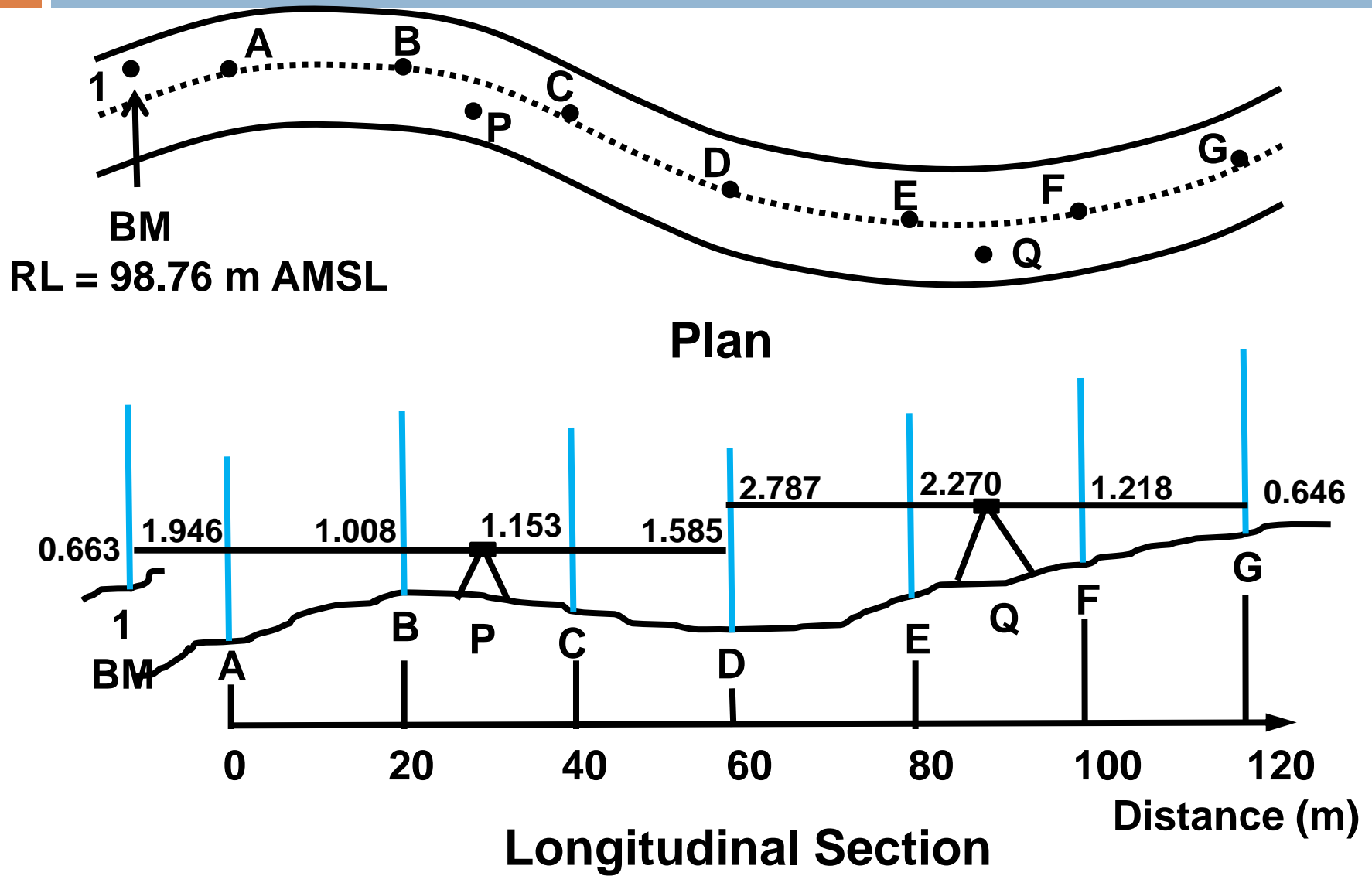
HI method for Elevation Calculation



HI method for Elevation Calculation



HI method for Elevation Calculation

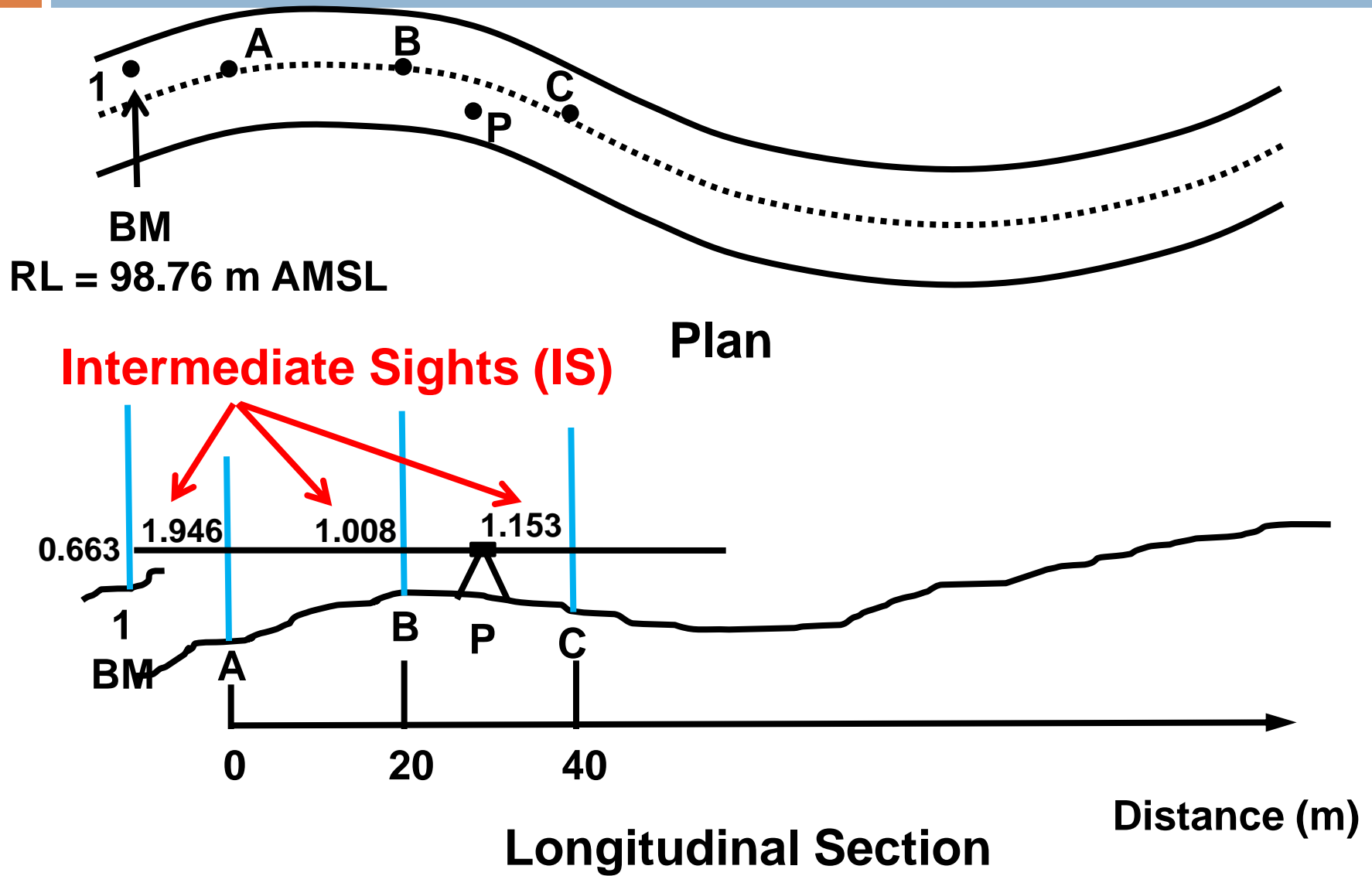


HI method for Elevation Calculation

Point	BS	IS	FS	HI	RL	Distance	Notes
1	0.663			99.423	98.760	-	BM

$$\mathbf{HI = RL + BS}$$

HI method for Elevation Calculation

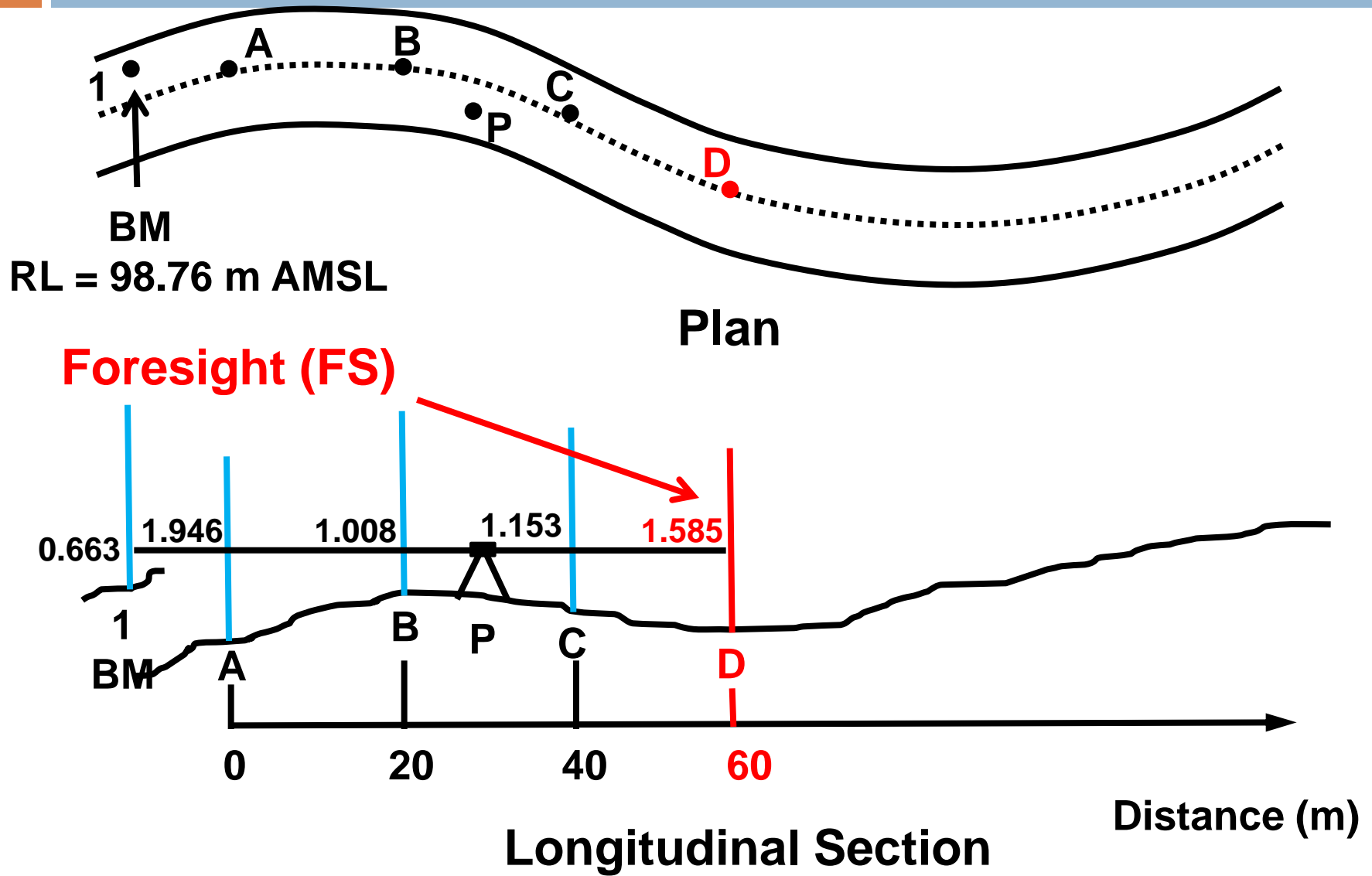


HI method for Elevation Calculation

Point	BS	IS	FS	HI	RL	Distance	Notes
1	0.663			99.423	98.760	-	BM
A		1.946			97.477	0	
B		1.008			98.415	20	
C		1.153			98.270	40	

