

Earthwork



Earthwork



Activities involve:

1. Excavating
2. Loading
3. Hauling
4. Placing
5. Compacting
6. Grading
7. Finishing



Equipment	Typical use
	Backacters (Backhoes): Excavating below ground level in confined spaces in firm soil, e.g. when digging drainage trenches; as small ‘handling cranes’, e.g. when laying drainage pipes.
	Bulldozers: Opening up access roads; clearing vegetation; stripping top soil; shallow excavating; moving earth over short distances (e.g. <100 m); spreading and rough-grading earth previously-moved by scrapers, trucks or wagons.



Face shovels: Excavating firm material above ground level, e.g. in cuttings, and previously-blasted rock in quarries.



Loader shovel: Several localized earthworks operations, e.g. digging/filling shallow trenches, excavating for manholes, loading loose materials onto trucks and wagons, stockpiling.



Graders: Accurate finishing work, e.g. trimming the subgrade and establishing the formation, and shaping shoulders, ditches and backslopes; maintaining haul roads. Also, for blending materials, including water.



Scrapers: Earthmoving operations which involve self-loading, hauling over various distances (e.g. <3 km), dumping and spreading of materials.



Trucks and wagons: General haulage operations over long distances (typically 1–10 km).

Earthwork

- Highways involve considerable amount of earthwork.
- Earthwork is simply the quantity of material to be moved or put in place to convert the natural condition and configuration within the ROW of the road to the section and grades described in the plans.
- Classification of earthwork operations
 - Clearing and grubbing
 - Excavation
 - Roadway and drainage excavation
 - Excavation for structures
 - Borrow excavation



Earthwork

- Clearing and grubbing
 - The first operation to be undertaken in road projects.
 - Definition: the removal of trees, stumps, roots, down timber, rotten wood, rubbish and other objectionable materials from an area marked on the plans.
 - Clearing refers to the removal of materials above existing ground surface, and
 - Grubbing means the removal of roots, stumps and similar objects to a nominal depth below the surface.
 - Clearing and grubbing constitute a single contact item that includes the removal of topsoil to a shallow depth.

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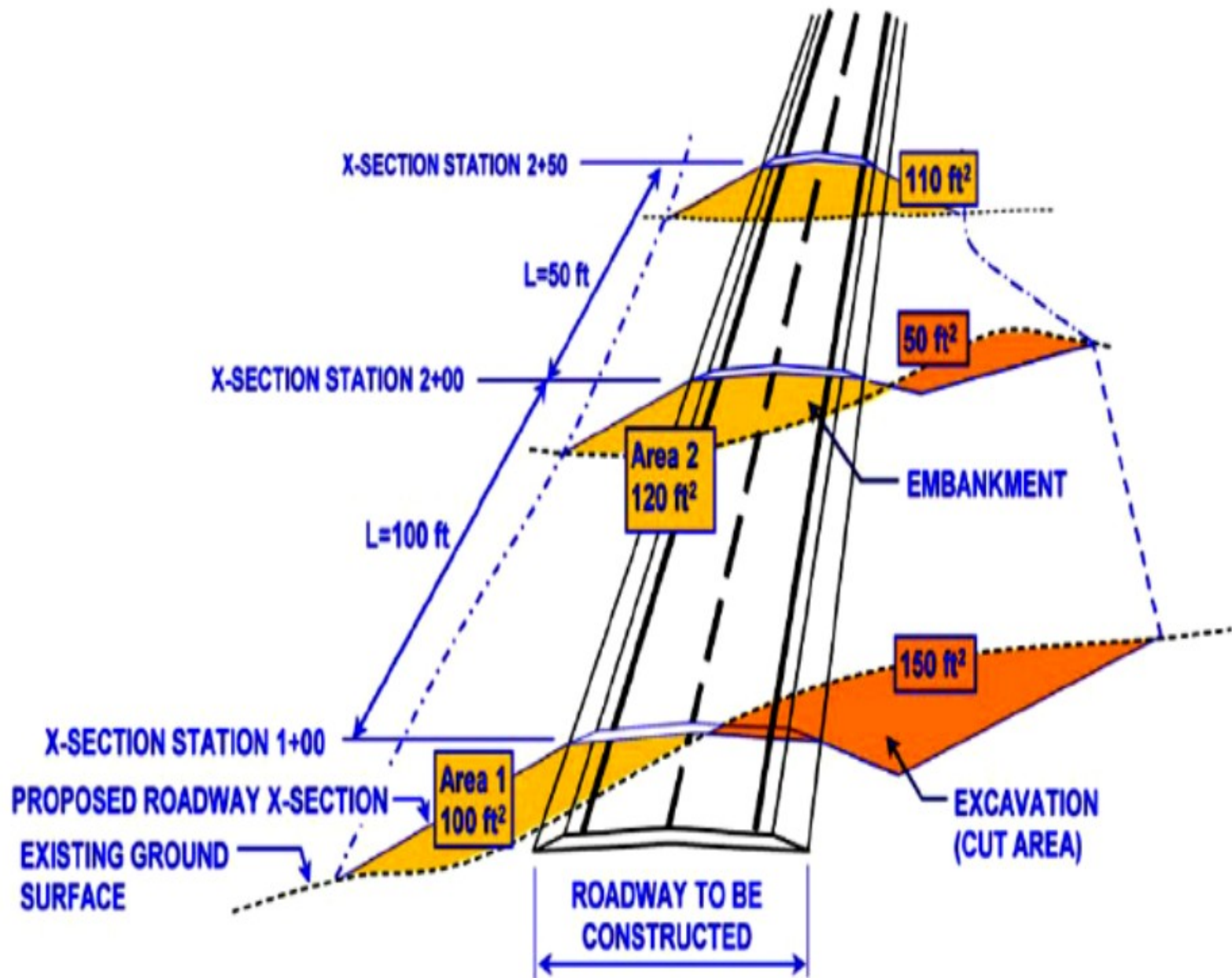
- **Excavation:** the process of loosening and removing earth or rock from its original position in a cut and transporting it to a fill section or to a waste deposit.
- Roadway and Drainage Excavation.
 - the excavation and grading of the roadway and ditches, including the removal and disposal of all excavated material and all work needed for the construction and completion of the cuts, embankments, slopes, ditches, approaches, intersections and similar portions of the work.
- Excavation for structures.
 - the excavation of material in order to permit the construction of pipe culverts, concrete box culverts, foundations for bridges, retaining walls, and practically all other structures that may be required in a particular job.

Earthwork

- **Excavation:** the process of loosening and removing earth or rock from its original position in a cut and transporting it to a fill or to a waste deposit.
- Borrow excavation.
 - when sufficient material for the formation of embankments and other elements of the roadway structure is not available from excavation performed within the limits of the right-of-way, additional suitable material is generally taken from borrow pits.

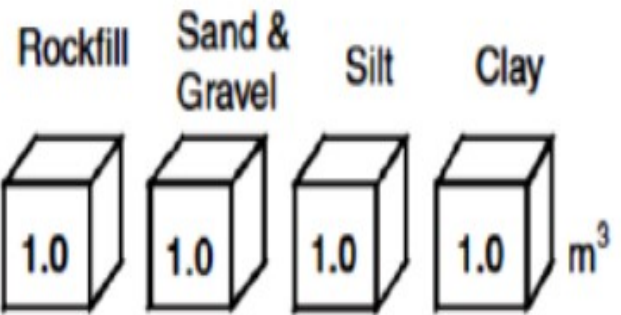
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- Classification of Excavation
 - Rock excavation
 - material that cannot be excavated without blasting or the use of rippers and all boulders or other detached stones.
 - Common excavation
 - excavation and disposal of all materials of whatever character encountered in the work, which are not classified as rock, borrow.
 - Borrow excavation
 - excavation of approved material required for construction of embankments.
 - Unsuitable excavation
 - the removal and disposal of deposits of saturated or unsaturated mixtures of soil and organic matter not suitable for embankment material.

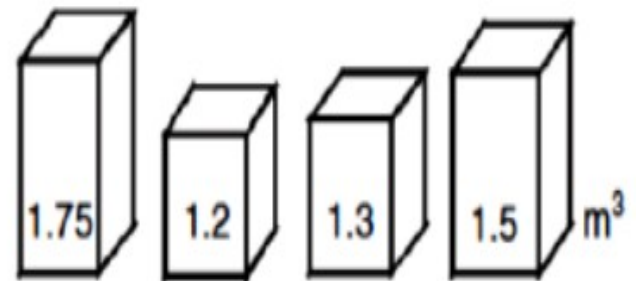




Normal state



Loose state



Compact state



Earthwork

Haul and Overhaul

- **Free Haul**: when material is excavated it will be moved over a certain distance free of charge. NB: Only the excavation cost is paid, not the transportation cost of the material.
 - Free Haul Distance (FHD): Distance over which excavated material is moved free of charge (usually 300 – 500 m, but ranges 150 – 900 m).
- **Overhaul**: is defined as the distance over which the excavated material must be hauled less the free haul distance. NB: there is extra payment for transporting material in addition to excavation cost.
 - Overhaul distance (OHD): Distance over which excavated material is transported beyond the free-haul distance.
$$\text{OHD} = \text{HD} - \text{FHD}$$
- **Economic Overhaul** (EOH): Economic overhaul is a distance beyond which it is not economic to overhaul.
 - Limit of Economic Overhaul (LEH) - is the distance beyond which it is uneconomic to overhaul plus the free haul distance.
$$\text{LEH} = \text{EOH} + \text{FHD}$$

Earthwork

- Haul and Overhaul

- Haul – is equal to the sum of the products of each volume of material and the distance through which it is moved.
- Waste – is the volume of material, which must be exported from a section of the road due to a surplus or unsuitability.
- Borrow – is that volume of material, which must be imported in to section of the road due to a deficiency of (suitable) material.

