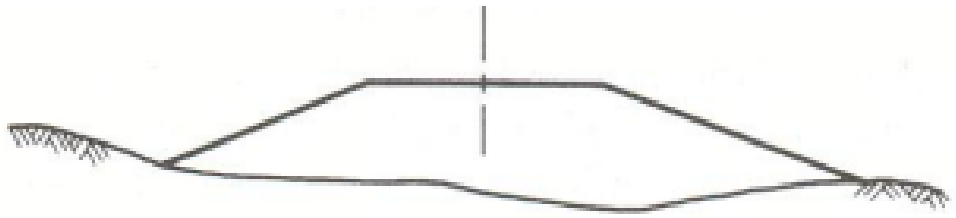
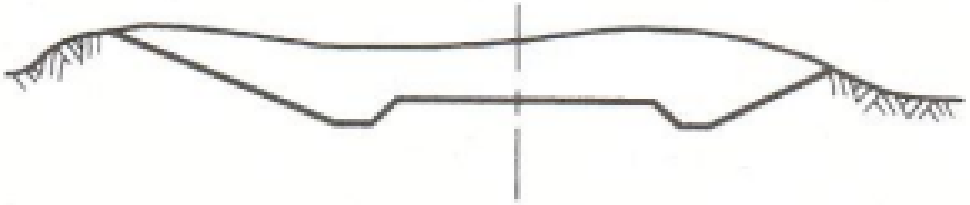
Aim: Earthwork Analysis.

Objectives: At the end of the lesson, the students should be able to:

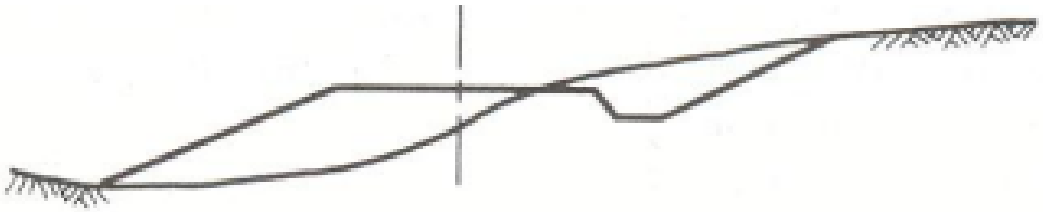
- Discuss the methods used to achieve excavated volume calculation.
- Calculate the volumes of excavation using an appropriate method.



(a) Fill



(b) Cut



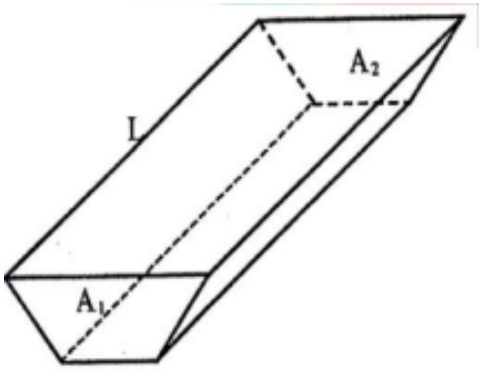
(c) Fill and cut

Calculating Earthwork Quantities

1. **Cross-section Method.**

- Cross-sectional land surveying is a manual approach to mapping existing and proposed terrain, involving regular measurements across the site.
- By analysing the cut and fill areas at each cross-section, and averaging these values between adjacent sections, the total cut and fill volumes can be calculated.
- This method, while labour-intensive, allows for a detailed, granular analysis of the site's topography and earthwork requirements.
- However, the trade-off is that the accuracy of the cross-section approach is inversely proportional to the spacing between measurement points - closer sections yield higher precision but take longer, while wider spacing is faster but less precise.
- The specific mathematical techniques employed are the end area method and prismoidal formula, which provide the volumetric calculations based on the cross-sectional data.

End Area Method



$$V = \left(\frac{A_1 + A_2}{2}\right). L$$

Where:

$$V = Volume$$

$$A_1 \text{ and } A_2 \text{ are the areas of the end sections}$$

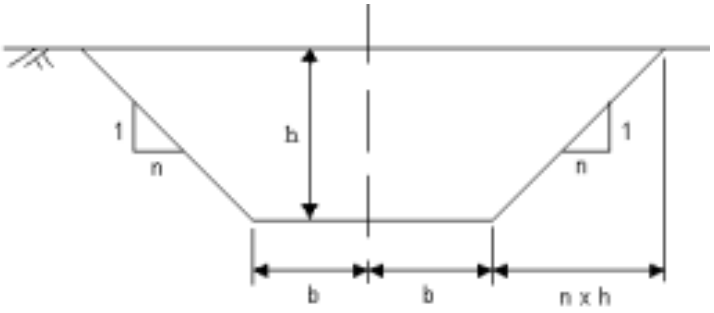
$$L = \text{distance between sections}$$