$$RL = HI - IS$$

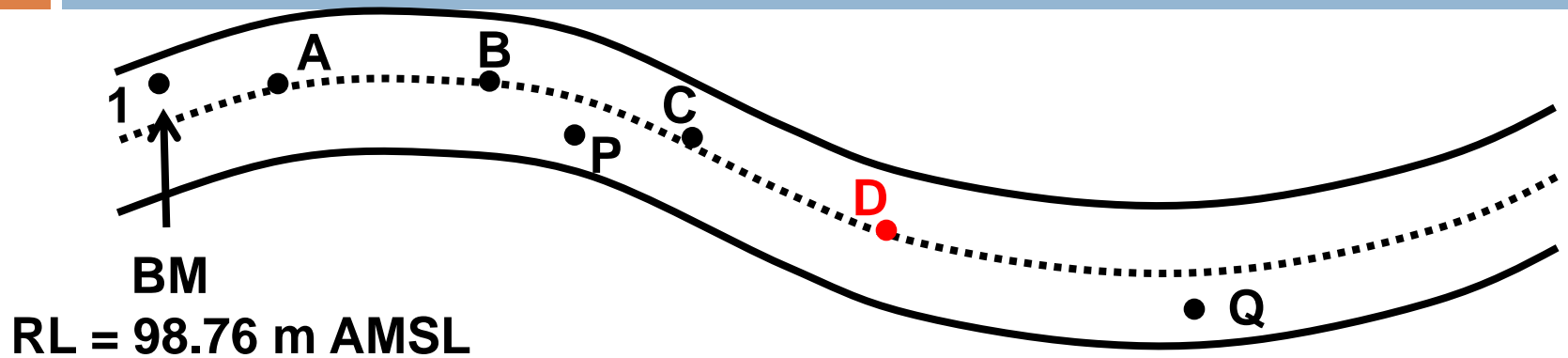
HI method for Elevation Calculation



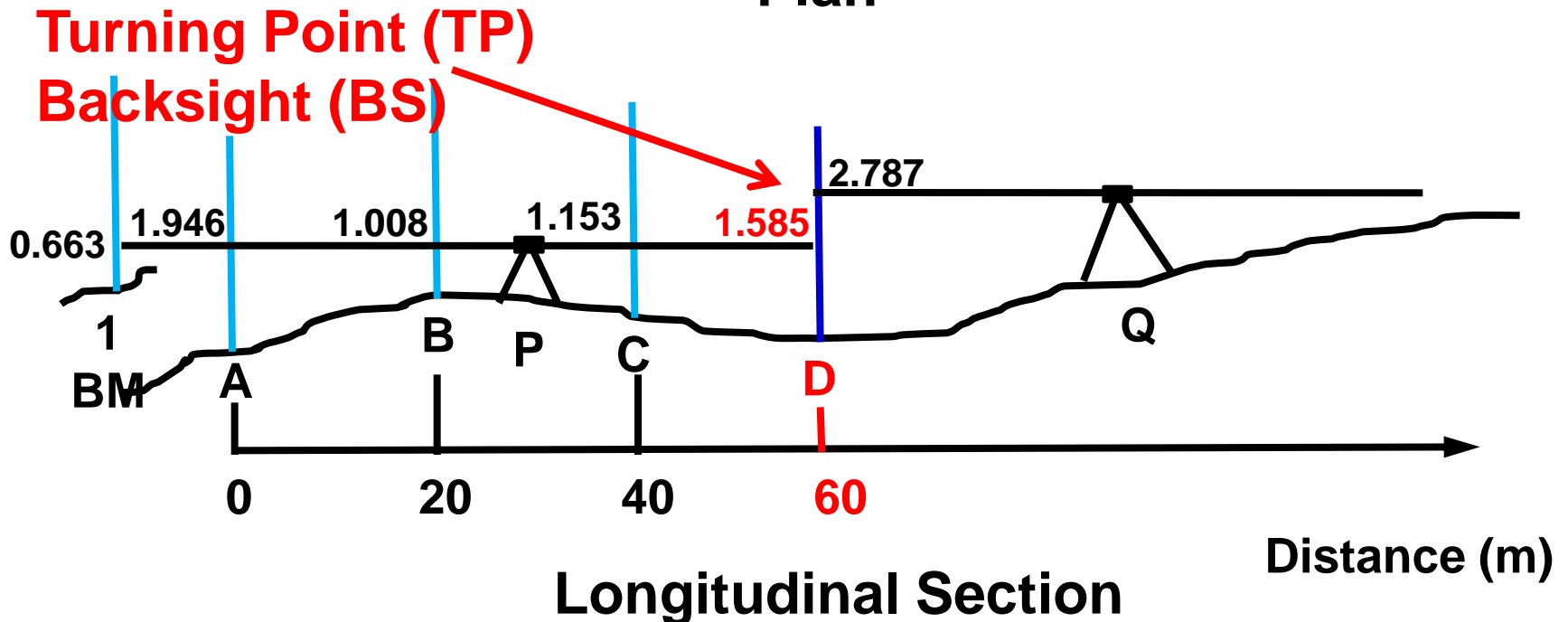
HI method for Elevation Calculation

Point	BS	IS	FS	HI	RL	Distance	Notes
1	0.663			99.423	98.760	-	BM
A		1.946			97.477	0	
B		1.008			98.415	20	
C		1.153			98.270	40	
D			1.585		97.838	60	

HI method for Elevation Calculation



Plan

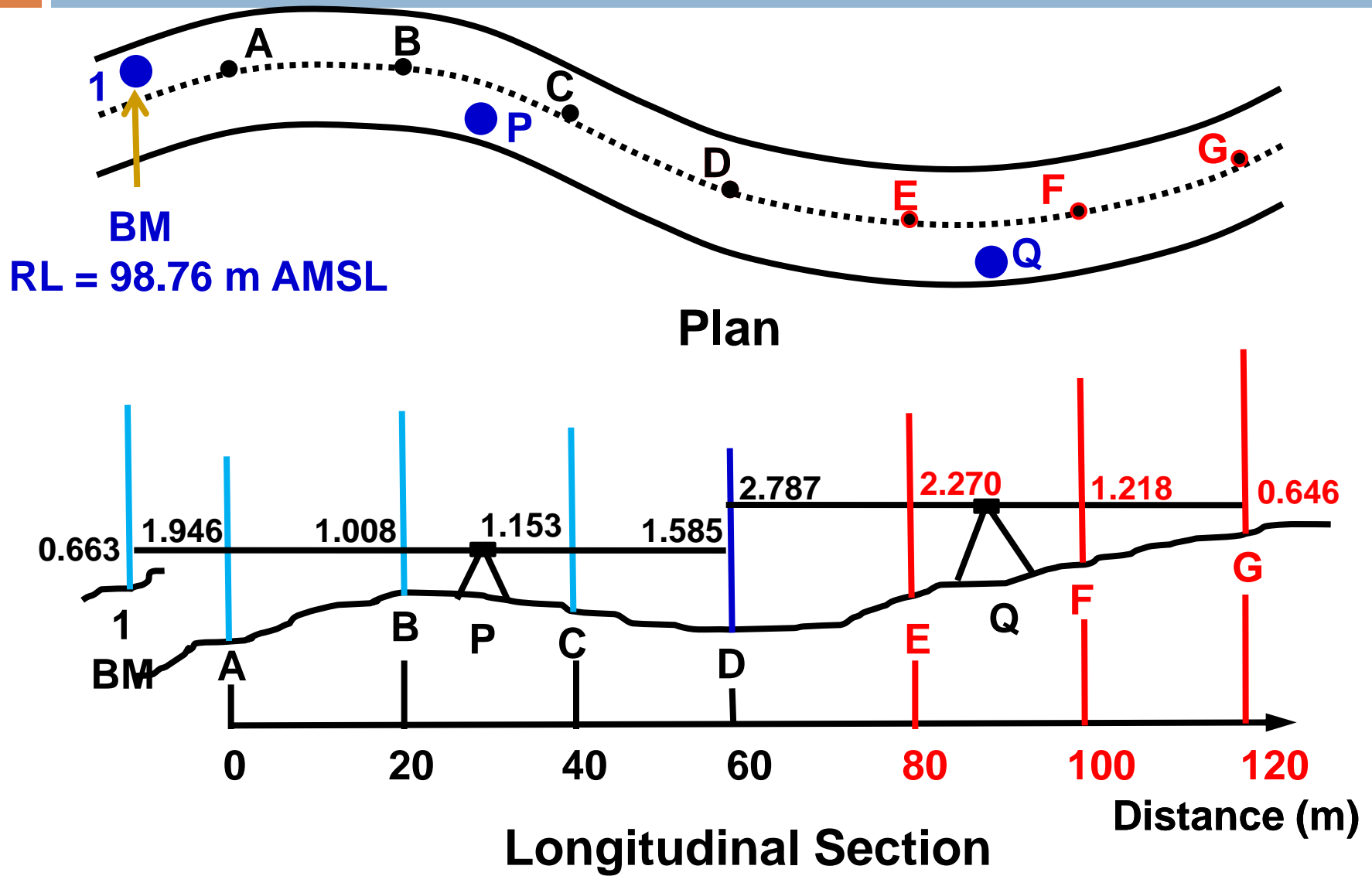


HI method for Elevation Calculation

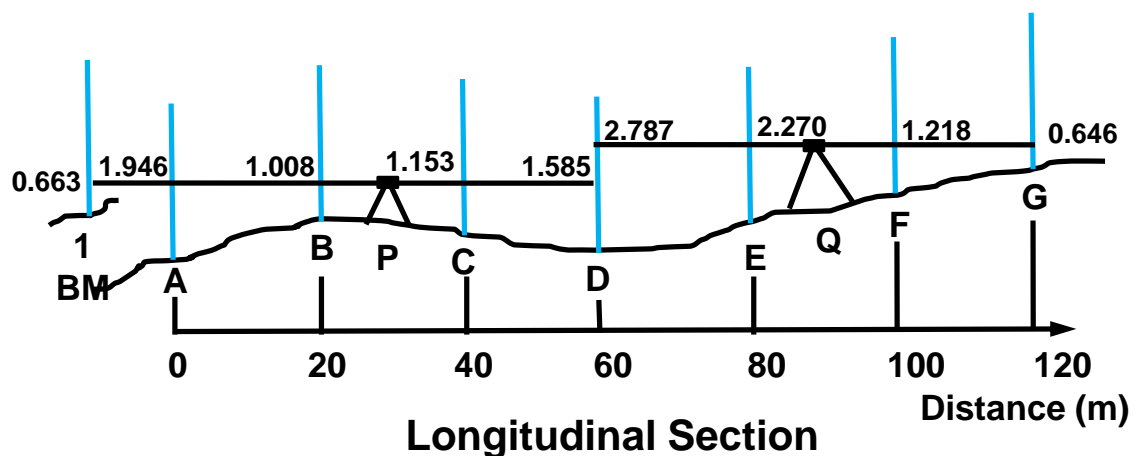
Point	BS	IS	FS	HI	RL	Distance	Notes
1	0.663			99.423	98.760	-	BM
A		1.946			97.477	0	
B		1.008			98.415	20	
C		1.153			98.270	40	
D	2.787		1.585	100.625	97.838	60	TP