Cost of 1 m³ of excavated material from cut & move to fill = $C_{exc} + C_{oh} \cdot L_e$

Cost of 1 m³ of excavated material, waste, borrow & place to fill = $C_{exc} + C_{bor}$

Maximum economical length of over - hauling :

$$C_{exc} + C_{oh} \cdot L_e = C_{exc} + C_{bor} \quad [\text{NB: } L_e = EOH]$$

$$EOH \leq \frac{C_{bor}}{C_{oh}} \Rightarrow \text{Total economic haul distance, } LEH = FHD + EOH$$

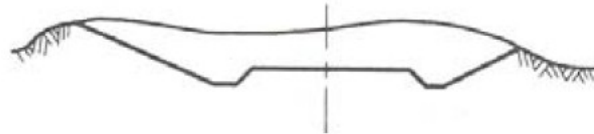
Earthwork

Estimation of Earthwork Quantities

The estimation of the quantity of material which must be excavated (cut), and the quantity of material required to raise the elevation of the existing ground (fill), is very useful in the development of a cost estimate for road projects.



FILL (Embankment)



CUT (Excavation)



CUT and FILL

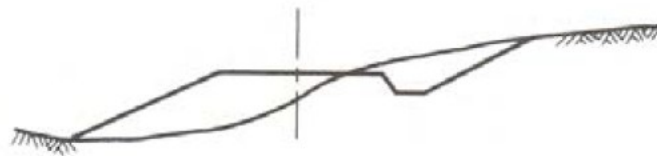
Earthwork

Estimation of Earthwork Quantities

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CUT (Excavation) .



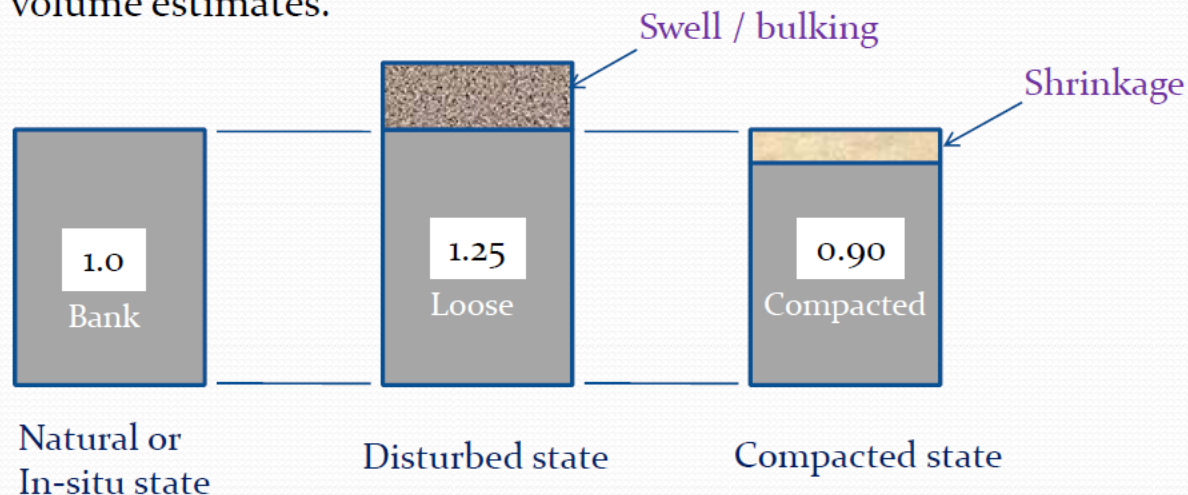
CUT and FILL

Earthwork

Estimation of Earthwork Quantities

- Soil Volume Changes

- Excavated in-situ material used in embankments or fills may swell or shrink. It is important to determine the properties of a material in order to evaluate how these properties will affect the earthwork volume estimates.



Earthwork

Estimation of Earthwork Quantities

- Soil Volume Changes

- Material volume increases during excavation
- Decreases during compaction
- Varies with
 - Soil type
 - Fill depth
 - high fill: 10 – 15 %
 - shallow fill: 20 – 25 %

Swell:

- Excavated rock 5 – 25%

Shrinkage:

- Light soil
 - Ordinary soil 10 – 20%
 - Swampy soil 20 – 40%
- Heavy soil upto 10%

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Soil Volume Changes

$$\text{Swell (\%)} = \left(\frac{\text{Bank density}}{\text{Loose density}} - 1 \right) \times 100$$

$$\text{Shrinkage (\%)} = \left(1 - \frac{\text{Bank density}}{\text{Compacted density}} \right) \times 100$$

$$\text{Load Factor} = \frac{\text{Loose density}}{\text{Bank density}} = \frac{1}{1 + \text{swell}}$$

$$\text{Shrinkage (Compaction) Factor} = \frac{\text{Bank density}}{\text{Compacted density}} = 1 - \text{Shrinkage}$$

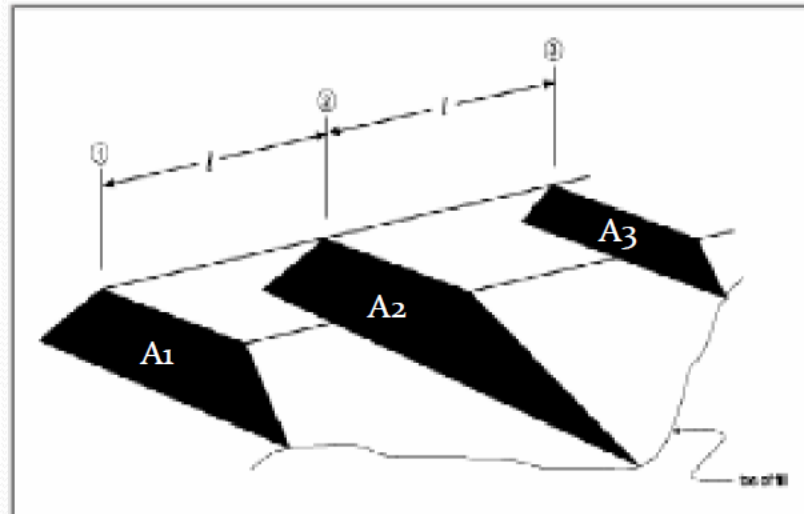
$$\text{Bank Volume} = \text{Loose Volume} \times \text{Load Factor}$$

$$\text{Compacted Volume} = \text{Bank Volume} \times \text{Shrinkage Factor}$$

Earthwork

Estimation of Earthwork Quantities

- Estimation of the area of cross-section as a cut and fill.
- The distance between these areas, l (or L)
- Volume of earthwork
 - Cut volume and
 - Fill volume.
- Area of cross section
 - Coordinate method
 - Trapezoidal rule
 - Simpson's rule



Earthwork

- Calculation of cross-sectional areas
 - Coordinate method:
 - With the coordinates of all the corners of a cross-section known, the area may be computed by means of the coordinate method.
 - The point of intersection of the center of formation with the centerline of the road (c) is used as the origin.
 - The cut above the formation are written as plus (+) and those below as minus (-).
 - The distances to the right are written as plus (+) and those to the left as minus (-).