For n sections, distance L apart,

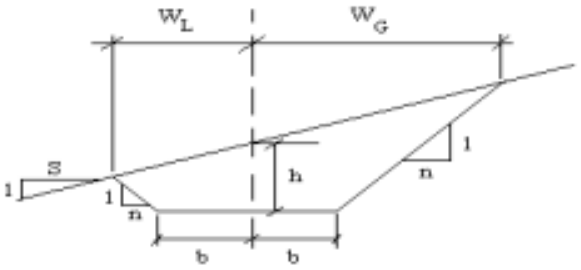
$$V = \frac{L}{2}\left(A_1 + A_n + 2\left[A_2 + A_3 + \ldots + A_{n-1}\right]\right)$$

For typical cut cross section shown below, the area is calculated using:

$$Area = h\,.\,2b + \frac{2nh^2}{2} = h\,(2b + nh)$$



For typical sloping cut cross section shown below, the area is calculated using:



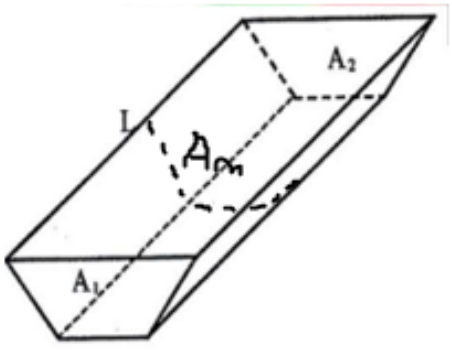
$$Area = \frac{1}{2}\left(h + \frac{b}{n}\right)\left(W_L + W_G\right) - \frac{b^2}{n}$$

Where

$$W_L = \frac{S\,(b+nh)}{(S+n)}$$

$$W_G = \frac{S\,(b+nh)}{(S-n)}$$

Prismoidal Formula



$$V = \frac{\left(A_1 + 4A_m + A_2\right)}{6 \cdot L}$$

Where V is the volume and A_1 and A_2 are end areas at ends of section.

$$A_m = cross\ sectional\ area\ in\ middle\ of\ section$$

$$L = length\ from\ A_1\ to\ A_2$$

2. Contour Line or Grid Method

- The grid-based volume calculation method involves superimposing a defined matrix over the project site and determining the cut/fill requirements at each grid intersection.
- By multiplying the cut or fill depth at each grid node by the corresponding cell area, the individual volumes can be aggregated to arrive at the total earthwork quantities.
- While this manual approach allows for a granular analysis of the site's topography, it is a labour-intensive process that is less efficient than automated volume calculation techniques.
- The trade-off with the grid method is that larger grid cells require less time to process but yield lower accuracy, whereas smaller cells provide higher precision but take longer to calculate.
- As with the cross-section method, the grid-based approach represents a detailed, hands-on technique for quantifying earthwork requirements, but it is ultimately constrained by the time and effort required to implement it.

Date: 22 May 2023

Taken for:

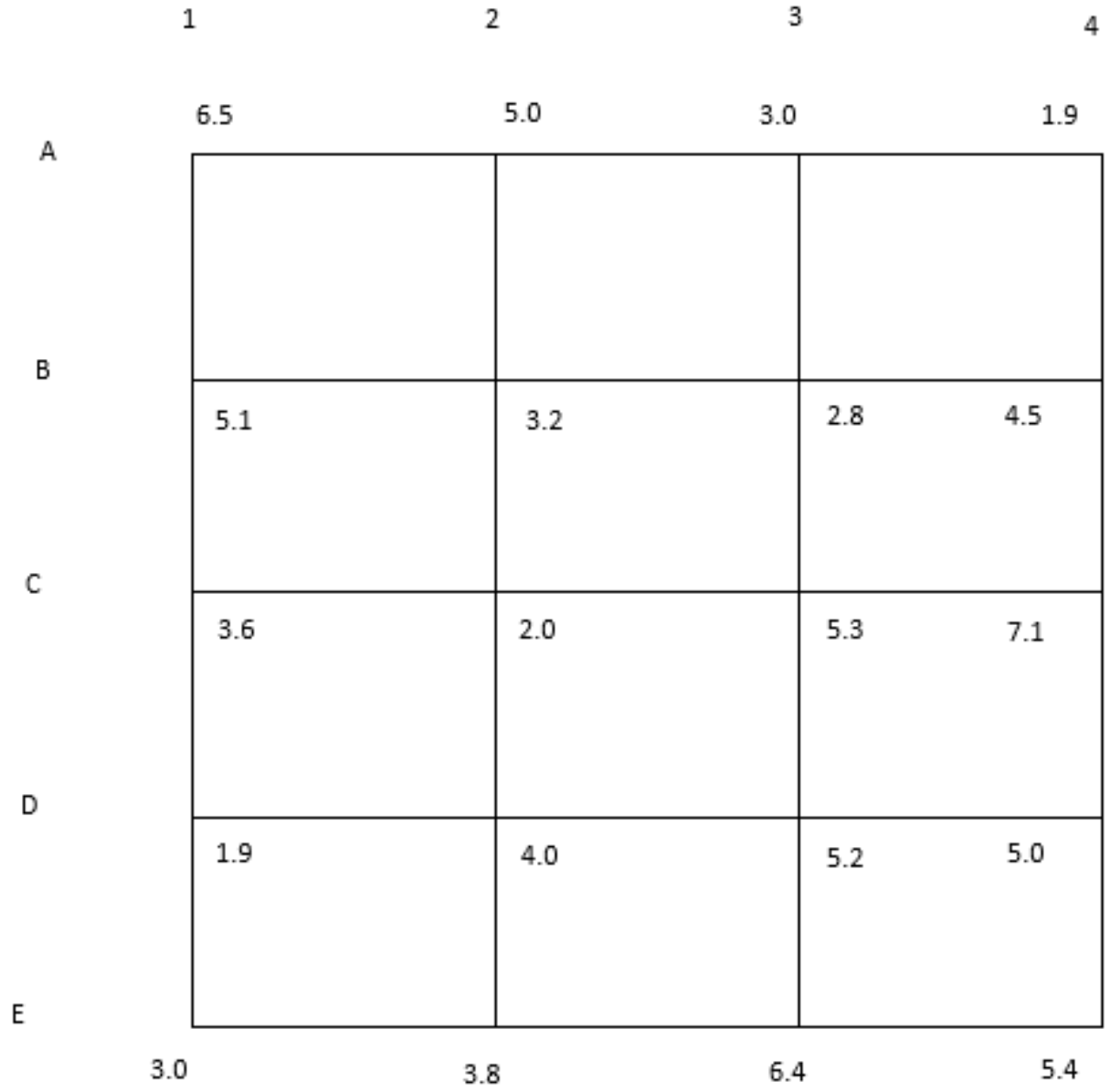
From: Calculating the volumes of excavation Example

To: Booking

BS	IS	FS	COLLIMATION OR HPC	Reduced level (RL Top of peg)	Distance	Remarks
1.500			7.500	6.000		TBM 1; 6.000
	1.000			6.500		Station 1A
	2.400			5.100		Station 1B
	3.900			3.600		Station 1C
	5.600			1.900		Station 1D
	4.500			3.000		Station 1E
	2.500			5.000		Station 2A
	4.300			3.200		Station 2B
	5.500			2.000		Station 2C
	3.500			4.000		Station 2D
	3.700			3.800		Station 2E
	4.500			3.000		Station 3A