$$\text{HI} = \text{RL} + \text{BS}$$

HI method for Elevation Calculation



Point	BS	IS	FS	HI	RL	Distance	Notes
1	0.663			99.423	98.760	-	BM
A		1.946			97.477	0	
B		1.008			98.415	20	
C		1.153			98.270	40	
D	2.787		1.585	100.625	97.838	60	TP
E		2.270			98.355	80	
F		1.218			99.407	100	
G			0.646		99.979	120	



Point	BS	IS	FS	HI	RL	Distance	Notes
1	0.663			99.423	98.760	-	BM
A		1.946			97.477	0	
B		1.008			98.415	20	
C		1.153			98.270	40	
D	2.787		1.585	100.625	97.838	60	TP
E		2.270			98.355	80	
F		1.218			99.407	100	
G			0.646		99.979	120	

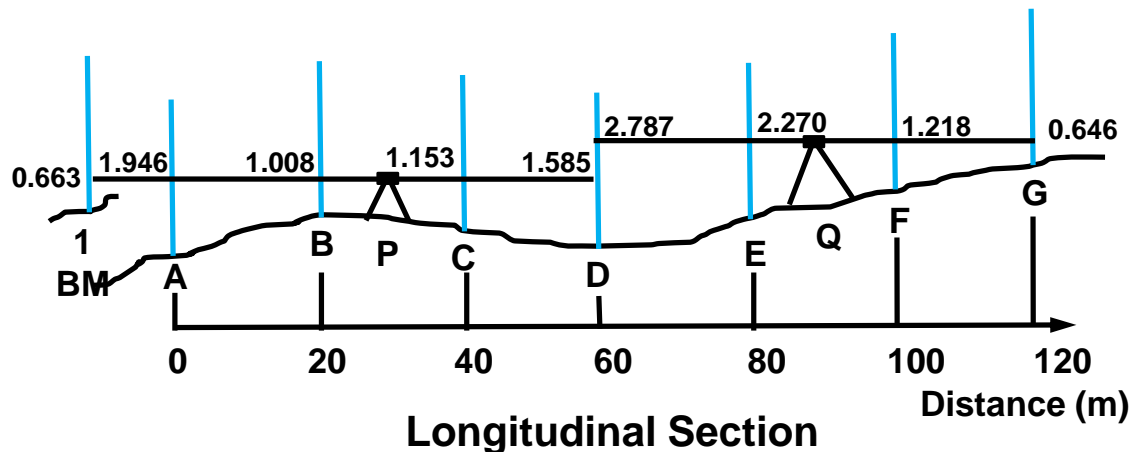
SUM **3.450** **7.595** **2.231**

Check 1

No. of BS = No. of FS

No. of BS = 2

No. of FS = 2



Point	BS	IS	FS	HI	RL	Distance	Notes
1	0.663			99.423	98.760	-	BM
A		1.946			97.477	0	
B		1.008			98.415	20	
C		1.153			98.270	40	
D	2.787		1.585	100.625	97.838	60	TP
E		2.270			98.355	80	
F		1.218			99.407	100	
G			0.646		99.979	120	

SUM **3.450** 7.595 **2.231**

Check 2

$\Sigma BS - \Sigma FS = \text{RL of last point} - \text{RL of first point}$

$$\Sigma BS - \Sigma FS = 3.450 - 2.231 = 1.219$$

$$RL_{\text{last}} - RL_{\text{first}} = 99.979 - 98.760 = 1.219$$

Point	BS	IS	FS	HI	RL	Distance	Notes
1	0.663			99.423	98.760	-	BM
A		1.946			97.477	0	
B		1.008			98.415	20	
C		1.153			98.270	40	
D	2.787		1.585	100.625	97.838	60	TP
E		2.270			98.355	80	
F		1.218			99.407	100	
G			0.646		99.979	120	

SUM **3.450** **7.595** **2.231**

Check 3

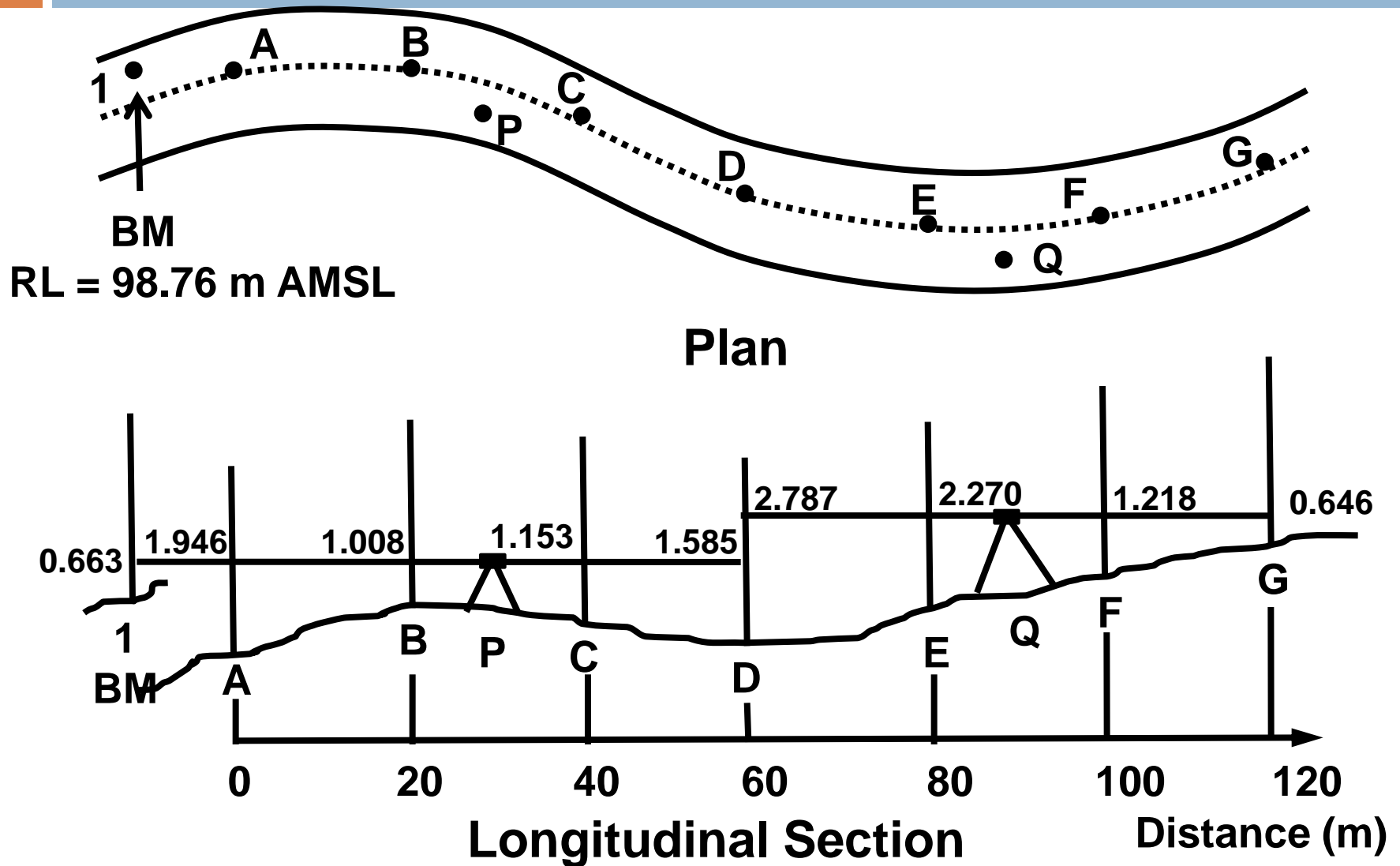
$$\Sigma RL - RL_{\text{first point}} = [\Sigma (\text{No. of IS and FS} \times HI)] - \Sigma IS - \Sigma FS$$