Earthwork

- Calculation of cross-sectional areas
 - Coordinate method:

$$\begin{array}{ccccccccc} Y_1 & & Y_2 & & Y_3 & & Y_4 & & Y_5 & & Y_6 & & Y_1 \\ & \searrow & & \searrow & & \searrow & & \searrow & & \searrow & & \searrow & \\ X_1 & & X_2 & & X_3 & & X_4 & & X_5 & & X_6 & & X_1 \end{array}$$

- The products along the marked diagonals are all positive and the product along the unmarked diagonals are all negative.
 - The difference gives double area of the section.
- Area, A

$$A = 1/2 \left[(Y_1X_2 + Y_2X_3 + Y_3X_4 + \cdots + Y_{n-1}X_n) - (X_1Y_2 + X_2Y_3 + X_3Y_4 + \cdots + X_{n-1}Y_n) \right]$$

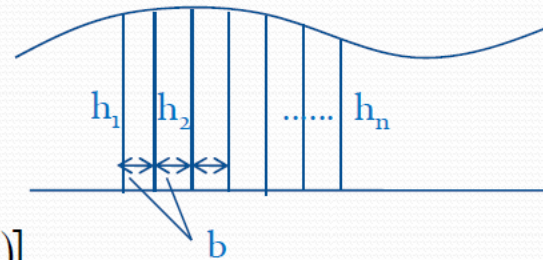
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- Calculation of cross-sectional areas
 - Trapezoidal rule:
 - assumes that if the uniform interval (b) between the offsets is small, the boundary can be approximated to a straight line between the offsets.

$$A_1 = 1/2(h_1 + h_2) \cdot b$$

$$A_2 = 1/2(h_2 + h_3) \cdot b$$

$$A = b/2[h_1 + h_n + 2(h_2 + h_3 + \dots + h_{n-1})]$$

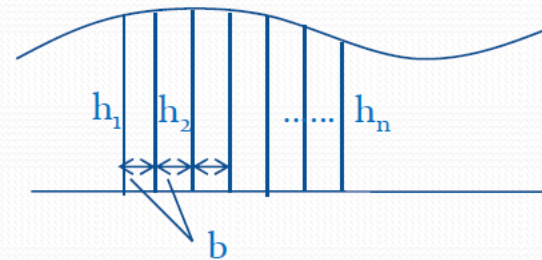


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- Calculation of cross-sectional areas
 - Simpson's rule:
 - assumes that instead of being made up of a series of straight lines the boundary consists of a series of parabolic arcs.

$$A_1 + A_2 = b/3(h_1 + 4h_2 + h_3)$$

$$A_2 + A_4 = b/3(h_3 + 4h_4 + h_5)$$

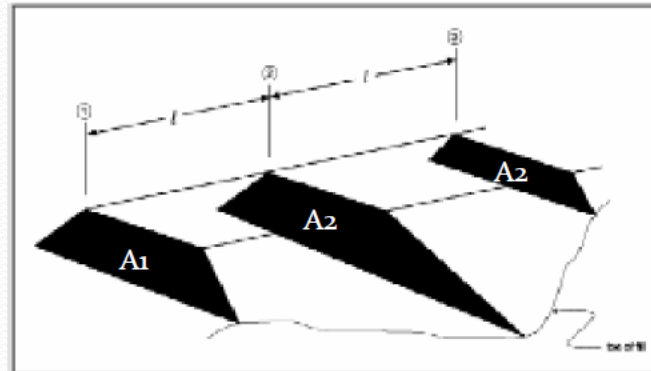


$$A = b/3[h_1 + h_n + 2(h_3 + h_5 + \dots + h_{n-2}) + 4(h_2 + h_4 + \dots + h_{n-1})]$$

... and n is an odd number

Earthwork

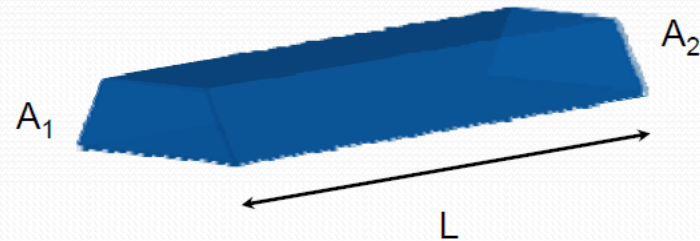
- Computation of Volumes
 - Average end-area method
 - based on the volume of a right prism whose volume is equal to the average end area multiplied by the length.
 - Prismoidal method
 - a prismoid is a solid whose ends are parallel and whose sides are plane surfaces.



Computing Volumes

Average end areas method

$$V = \frac{1}{2} (A_1 + A_2)L$$



$$V = L/2 [A_1 + A_n + 2(A_2 + A_3 + \dots + A_{n-1})]$$

Where

- A_1, A_2 : end cross-section areas
- L : distance between cross-sections

Example

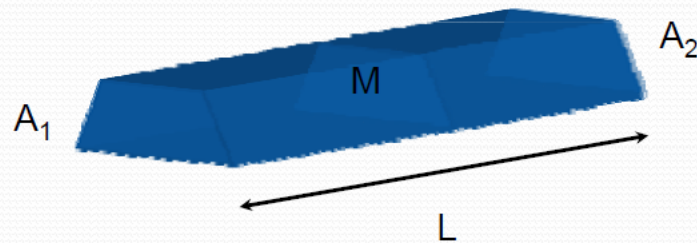
$$A_0 = 39.2 \text{ m}^2 \quad A_1 = 36.5 \text{ m}^2 \quad L = 20 \text{ m}$$

$$V = \frac{1}{2} (39.2 \text{ m}^2 + 36.5 \text{ m}^2)(20 \text{ m}) = 757 \text{ m}^3$$

Computing Volumes

Prismoidal method

$$V = L/6 (A_1 + 4M + A_2)$$



$$V = 2L/6 [A_1 + A_n + 2(A_3 + A_5 + \dots + A_{n-2}) + (A_2 + A_4 + \dots + A_{n-1})]$$

... and n is an odd number

Where

- A_1, A_2 : cross-section areas
- M: area of middle section
- L: distance between cross-sections

Earthwork

- Tabulation of earthwork quantities

[illegible]

Earthwork

- Mass-Haul Diagrams

- A Mass Haul Diagram is a continuous curve representing the cumulative volume of earthwork along the linear profile of a roadway or airfield
- Mass diagrams are extremely useful in determining the most economical distribution of material
- Horizontal stationing is plotted along the x-axis
- Net earthwork values are plotted along the y-axis
 - cumulative earthwork from the origin to that Point
 - upward sloping curves (rising left to right) indicate a cut
 - downward sloping curves (falling left to right) occur in a fill section
 - peaks indicate a change from cut to fill and
 - valleys occur when the earthwork changes from fill to cut

Earthwork

- Mass-Haul Diagrams

- Any horizontal line which joins points on the curve where balance is achieved is called a *balance line*. The FHD and/or the limit of economic overhaul are established and plotted on the mass haul diagram.
- A vertical break between any two balance lines indicates an area where balance does not occur. At these breaks a shortfall (borrow) or excess (waste) material exists.
- A positive value at the end of the curve indicates that a waste operation will be the net result
- A negative value at the end of the curve indicates that borrow is required to complete the fill