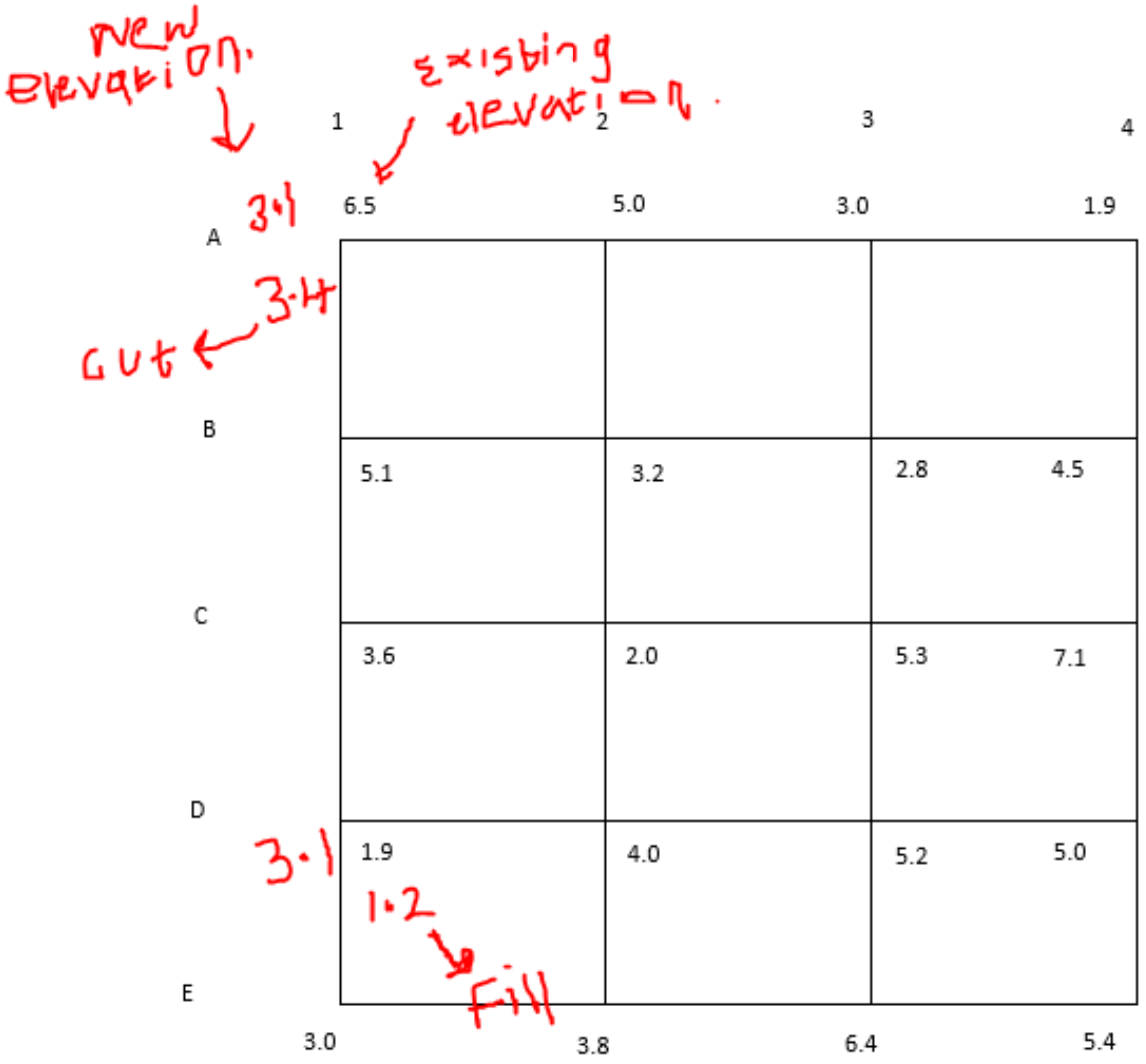
	4.700			2.800		Station 3B
	2.200			5.300		Station 3C
	2.300			5.200		Station 3D
	1.100			6.400		Station 3E
	5.600			1.900		Station 4A
	3.000			4.500		Station 4B
	0.400			7.100		Station 4C
	2.500			5.000		Station 4D
	2.100			5.400		Station 4E
		1.502		5.998		TBM 1 (6.000 **reqd.,** 2mm error, Therefore, ok.)
1.500		**1.502**		**6.000**		Sum of BS & FS
		(1.500)		**(5.998)**		Difference in BS & FS, Difference between 1st & last RL
		0.002		**0.002**		The difference should be equal.
	Booking Checks: Difference in BS – FS = Difference between 1st & last RL. Therefore, Levels have been booked correctly however, there is a misclosure of 2mm error.					

	Allowable Misclosure/Error The allowable misclosure is, $\pm 5\sqrt{No\ of\ instrument\ setup}$ $\pm 5\sqrt{1}$ $\pm 5\ mm > 2mm$, therefore, OK.



Grid size = 2 m X 2 m

Formation level/New elevation = 3.100 m



Depth cut = Existing elevation (EE) – Formation level (FL)

[Note: EE > FL]

Depth fill = Formation level – Existing elevation

[Note: FL > EE]

Frequency = Number of squares in each station.

Area constant = area of each grid = 2 m X 2 m = 4 m^2

Volume of cut = Depth cut X Frequency X Area constant

Volume of fill = Depth fill X Frequency X Area constant

Use MS Excel Sheet

Station	Formation level	Existing elevation	Depth cut	Depth fill	Frequency	Area constant	Volume cut	Volume fill
1A	3.1	6.5	3.4	0	1	4	13.6	0
1B	3.1	5.1	2	0	2	4	16	0
1C	3.1	3.6	0.5	0	2	4	4	0
1D	3.1	1.9	0	1.2	2	4	0	9.6
1E	3.1	3	0	0.1	1	4	0	0.4
2A	3.1	5	1.9	0	2	4	15.2	0
2B	3.1	3.2	0.1	0	4	4	1.6	0
2C	3.1	2	0	1.1	4	4	0	17.6
2D	3.1	4	0.9	0	4	4	14.4	0
2E	3.1	3.8	0.7	0	2	4	5.6	0
3A	3.1	3	0	0.1	2	4	0	0.8
3B	3.1	2.8	0	0.3	4	4	0	4.8
3C	3.1	5.3	2.2	0	4	4	35.2	0
3D	3.1	5.2	2.1	0	4	4	33.6	0