$$\Sigma RL - RL_{\text{first point}} = 689.741$$

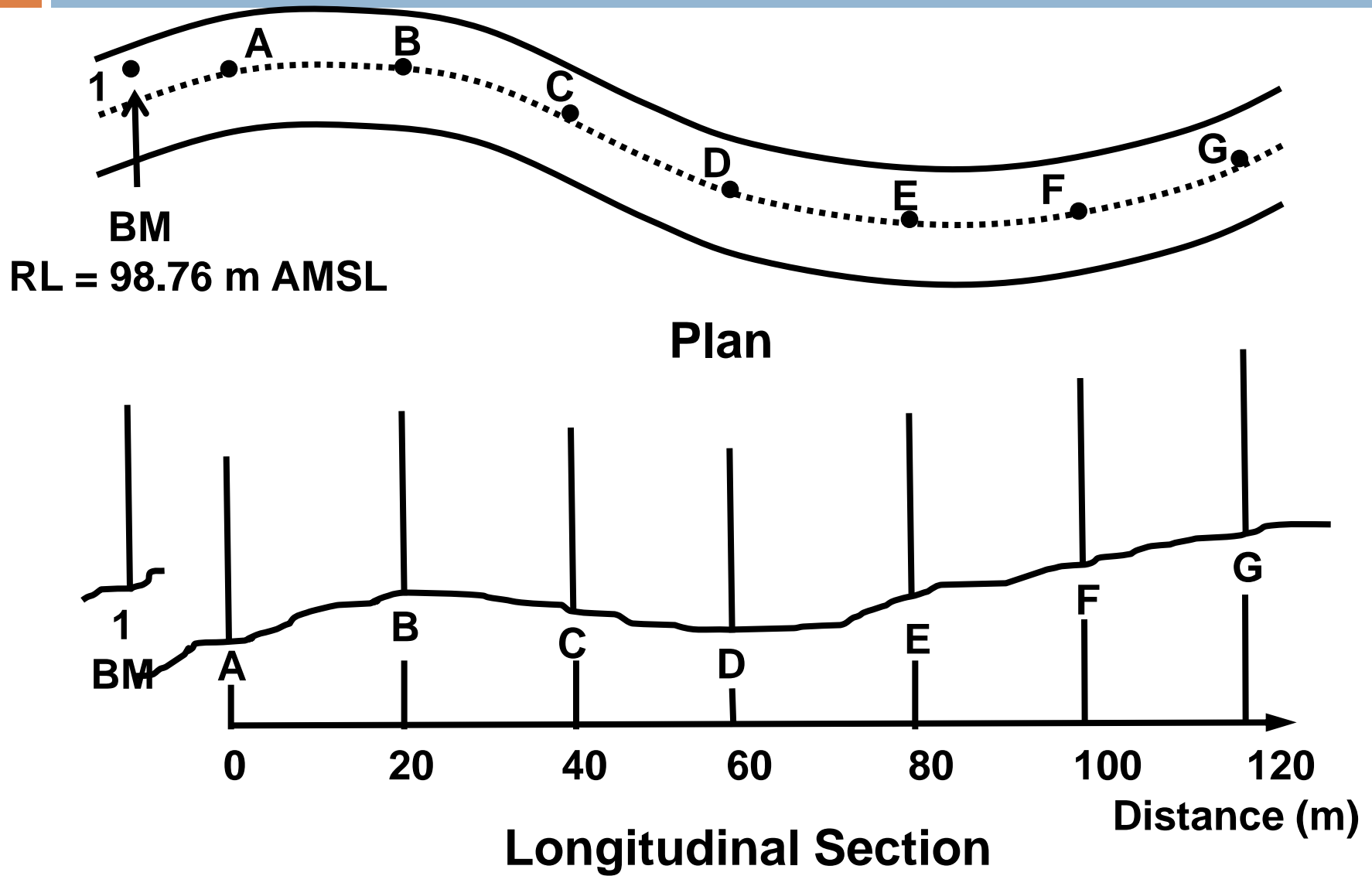
$$[\Sigma (\text{No. of (IS and FS)} \times HI)] - \Sigma IS - \Sigma FS = 689.741$$

$$= [99.423 \times 4 + 100.625 \times 3] - 7.595 - 2.231 = 689.741$$

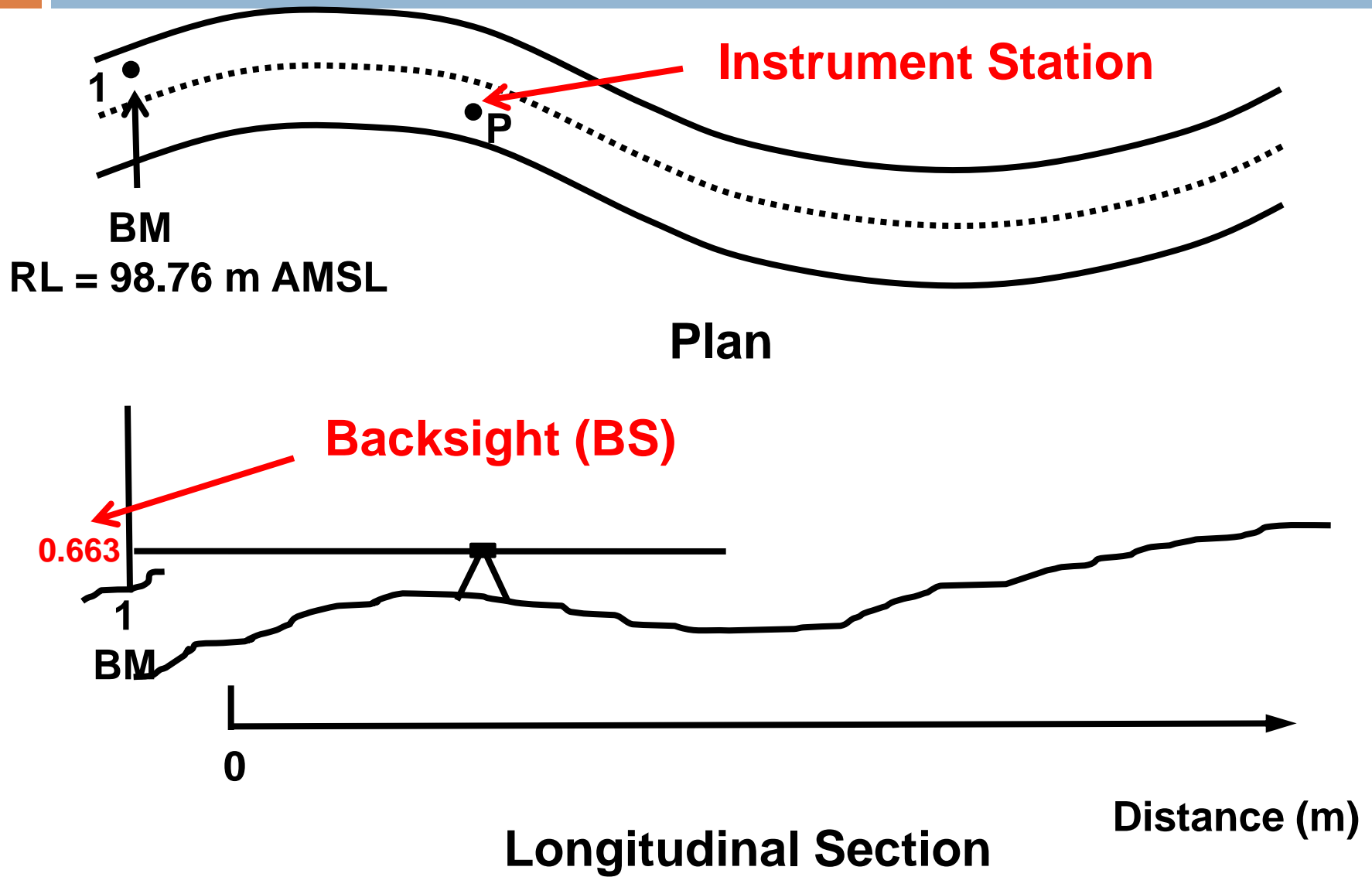
Differential method for Elevation



Differential method for Elevation



Differential method for Elevation

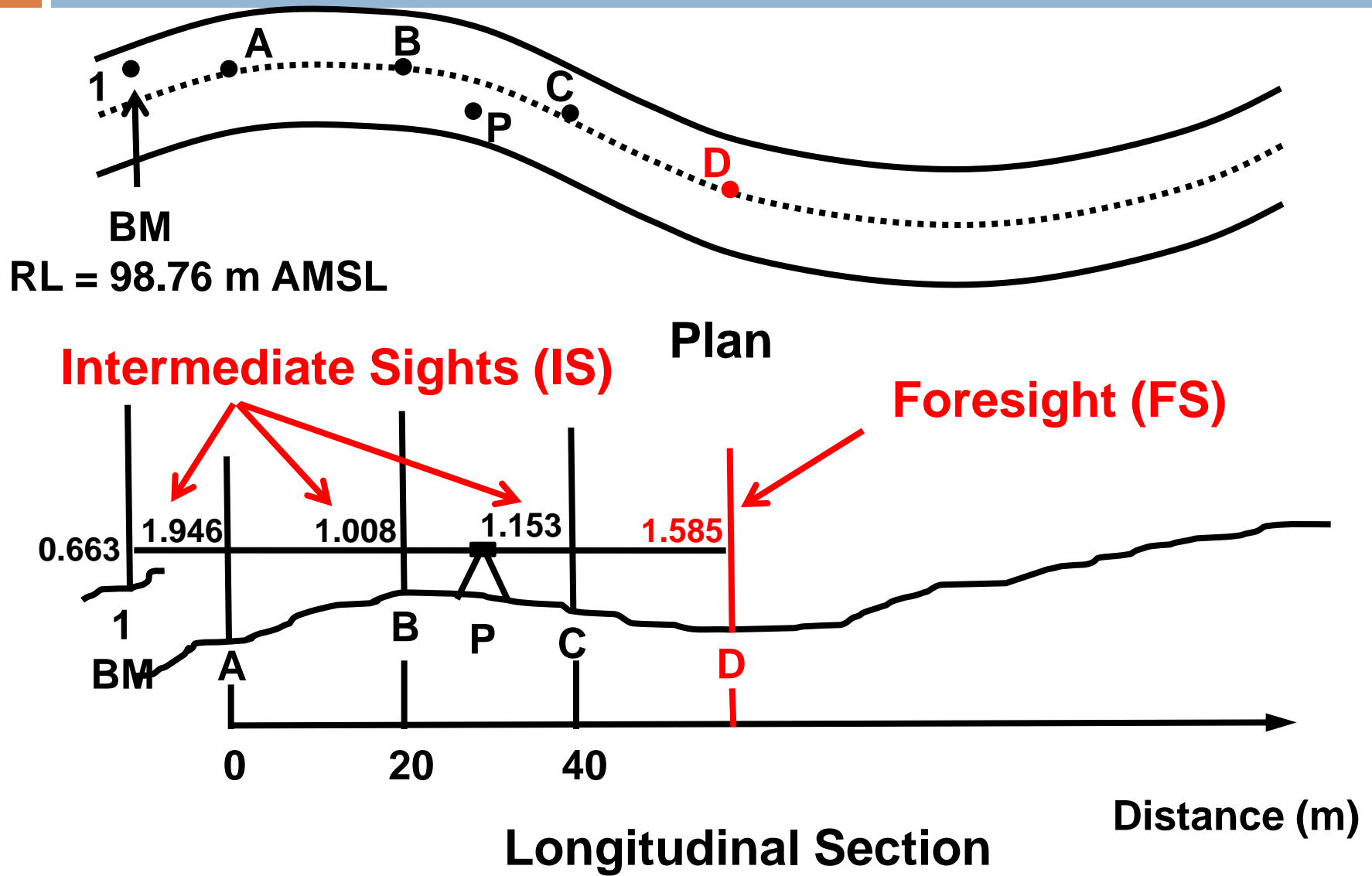


Differential method for Elevation

Point	BS	IS	FS	Rise	Fall	RL	Distance	Notes
1	0.663					98.760	-	BM
A		1.946			1.283	97.477	0	

$$\begin{aligned}\Delta H_{1A} &= \text{BS} - \text{IS} \\ &= 0.633 - 1.946 = -1.283 \text{ (fall)}\end{aligned}$$