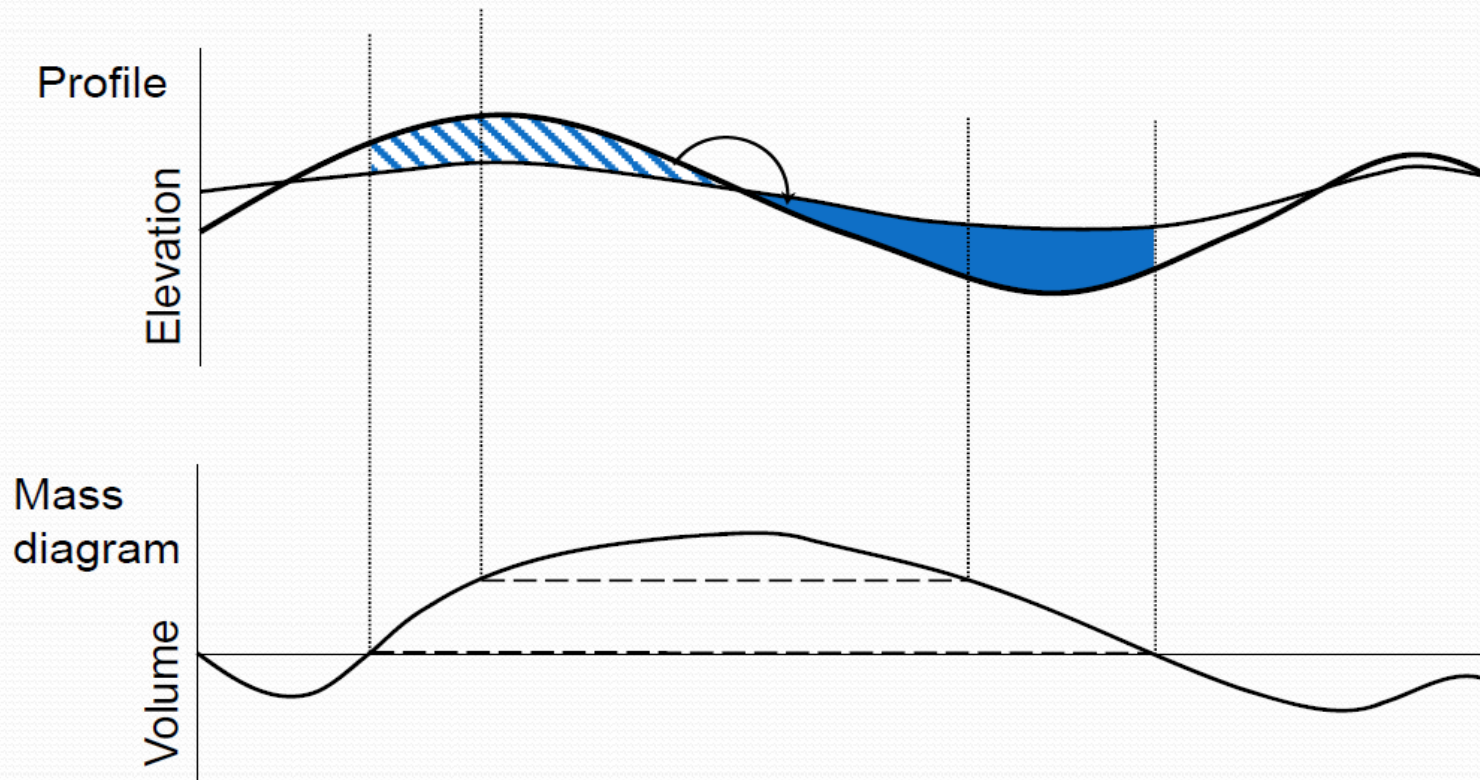
Earthwork

Mass-Haul Diagram

■ Fill areas

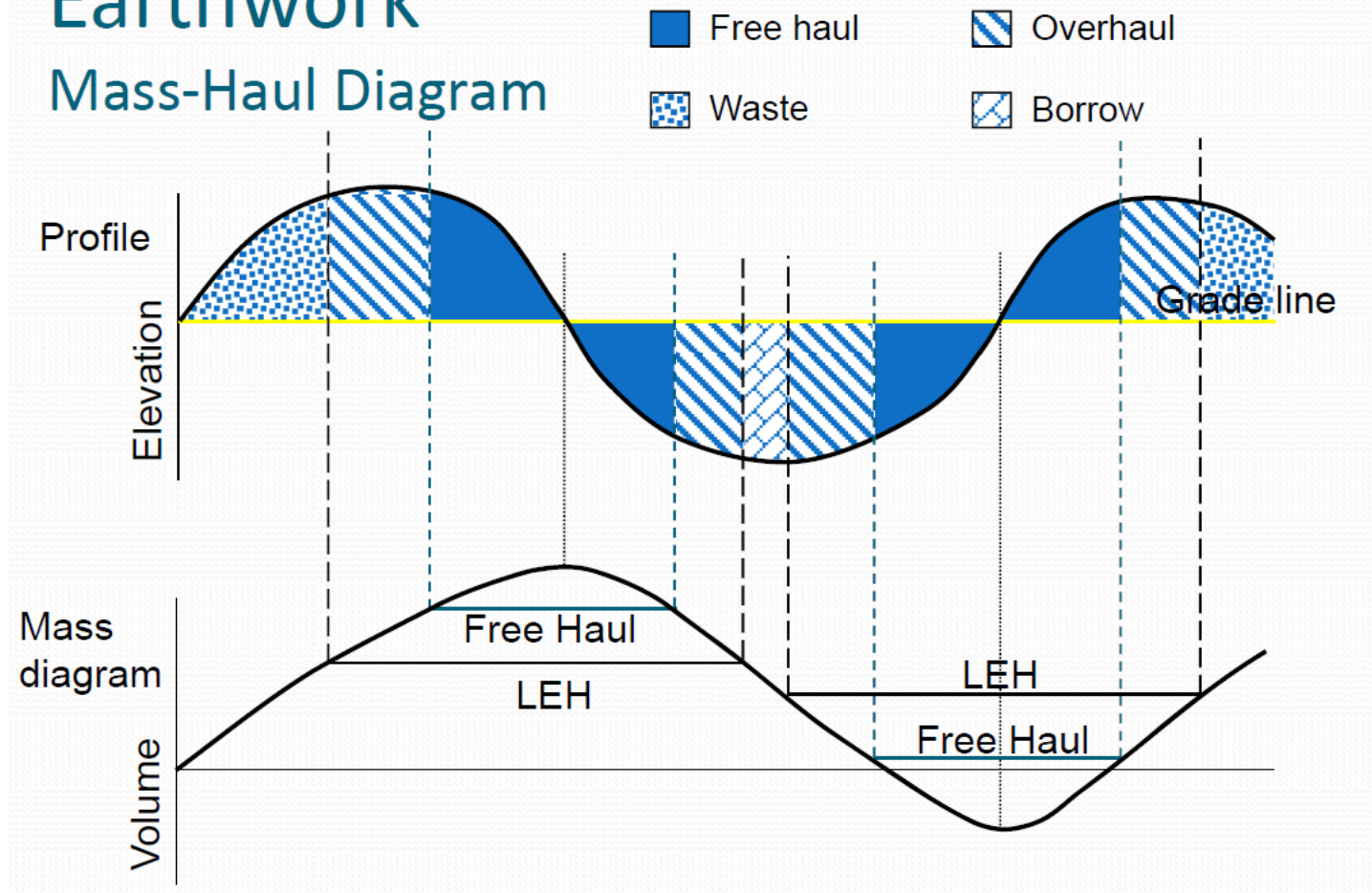
▨ Cut areas

----- Any horizontal line on mass diagram is a balance line – within balance line cut = fill



Earthwork

Mass-Haul Diagram



Earthwork

- Calculation of Mass-haul diagrams manually
 - Compute the net earthwork values for each station, applying the appropriate shrink factor
 - Net cuts have a positive value, net fills have a negative value
 - The value (earthwork quantity) at the first station (origin) = 0
 - Plot the value of each succeeding station which equals the cumulative value to that point
 - Identify the resulting balanced sections, which are bounded by points that intersect the x-axis
 - The scale length of a horizontal line connecting the centre of gravity of the cut and fill sections is the average length of haul within that balanced section
 - Determine earthwork volumes within each balanced section
 - Determine whether there is an overall balance, waste or if borrow is required

Mass-Haul Diagram

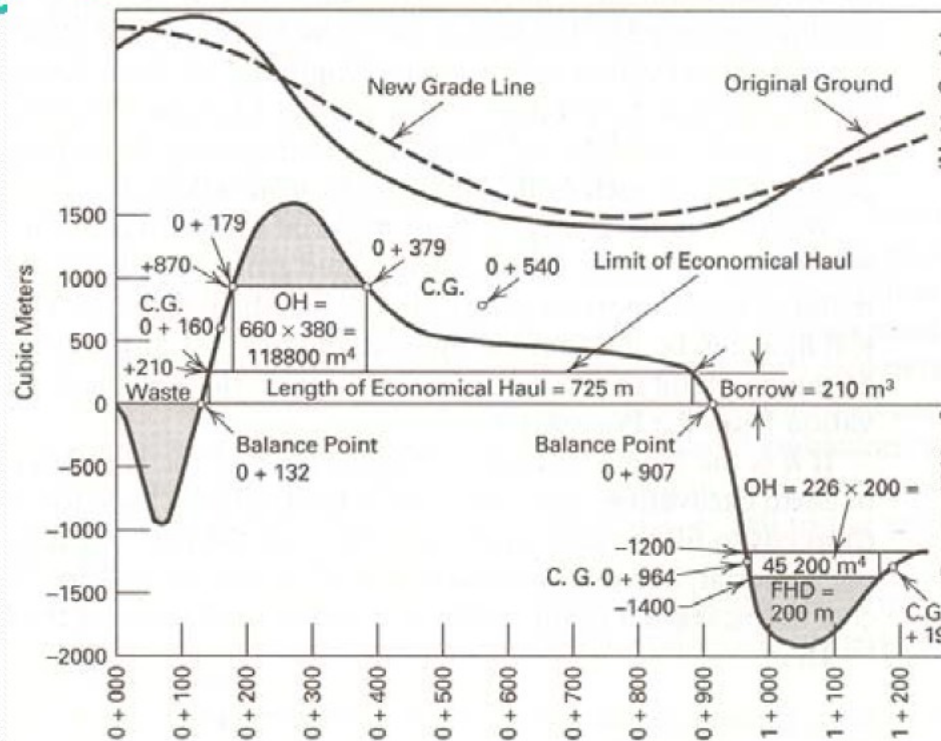


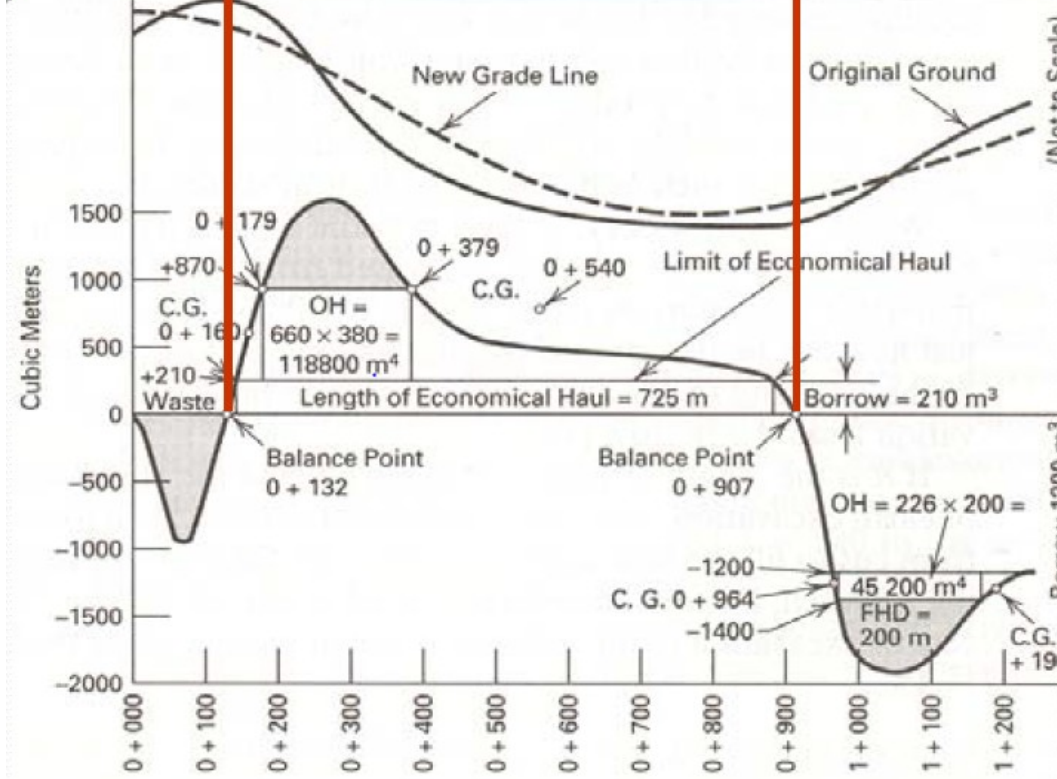
FIGURE 13-8 Example mass diagram. (NOTE: The numbers used here are for illustrative purposes only and may not be representative of values used in engineering practice.)