3E	3.1	6.4	3.3	0	2	4	26.4	0
4A	3.1	1.9	0	1.2	1	4	0	4.8
4B	3.1	4.5	1.4	0	2	4	11.2	0
4C	3.1	7.1	4	0	2	4	32	0
4D	3.1	5	1.9	0	2	4	15.2	0
4E	3.1	5.4	2.3	0	1	4	9.2	0
						Σ	233.2	38

Bulk cut = 233.2 m^3

Bulk fill = 38.0 m^3

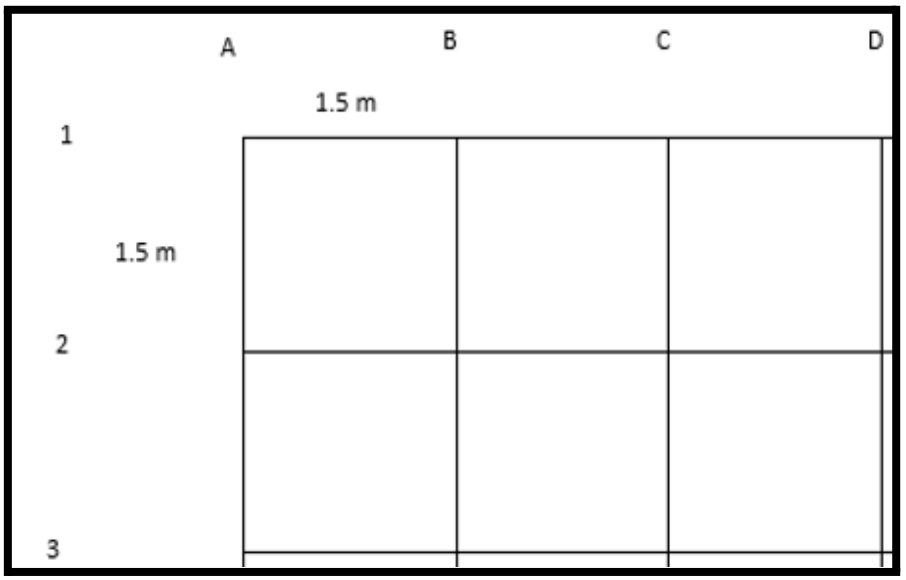
Dispose surplus = 195.2 m^3

Self-assessment Task

Task 1

A grid size of 1.5 m X 1.5 m is set up. If the required formation level is 9.850 m, use the grid method to determine:

a) the reduced level at each station;
b) the total volume of cut;
c) the total volume of fill; and
d) the volume of earthwork quantities (dispose or import).



BS	IS	FS	COLLIMATION OR HPC	Reduced level (RL Top of peg)	Remarks
1.863				10.000	TBM 1; 10.000
	1.765				Station 1A
	2.430				Station 1B
	1.657				Station 1C
	1.875				Station 1D
	2.130				Station 2A
	2.140				Station 2B

1.970					Station 2C
1.430					Station 2D
1.659					Station 3A
1.702					Station 3B
2.200					Station 3C
2.268					Station 3D
		1.860			TBM 1 (10.000 **reqd.,** …mm error, Therefore, ...
					Sum of BS & FS
					Difference in BS & FS, Difference between 1st & last RL
					The difference should be equal.
	Booking Checks: Difference in BS – FS = Difference between 1st & last RL. Therefore, Levels have been booked correctly however, there is a misclosure...				
	Allowable Misclosure/Error Allowable Misclosure/Error The allowable misclosure is, $\pm 5\sqrt{No\ of\ instrument\ setup}$ …				

Station	Formation level	Existing elevation	Depth cut	Depth fill	Frequency	Area constant	Volume cut	Volume fill
1A	9.850							
1B	9.850							
1C	9.850							
1D	9.850							
2A	9.850							
2B	9.850							
2C	9.850							
2D	9.850							
3A	9.850							
3B	9.850							
3C	9.850							
3D	9.850							
						Σ		

Task 2

Discuss at least ANY TWO mathematical methods which could be adopted to calculate volume excavations.