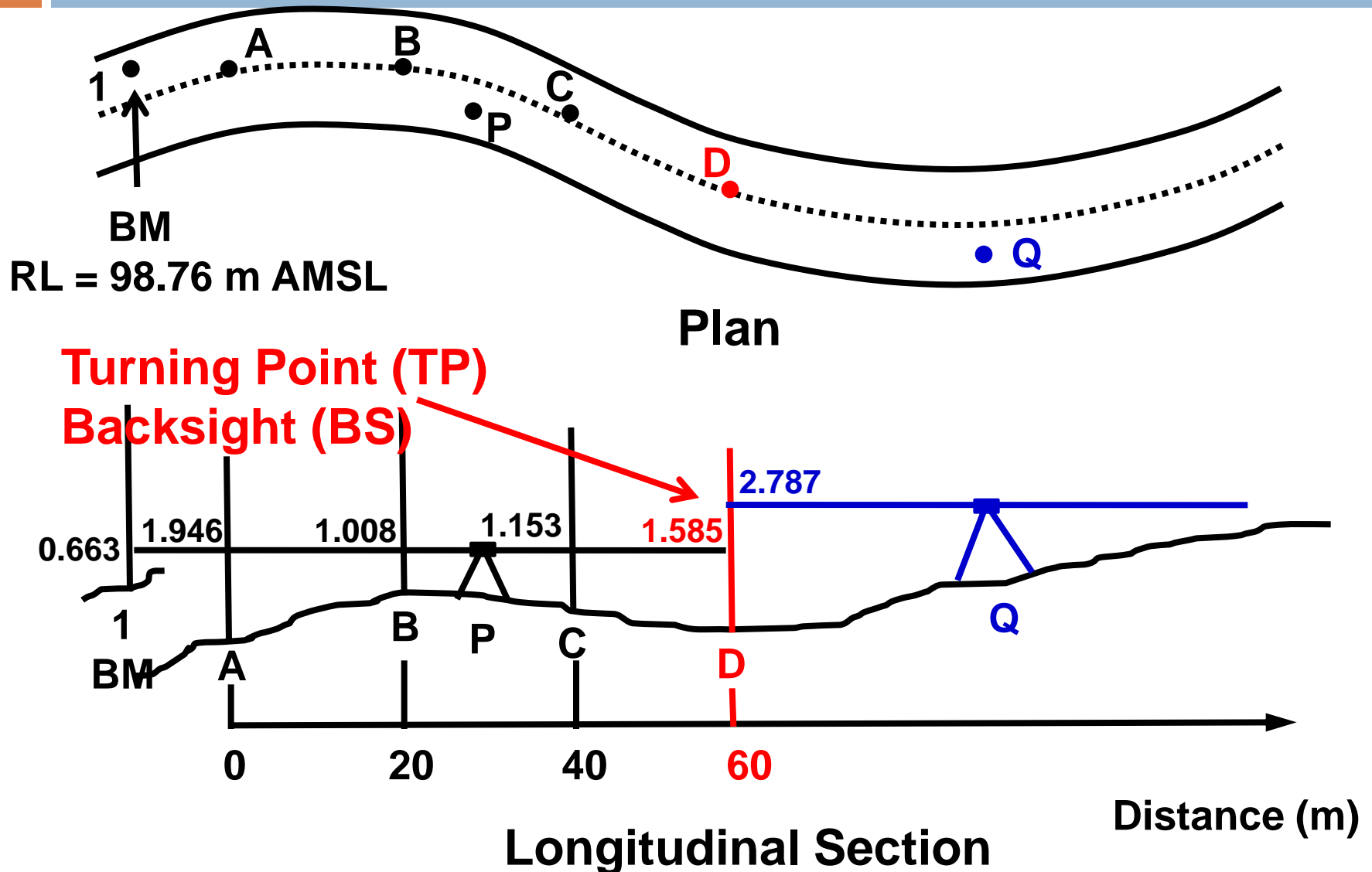
Differential method for Elevation



Differential method for Elevation

Point	BS	IS	FS	Rise	Fall	RL	Distance	Notes
1	0.663					98.760	-	BM
A		1.946			1.283	97.477	0	
B		1.008		0.938		98.415	20	
C		1.153			0.145	98.270	40	
D			1.585		0.432	97.838	60	

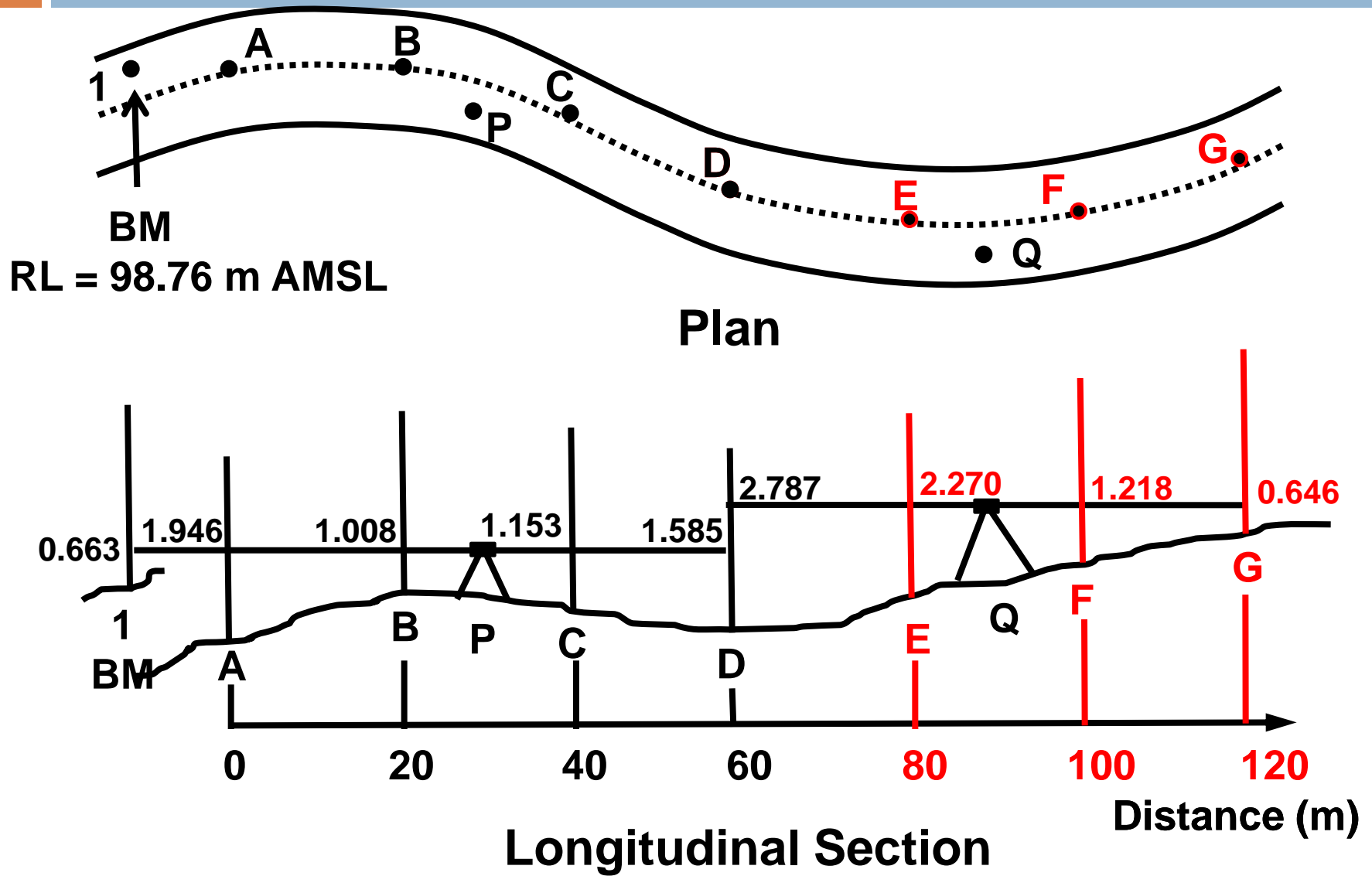
Differential method for Elevation



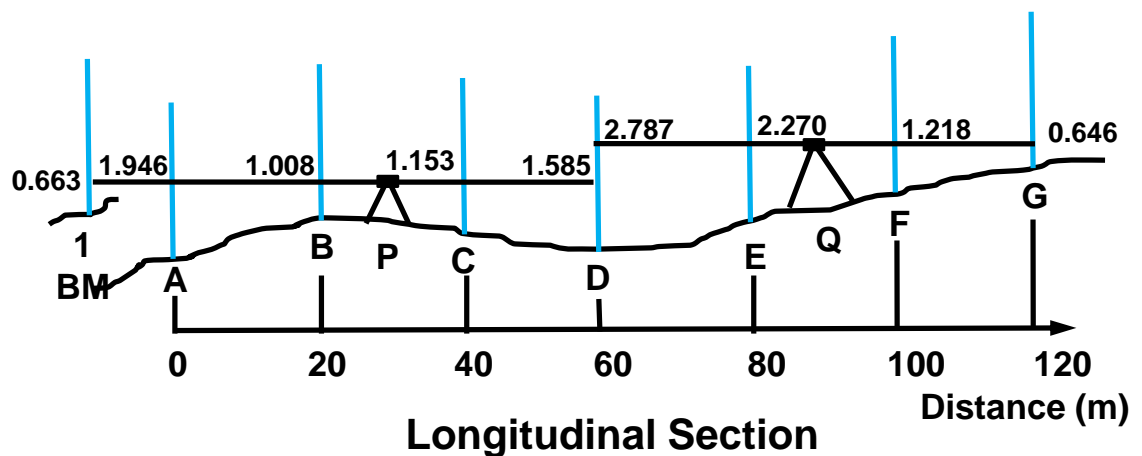
Differential method for Elevation

Point	BS	IS	FS	Rise	Fall	RL	Distance	Notes
1	0.663					98.760	-	BM
A		1.946			1.283	97.477	0	
B		1.008		0.938		98.415	20	
C		1.153			0.145	98.270	40	
D	2.787		1.585		0.432	97.838	60	TP

Differential method for Elevation



Point	BS	IS	FS	Rise	Fall	RL	Distance	Notes
1	0.663					98.760	-	BM
A		1.946			1.283	97.477	0	
B		1.008		0.938		98.415	20	
C		1.153			0.145	98.270	40	
D	2.787		1.585		0.432	97.838	60	TP
E		2.270		0.517		98.355	80	
F		1.218		1.052		99.407	100	
G			0.646	0.572		99.979	120	