Between Stations 0 + 00 and 0 + 132, cut and fill equal each other, distance is less than FHD of 200 m

Note:
Figure NOT to scale!

Source: Wright, 1996

Mass-Haul Diagram



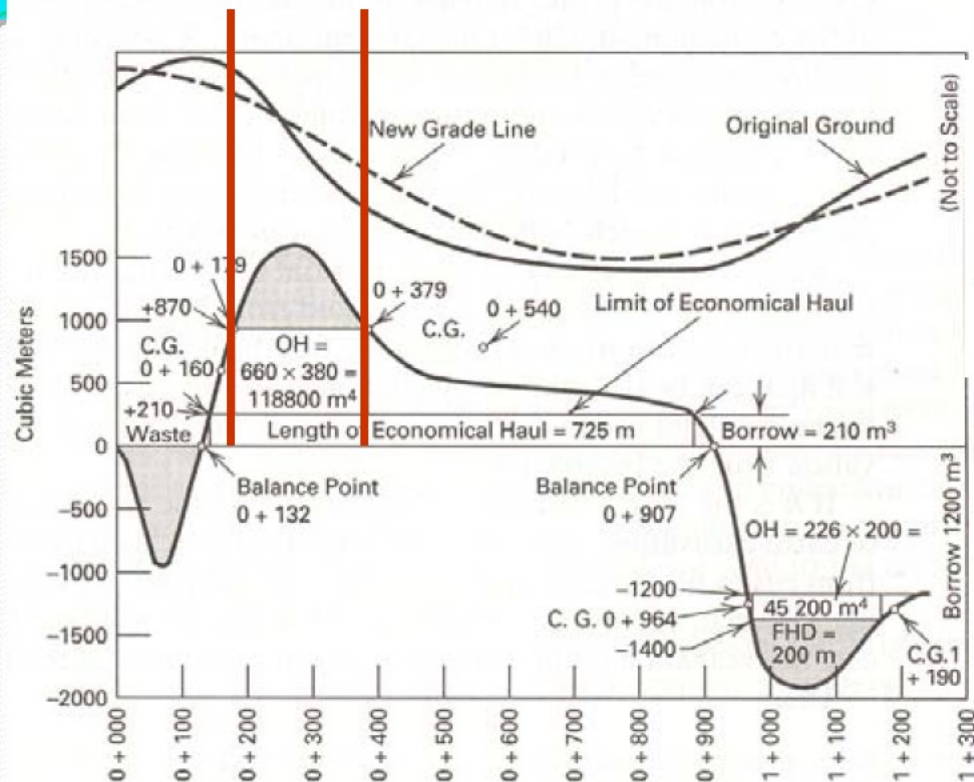
Between Stations 0 + 132 and 0 + 907, cut and fill equal each other, but distance is greater than either FHD of 200 m or LPH of 725 m

Distance =
 $[0 + 907] - [0 + 132] = 775$
 m

FIGURE 13-8 Example mass diagram. (NOTE: The numbers used here are for illustrative purposes only and may not be representative of values used in engineering practice.)

Source: Wright, 1996

Mass-Haul Diagram



Between Stations 0 + 179 and 0 + 379, cut and fill equal each other, distance = FHD of 200 m
Treated as **freehaul**

FIGURE 13-8 Example mass diagram. (NOTE: The numbers used here are for illustrative purposes only and may not be representative of values used in engineering practice.)

Source: Wright, 1996

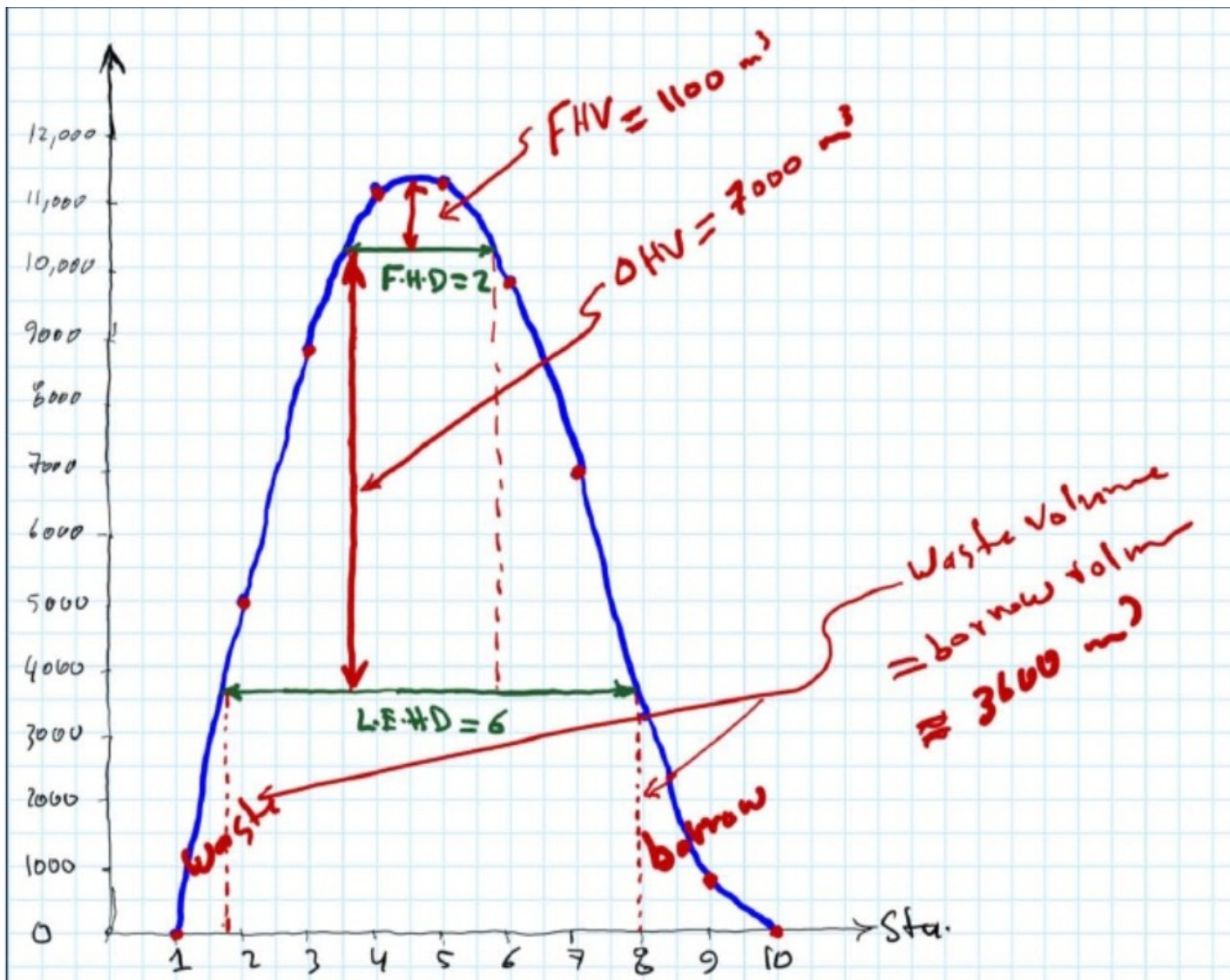
Earthwork

- Use of Mass-Haul Diagram
 - If mass haul is drawn for each trial grade line it can be used for selecting the most economical gradient which balance the cut and fill.
 - Once the formation level is designed, it can be used to indicate the most economical method of moving the earth around the project and a good estimate of the overall cost of the earth moving can be calculated.
 - The required volumes of material are known before construction begins enabling suitable plant and machinery to be chosen and sites for spoil heaps and borrows pits to be located and direction of haul to be established.