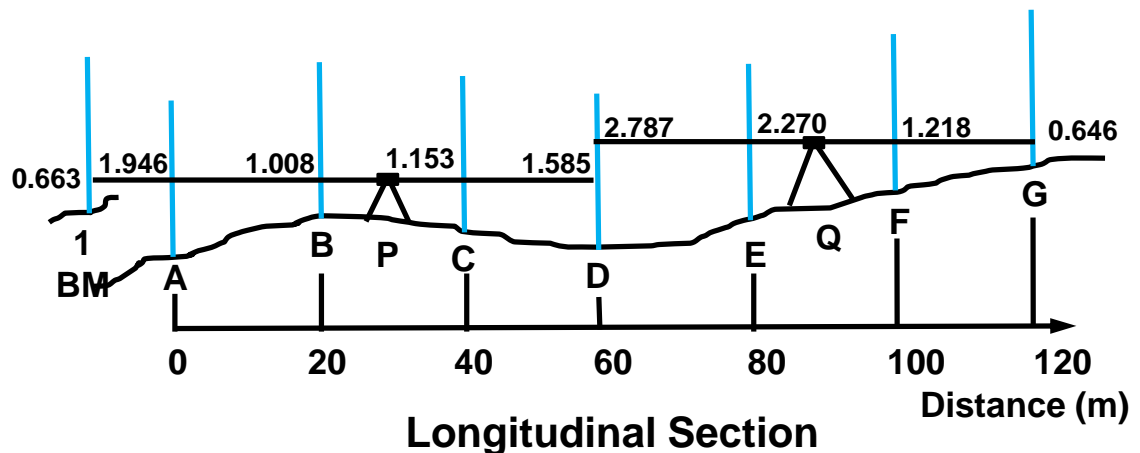
Point	BS	IS	FS	Rise	Fall	RL	Distance	Notes
1	0.663					98.760	-	BM
A		1.946			1.283	97.477	0	
B		1.008		0.938		98.415	20	
C		1.153			0.145	98.270	40	
D	2.787		1.585		0.432	97.838	60	TP
E		2.270		0.517		98.355	80	
F		1.218		1.052		99.407	100	
G			0.646	0.572		99.979	120	
SUM	3.450	7.595	2.231	3.079	1.860			

Check 1

No. of BS = No. of FS

No. of BS = 2

No. of FS = 2



Point	BS	IS	FS	Rise	Fall	RL	Distance	Notes
1	0.663					98.760	-	BM
A		1.946			1.283	97.477	0	
B		1.008		0.938		98.415	20	
C		1.153			0.145	98.270	40	
D	2.787		1.585		0.432	97.838	60	TP
E		2.270		0.517		98.355	80	
F		1.218		1.052		99.407	100	
G			0.646	0.572		99.979	120	
SUM	3.450	7.595	2.231	3.079	1.860			

Check 2

$$\begin{aligned}
 \Sigma BS - \Sigma FS &= \Sigma Rise - \Sigma Fall &&= RL_{\text{last}} - RL_{\text{first}} \\
 3.450 - 2.231 &= 3.079 - 1.860 &&= 99.979 - 98.760 \\
 1.219 &= 1.219 &&= 1.219
 \end{aligned}$$

4.9 General Notes

1. Accuracy at field work comes first.
2. If only difference between two points is needed, no intermediate sights are required.
3. BS and FS distances shall be equal.
4. Pay more attention to TP and should be on firm ground.
5. If the fieldwork starts at a point of unknown elevation, but passes through a BM, then:

4.9 General Notes

6. a. if BM is last point:

$$RL_{\text{first point}} = RL_{\text{last point (BM)}} + \sum FS - \sum BS$$

b. BM in the middle point:

Calculate HI and then RLs

7. If the point to be measured for elevation is the bottom of a bridge or a ceiling or the top of a barrier such a wall or a column, staff is inverted so that zero is at the point and negative sign is assigned to the measured value.

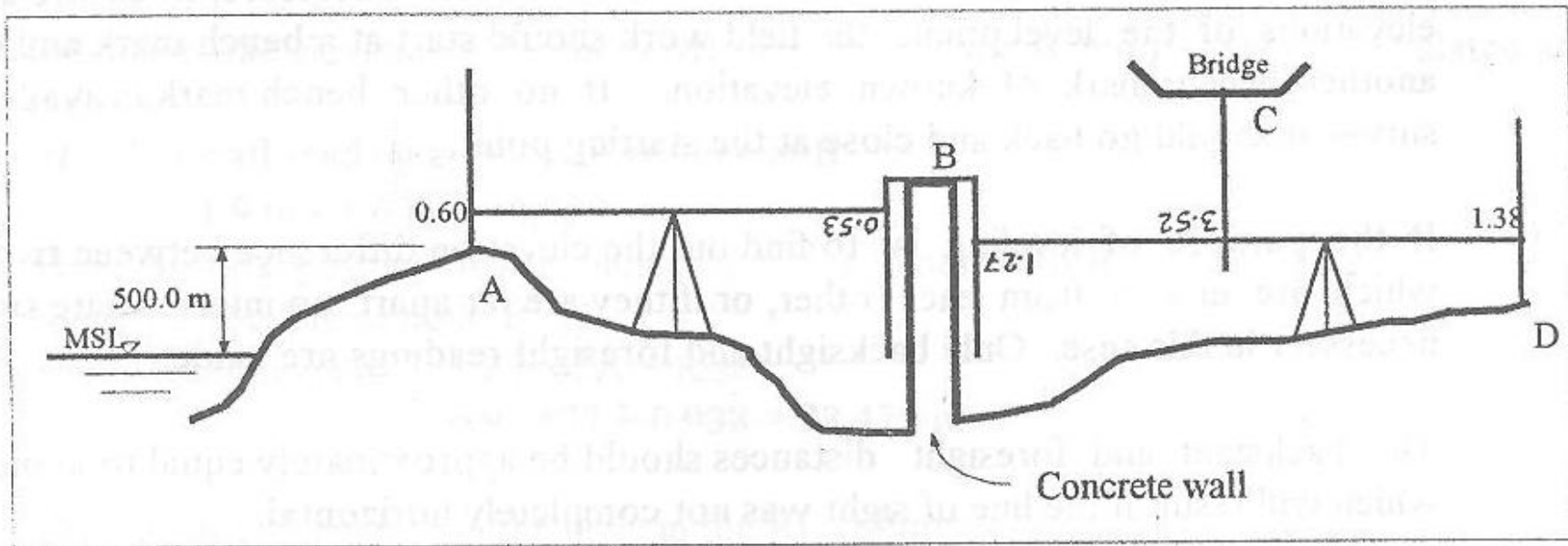


FIGURE 4.10: A leveling chain with a bridge and a concrete wall obstacle.

SOLUTION:

Point	BS	IS	FS	Rise	Fall	HI	RL	Notes
A	0.60					500.60	500.00	BM
B	-1.27		-0.53	1.13		499.86	501.13	Top of concrete wall (TP)
C		-3.52		2.25			503.38	Bottom of bridge
D			1.38		4.90		498.48	
SUM	-0.67	-3.52	0.85	3.38	4.90			

4.9 General Notes

Checks:

1) # of BS = # of FS = 2 OK

2)

BS - FS	= -0.67 - 0.85	= -1.52	
Rise - Fall	= 3.38 - 4.90	= -1.52	OK
RL _{last} - RL _{1st}	= 498.48 - 500.00	= -1.52	

3) $\Sigma RL - RL_{\text{first point}} = [\Sigma (\text{No. of IS and FS} \times HI)] - \Sigma IS - \Sigma FS$

$\Sigma RL - RL_{\text{first point}} = 1502.99$

$[\Sigma (\text{No. of (IS and FS)} \times HI)] - \Sigma IS - \Sigma FS$

$= [500.6 \times 1 + 499.86 \times 2] - 0.85 - (-3.52) = 1502.99 \text{ OK}$

4.14 Application of Leveling

The main uses of leveling are:

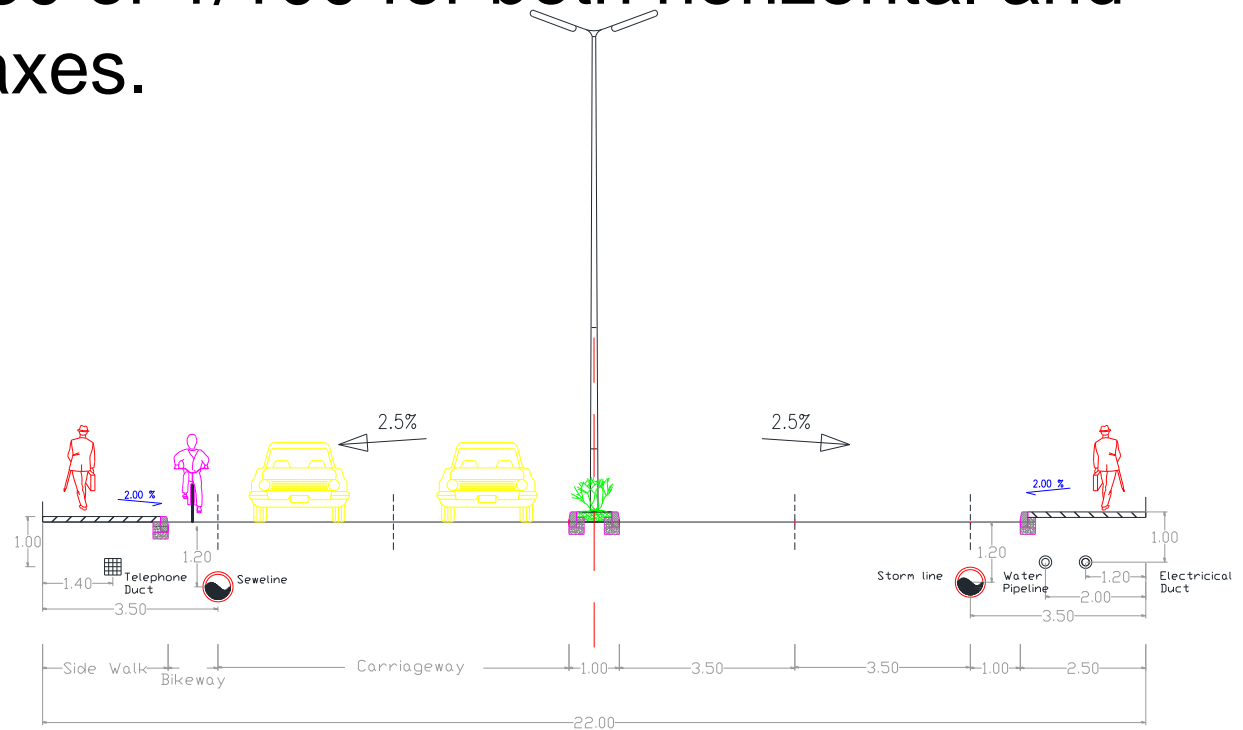
1. Profiles
2. Cross-sections
3. Contouring
4. Setting out levels

4.14.1 Profiles (longitudinal sections)

- Levels are taken at:
 1. Every 20, 50 or 100m depending on the topography
 2. Points at which gradient changes
 3. Street intersections
- Staff reading to 0.01m accuracy are adequate
- Scale 1/1000 horizontal and 1/100 vertical