Sol.:

Sta.	A cut (m ²)	A fill (m ²)	V cut (m ³)	V fill (m ³)	V fill (corr)	Cum Vol (m ³)
1+00	57		5000	-	-	5000
2+00	43					
3+00	35	0	3900	-	-	8900
4+00	15	06	2500	200	220	11180
5+00	05	10	1000	800	880	11300
			167	1600	1760	9707
6+00	0	22	-	2600	2860	6847
7+00		30	-	3250	3575	3272

8+00		35	-	2250	2475	797
9+00		10	-	725	797	0
10+00		4.5				



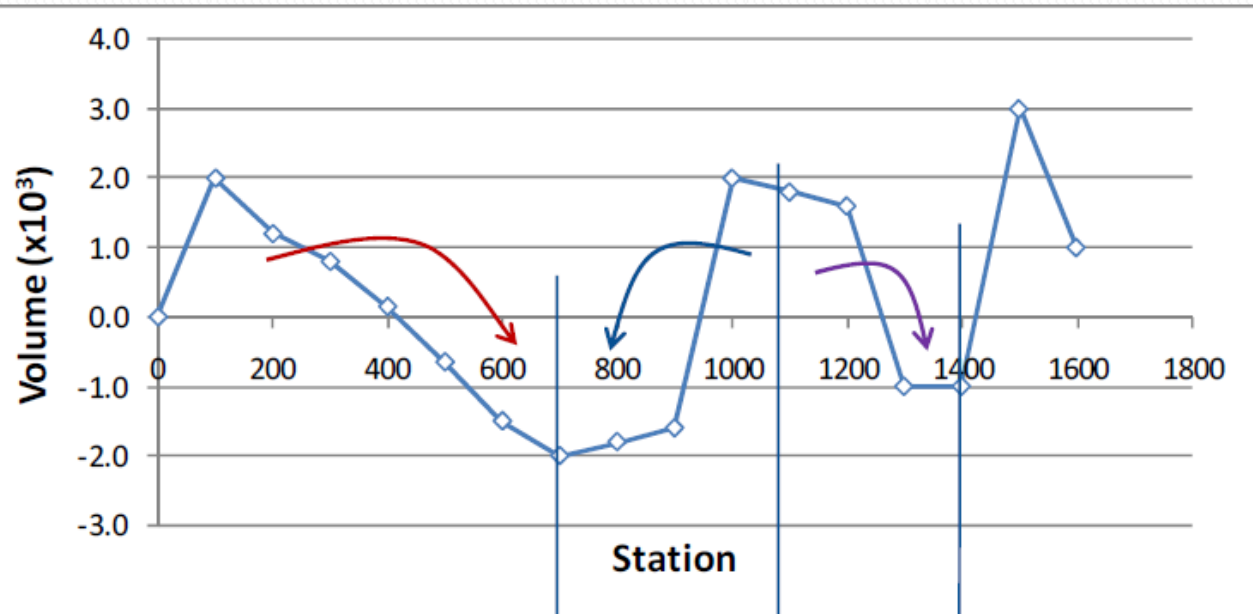
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- Example:
 - The tabulated data given below is the volume of cut and fill for a given road bed preparation.
 - Costs:
 Excavation $C_e = 3.00 \text{ Birr /m}^3$
 Borrow $C_b = 4.00 \text{ Birr /m}^3$
 Overhaul
 $C_{oh} = 1.35 \text{ Birr /m}^3 - \text{station}$
 $[1\text{-station} = 100 \text{ m}]$
 - FHD = 300 m
 - a) Draw the mass curve and the profile
 - b) Find out the total estimate of cost of the project

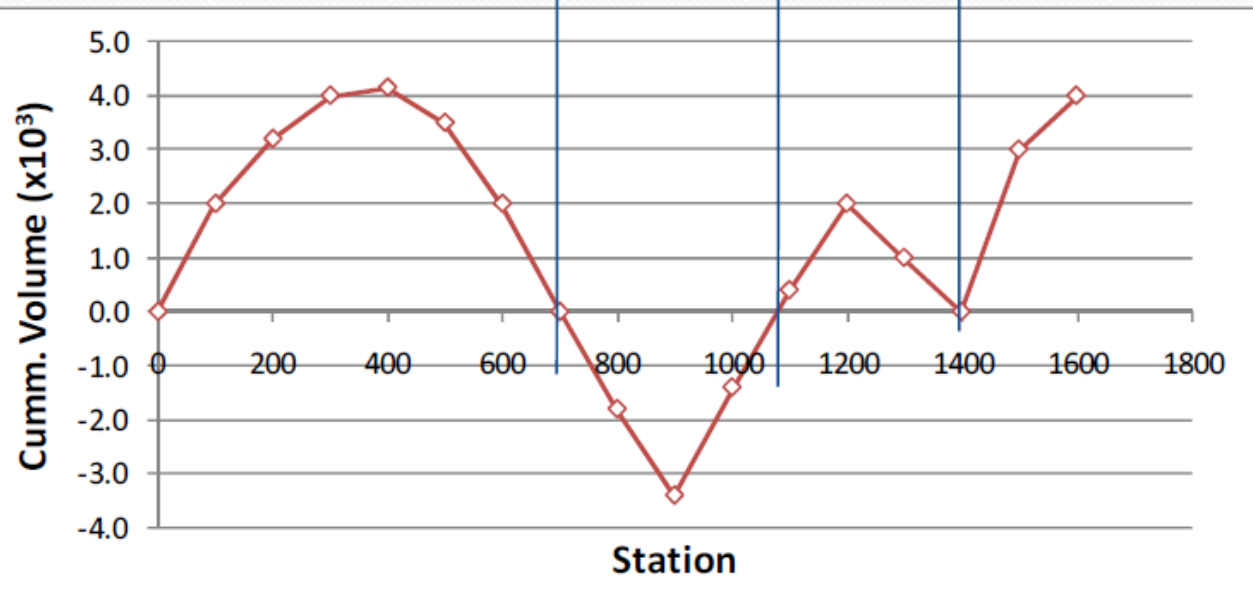
Station	Corrected Indiv. Volume (m^3) $\times 10^3$	
	Cut (+)	Fill (-)
0+000		
+100	2.00	
+200	1.20	
+300	0.80	
+400	0.15	
+500		0.65
+600		1.50
+700		2.00
+800		1.80
+900		1.60
1 + 000	2.00	
+100	1.80	
+200	1.60	
+300		1.00
+400		1.00
+500	3.00	
1 + 600	1.00	