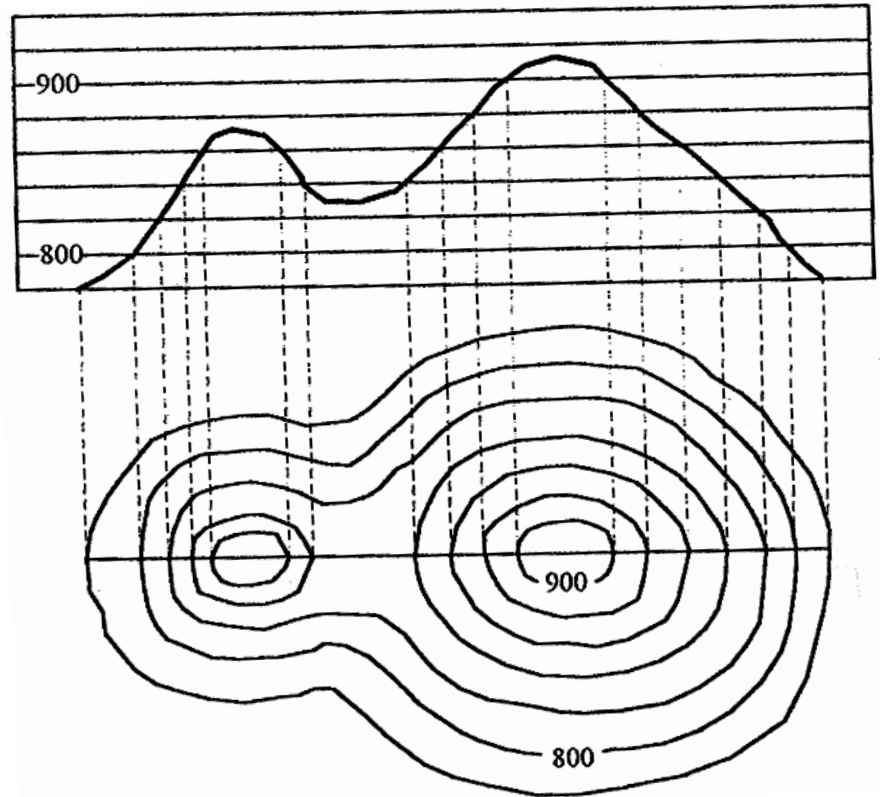
4.14.2 Cross-Sections

- Sections at right angles to the centerline of a proposed or existing project such as a road
- Scale 1/50 or 1/100 for both horizontal and vertical axes.



4.14.3 Contouring

A **contour** is an imaginary line connecting points on the ground that have the same elevation.



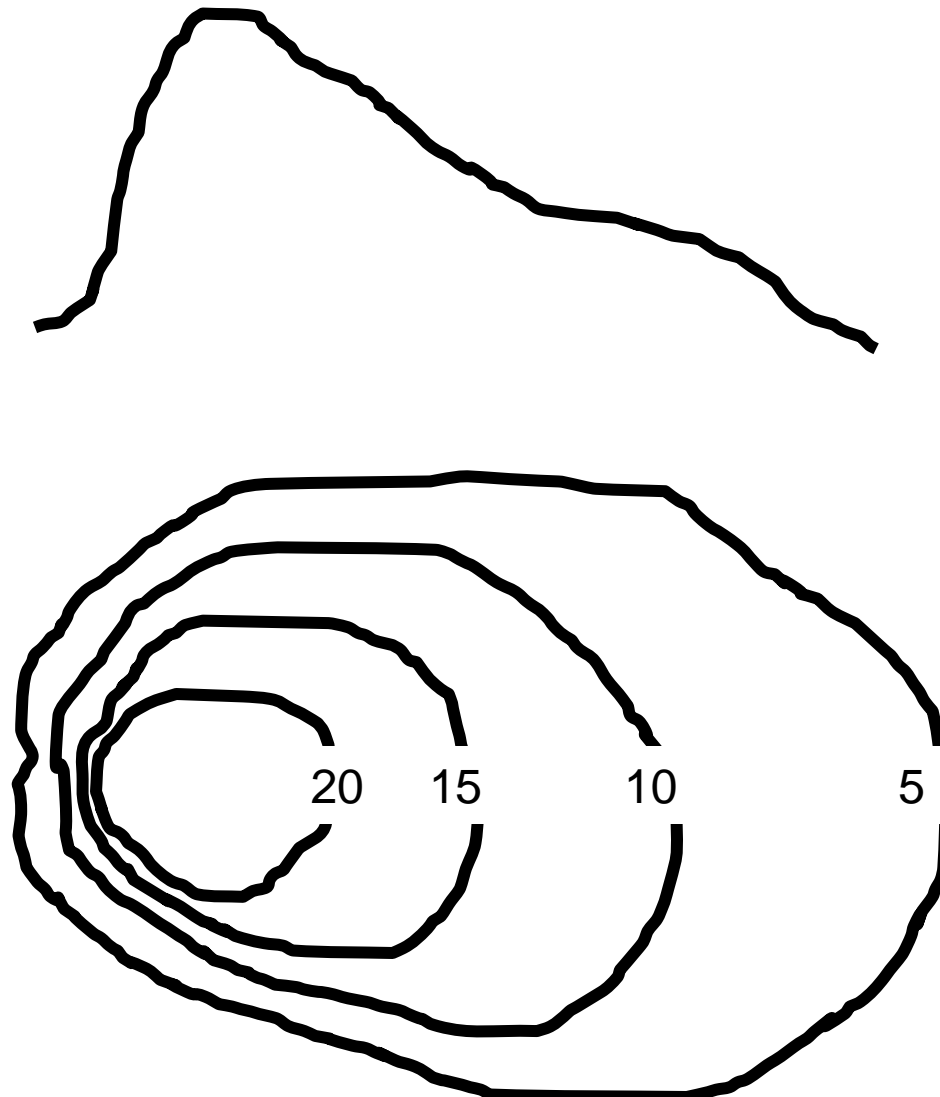
4.14.3 Contouring

A **contour interval**, the vertical distance or elevation difference between two successive contours depends on:

- Scale
- Purpose
- Accuracy, time and cost
- The topography
- Area covered

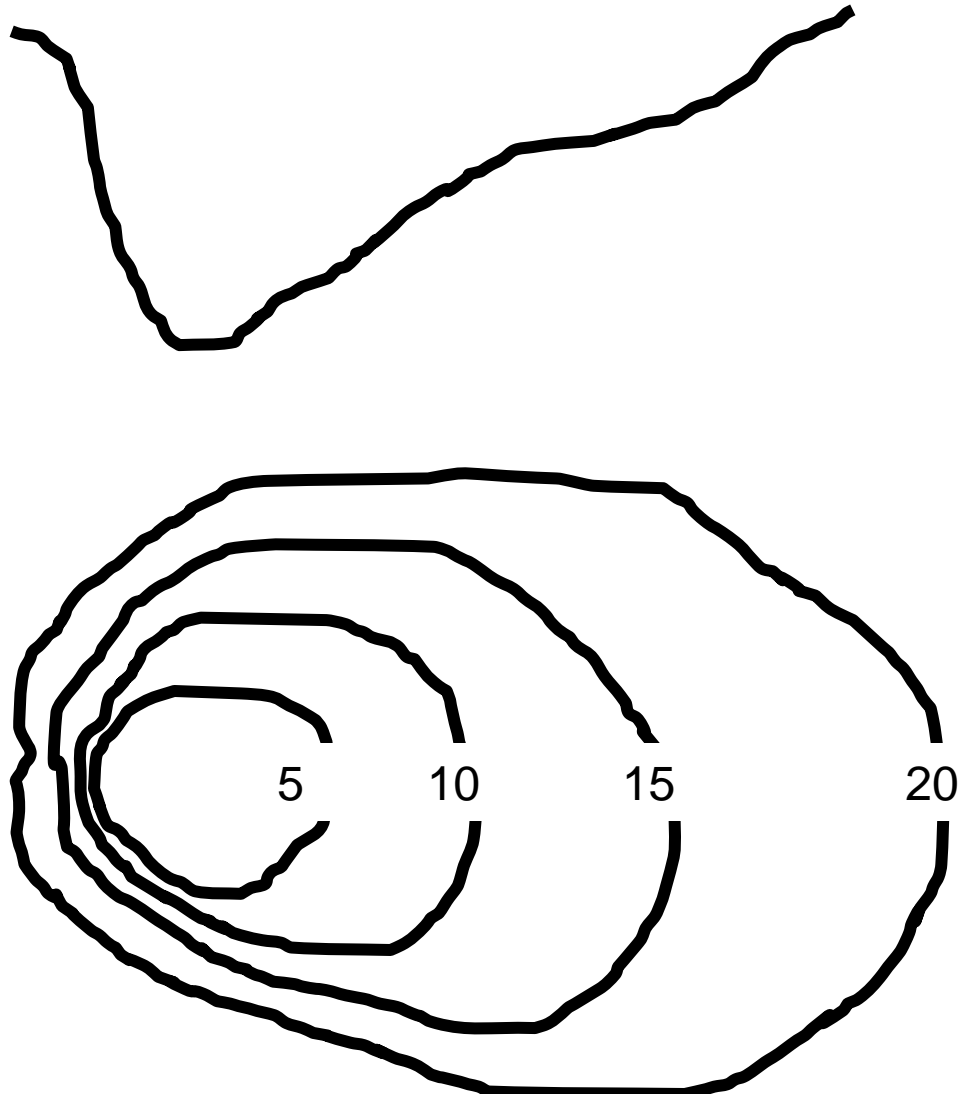
4.14.3 Contouring

Example



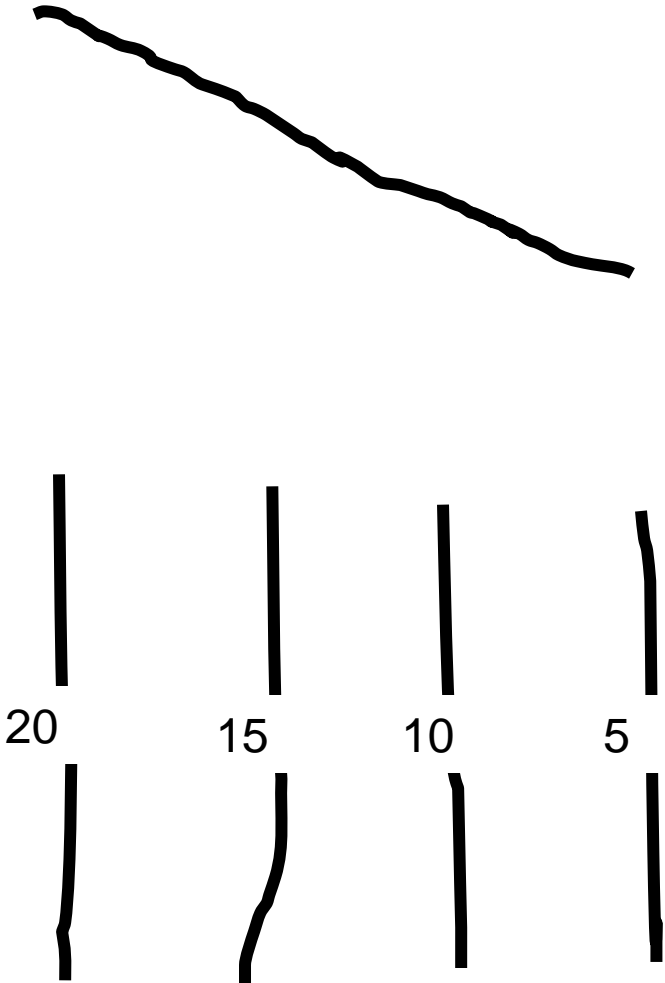
4.14.3 Contouring

Example



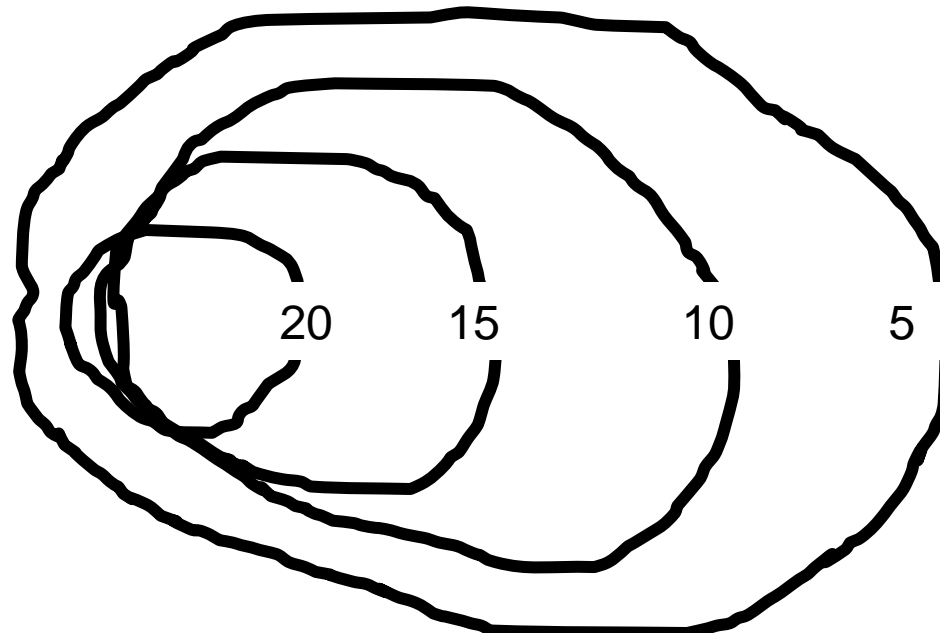
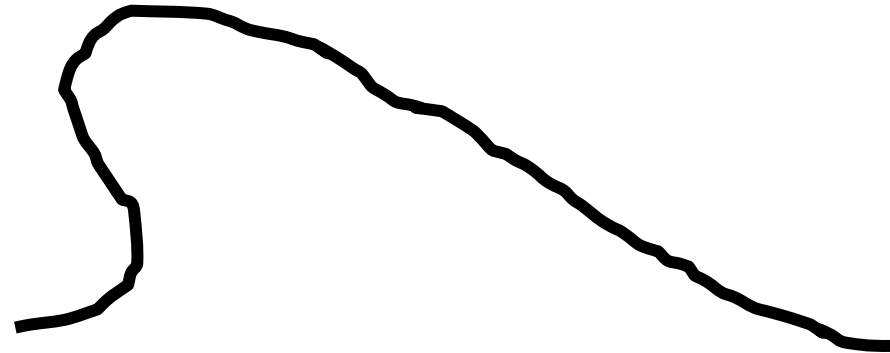
4.14.3 Contouring

Example



4.14.3 Contouring

Example



4.14.3 Contouring

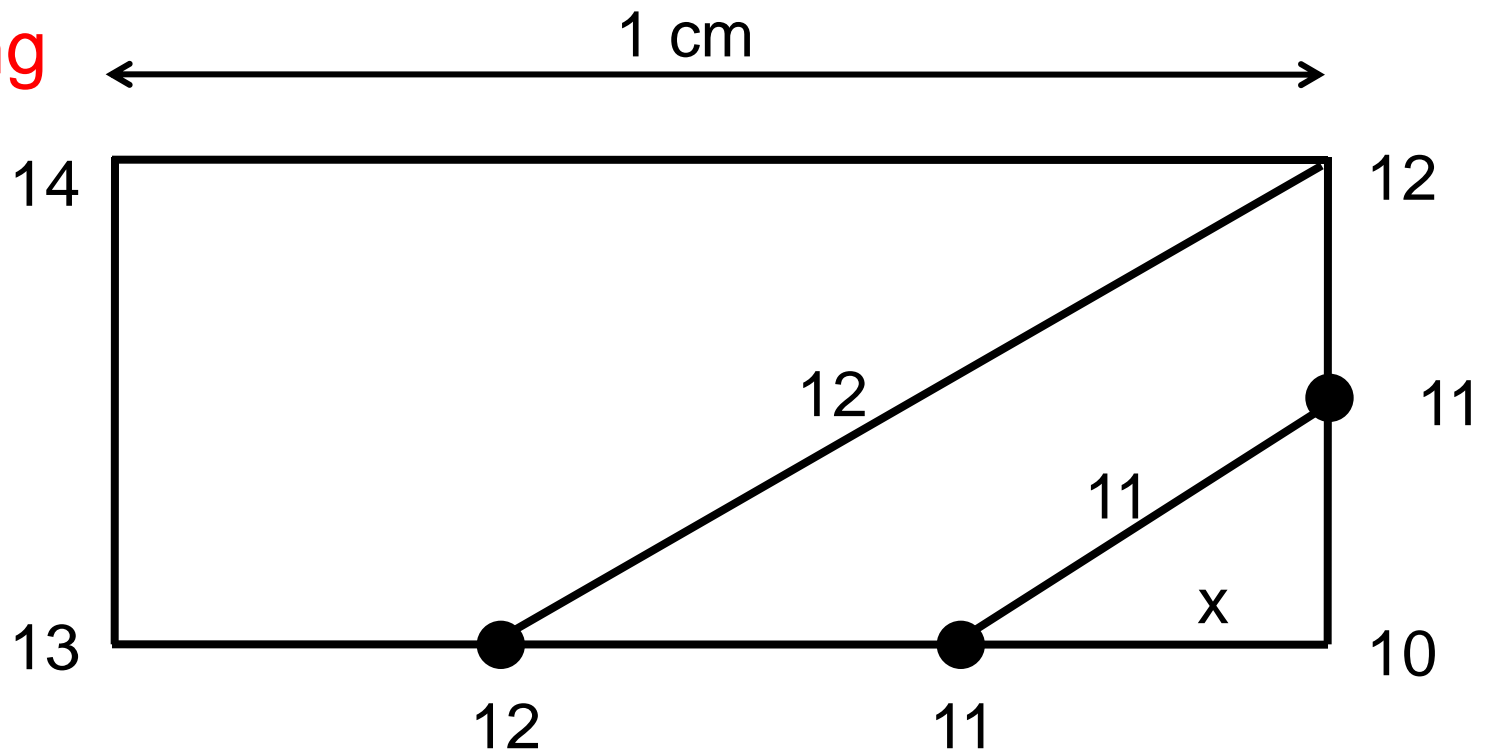
Methods of Contouring

Gridding

	1	2	3	4	5
A					
B					
C					
D					

4.14.3 Contouring

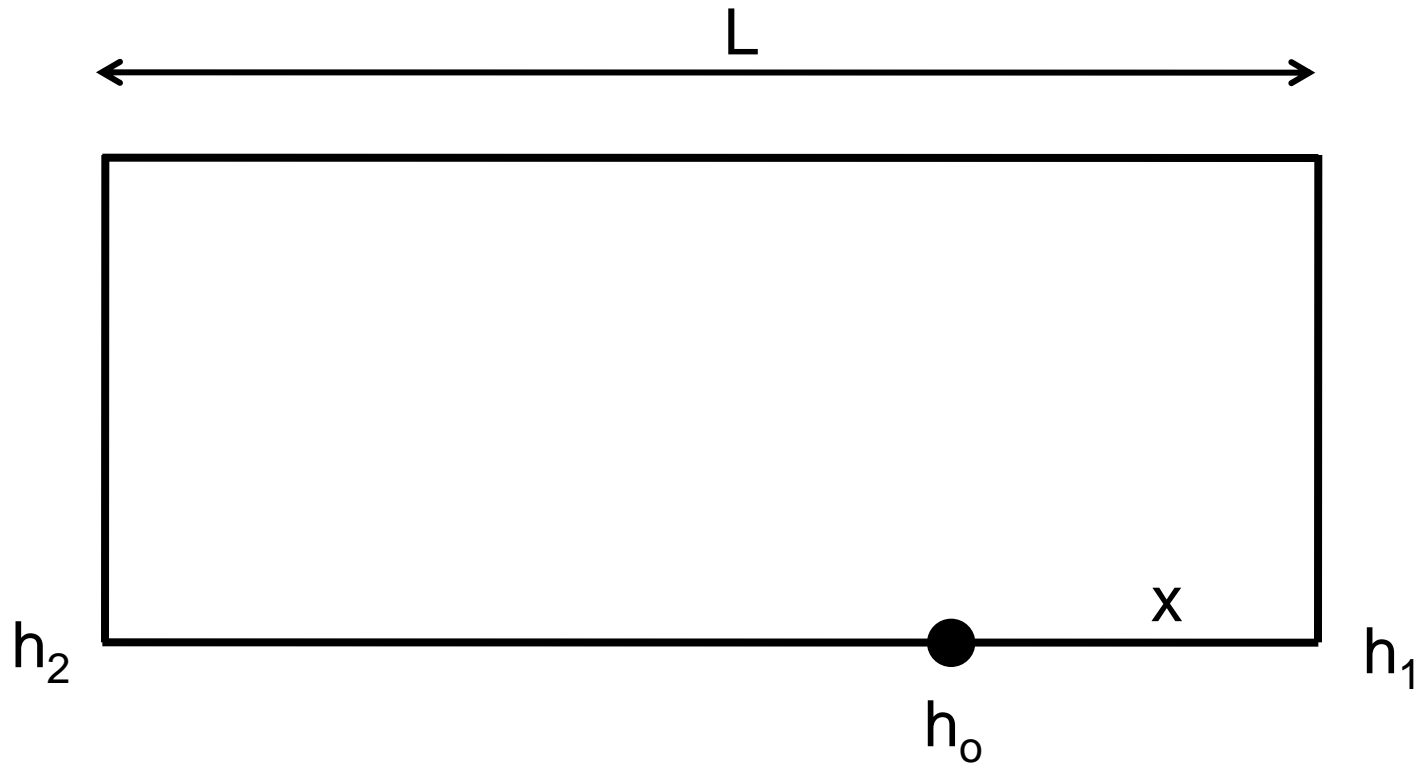
Gridding



$$x = \frac{11-10}{13-10} (1 \text{ cm}) = 0.33 \text{ cm}$$

4.14.3 Contouring

Gridding



$$x = \frac{h_o - h_1}{h_2 - h_1} (L)$$

4.14.3 Contouring

Gridding