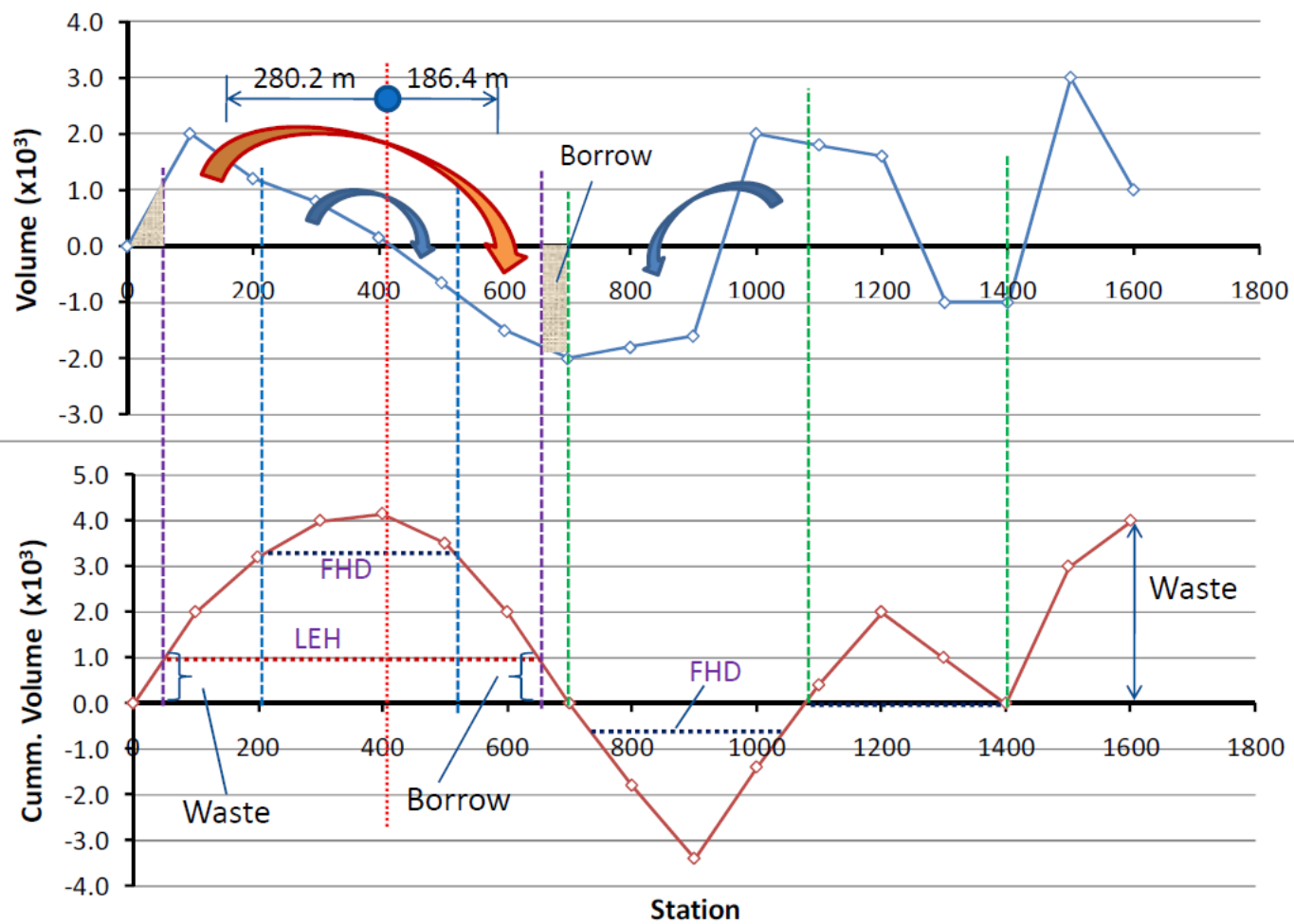
Earthwork

- Profile



- Mass-Haul diagram





Alternative 1

$$L_e = EOH = \frac{C_{bor}}{C_{oh}} = \frac{4.0 \text{ birr/m}^3}{1.35 \text{ birr/m}^3 - \text{sta}} = 3 \text{ stations} = 300 \text{ m}$$

$$LEH = EOH + FHD = 300 \text{ m} + 300 \text{ m} = 600 \text{ m}$$

1st loop :

Free haul distance, FHD = 300 m [line AB]

Limit of economic haul, LEH = 600 m [line CD]

Average economic hauling distance, AEHD = 4.7 stations = 470 m

Average over - haul distance, AOHD = 470 - 300 = 170 m (1.7 stations)

2nd loop :

Free haul distance, FHD = 300 m [line EF]

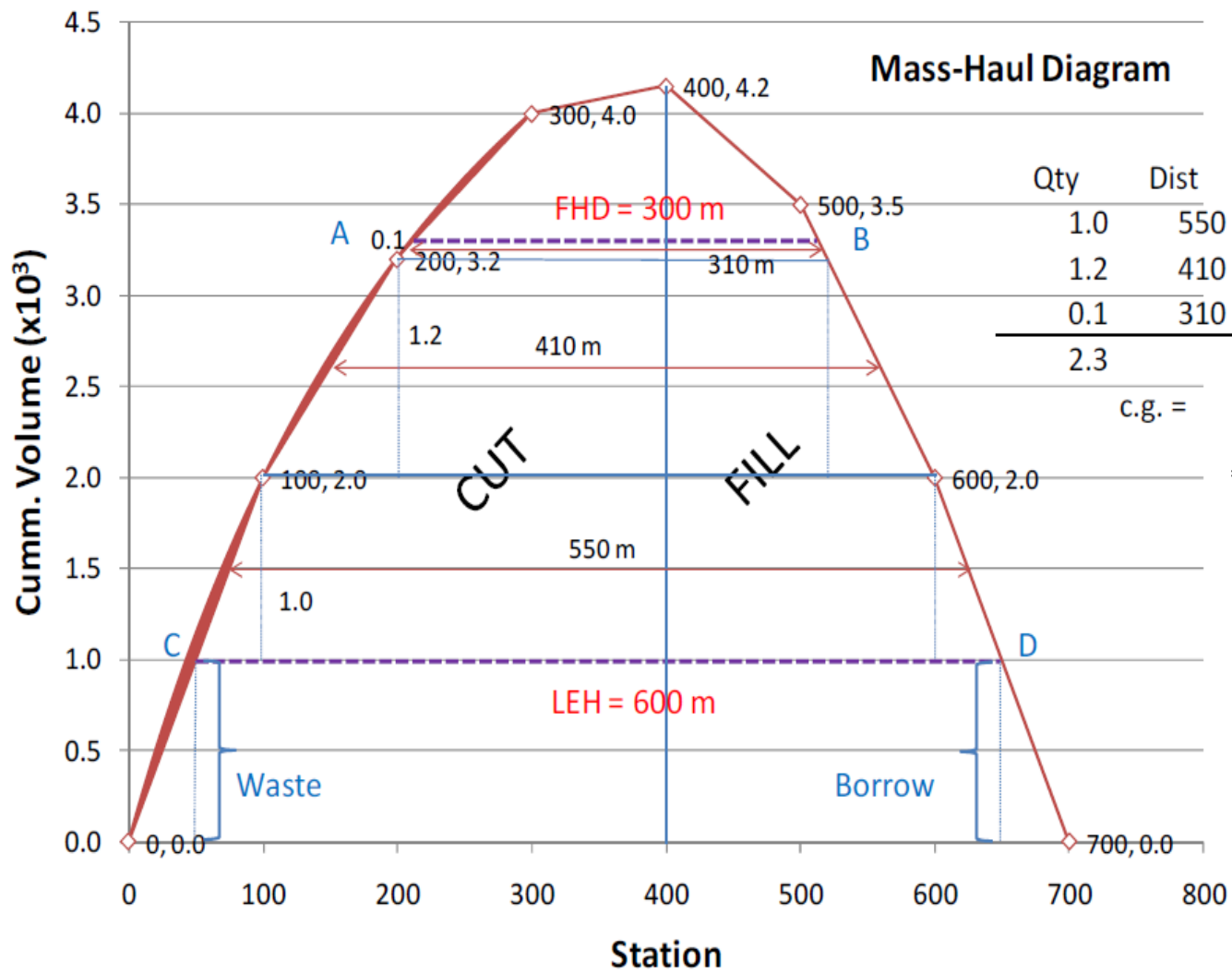
Limit of economic haul, LEH = 380 m [line GH]

Average economic hauling distance, AEHD = 3.4 stations = 340 m

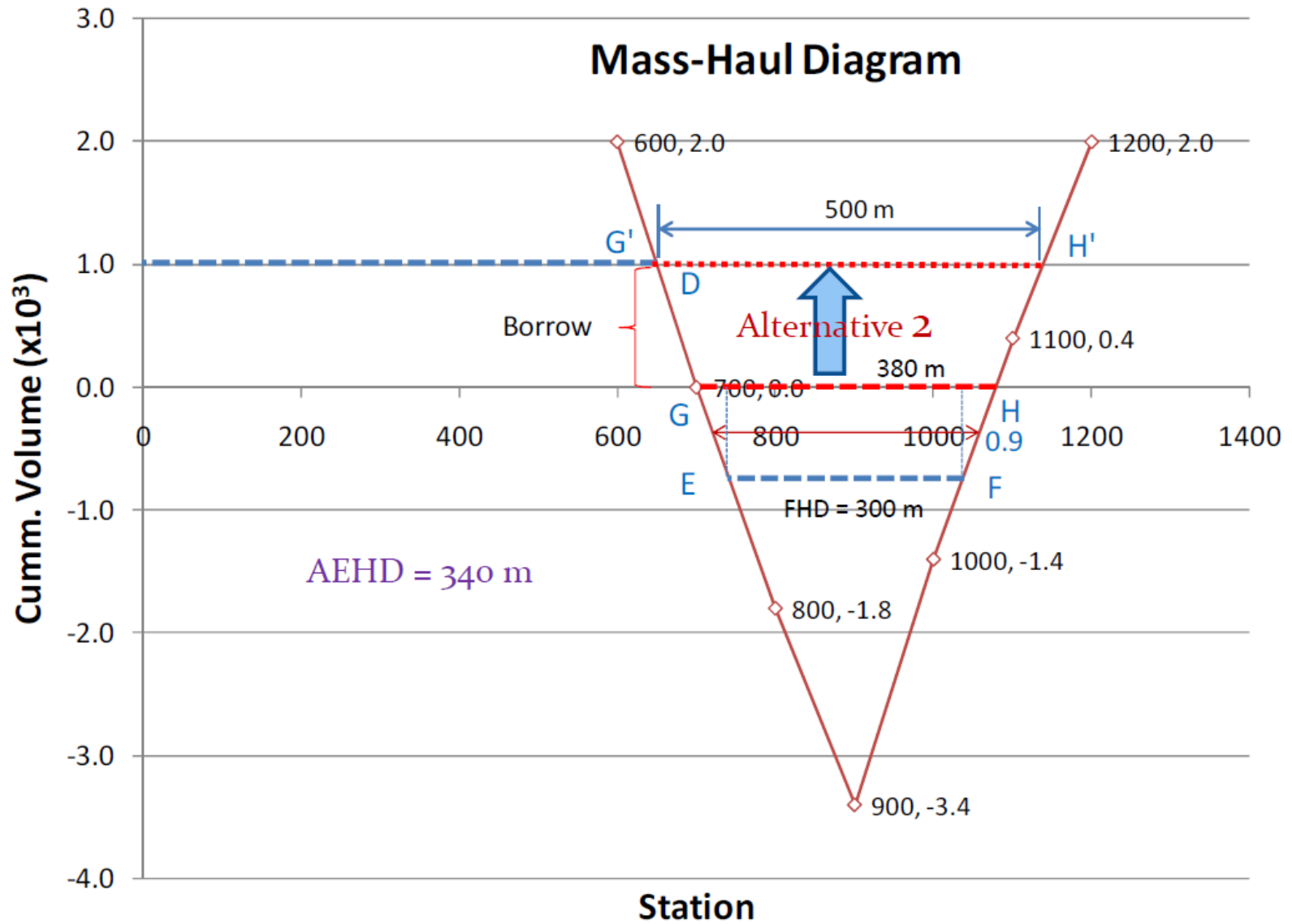
Average over - haul distance, AOHD = 340 - 300 = 40 m (0.4 station)

3rd loop : - No over hauling because the whole loop is with in free haul (< 3 station)

- The balance line is less than the free haul distance.



Mass-Haul Diagram



Earthwork

Cost summary

- Excavation cost

$$\begin{aligned} &= (4.15 + 3.4 + 2.0 + 4.0) \times 10^3 \text{ m}^3 \times 3.00 \text{ Birr/m}^3 \\ &= 40,650 \text{ Birr} \end{aligned}$$

- Borrow cost

$$\begin{aligned} &= 1.0 \times 10^3 \text{ m}^3 \times 4.00 \text{ Birr/m}^3 \\ &= 4,000 \text{ Birr} \end{aligned}$$

Total Cost

$$\begin{aligned} &= 40,650 + 4,000 + 5,765 \\ &= 50,415 \text{ Birr} \end{aligned}$$

- Overhaul cost

$$\begin{aligned} &= [1.7(3.3 - 1.0) + 0.5(0.9 - 0)] \times 10^3 \text{ m}^3 - \text{Sta} \times 1.35 \text{ Birr/m}^3 - \text{Sta} \\ &= 5,765 \text{ Birr} \end{aligned}$$

Alternative 2

1st loop :

Free haul distance, FHD = 300 m [line AB]

Limit of economic haul, LEH = 600 m [line CD]

Average economic hauling distance, AEHD = 4.7 stations = 470 m

Average over - haul distance, AOHD = 470 - 300 = 170 m (1.7 stations)

2nd loop :

Free haul distance, FHD = 300 m [line EF]

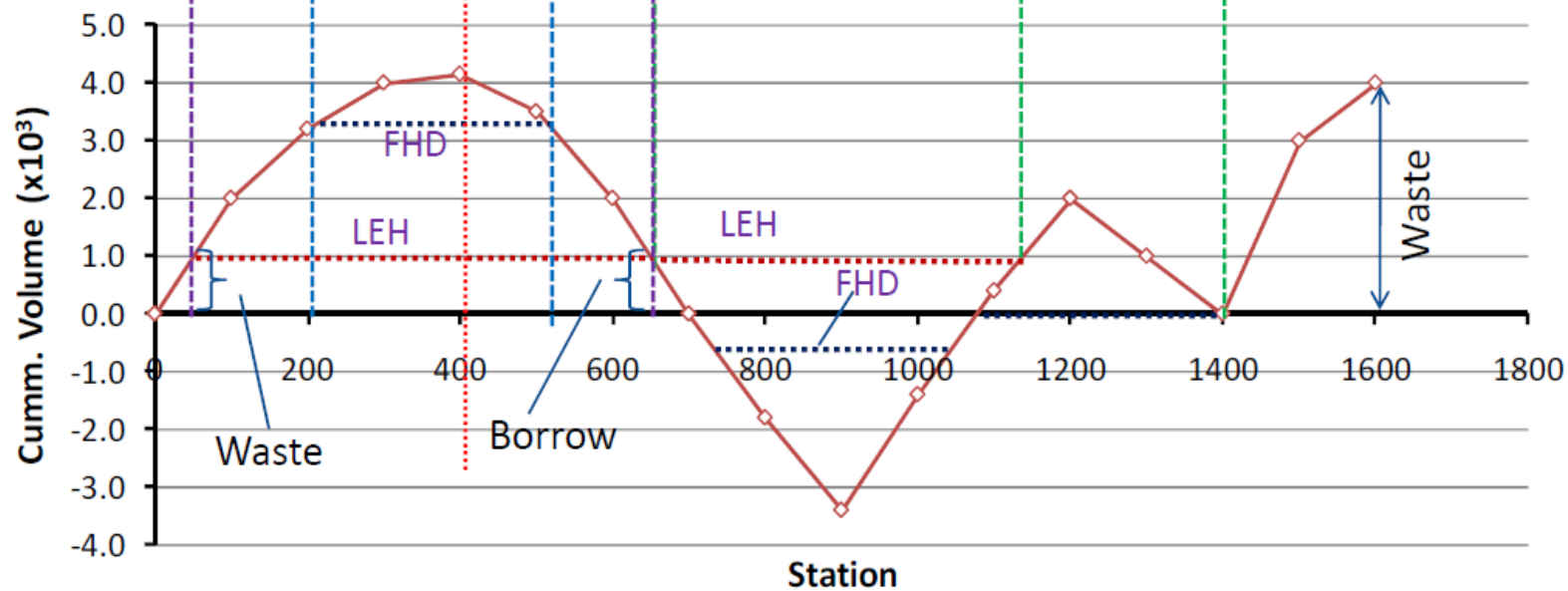
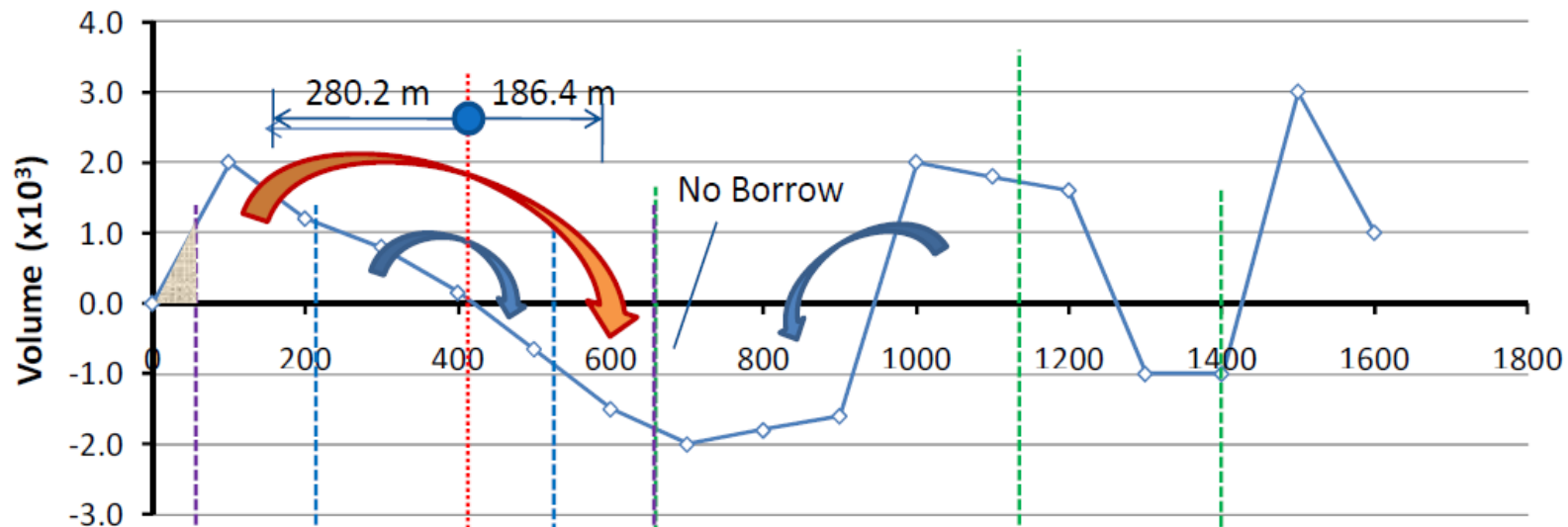
Limit of economic haul, LEH = 500 m [line G'H']

Average economic hauling distance, AEHD = 4.0 stations = 400 m

Average over - haul distance, AOHD = 400 - 300 = 100 m (1.0 station)

3rd loop :

- No over hauling because the whole loop is with in free haul (< 3 station)
- The balance line is less than the free haul distance.



Earthwork

Cost summary (Alternative 2)

- Excavation cost

$$\begin{aligned} &= (4.15 + 3.4 + 2.0 + 4.0) \times 10^3 \text{ m}^3 \times 3.00 \text{ Birr/m}^3 \\ &= 40,650 \text{ Birr} \end{aligned}$$

- Borrow cost

$$= 0 \quad (\text{No Borrow})$$

Total Cost

$$\begin{aligned} &= 40,650 + 0 + 7,844 \\ &= 48,494 \text{ Birr} \end{aligned}$$

- Overhaul cost

$$\begin{aligned} &= [1.7(3.3 - 1.0) + 1.0(1.0 - (-0.9))] \times 10^3 \text{ m}^3 - \text{Sta} \times 1.35 \text{ Birr/m}^3 - \text{Sta} \\ &= 7,844 \text{ Birr} \end{aligned}$$