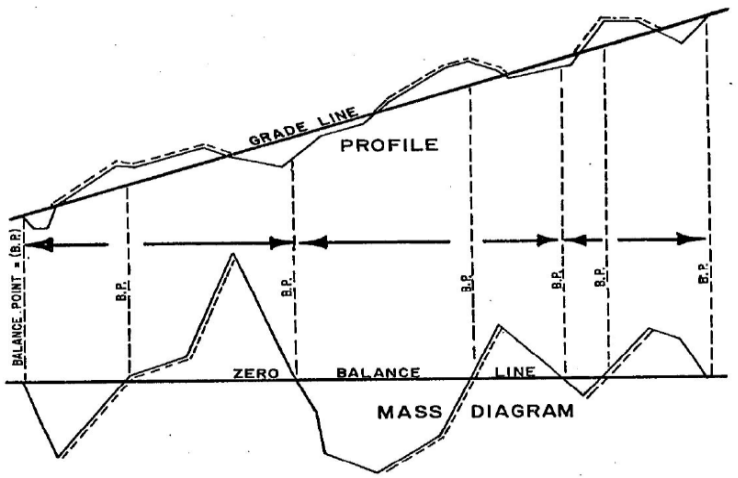

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Addis Ababa University
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SCHOOL OF CIVIL AND ENVIROMENT ENGINEERING

HIGHWAY ENGINEERING I
CENG 3202

Chapter IV
Highway Earth Work Quantities and Mass Haul Diagram

Tamru T.

2012EC (2019/20) 2nd Sem

Highway Grades and Terrain

- **Grade, Cut and Fill ---- Terrain**
- **Attempt to minimize amount of earthwork necessary**
  - Set grade line as close as possible to natural ground level
  - Set grade line so there is a balance between excavated volume and volume of embankment

Earthwork

- **Clearing, grubbing, roadway and drainage excavation,**
- **Excavation for structures, embankments, borrow, overhaul, machine grading, sub grade scarifying, rock fill,**
- **All the operations of preparing the sub grade foundation for highway or runway pavement.**

Earthwork calculation

- **Volume (m3) of excavation in its original position**

- **It uses field cross-sectional data**

Classification of Excavated Material

- **Common excavation: earth**
- **Loose rock: rock which can be removed with pick and bar**
- **Solid rock: comprises hard rock that can be removed only by the use of drilling and blasting equipment.**

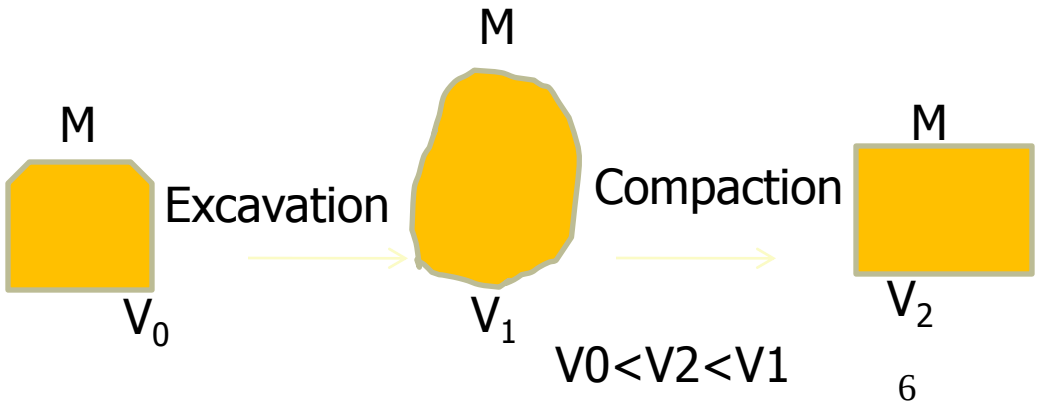
Cost Increases

Shrinkage

Percent shrinkage = (1 – (wt. bank measure / wt. compacted)) *100

% sh. = (1 – (γ_B / γ_C)) * 100

- **Material volume increases during Excavation**
- **Decreases during compaction**
- **Shrinkage factor 15 – 20%** Silty Clay, Sand
- **Varies with**
  - soil type
  - fill height
  - cut depth



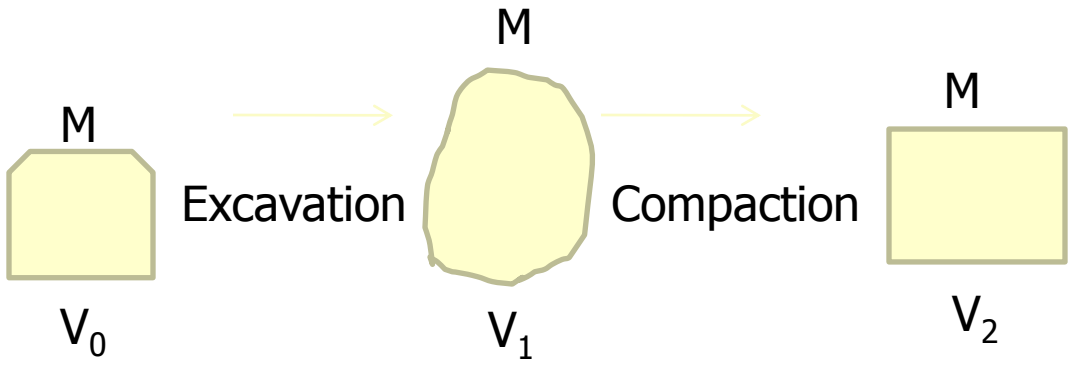
Swell

Percent swell = ((wt. bank measure / wt. loose measure) – 1) * 100

% sw. = $((\gamma_B / \gamma_L) - 1) * 100$

- **Excavated rock used in embankment occupies more space**
- **May amount to 30% or more**

Rock

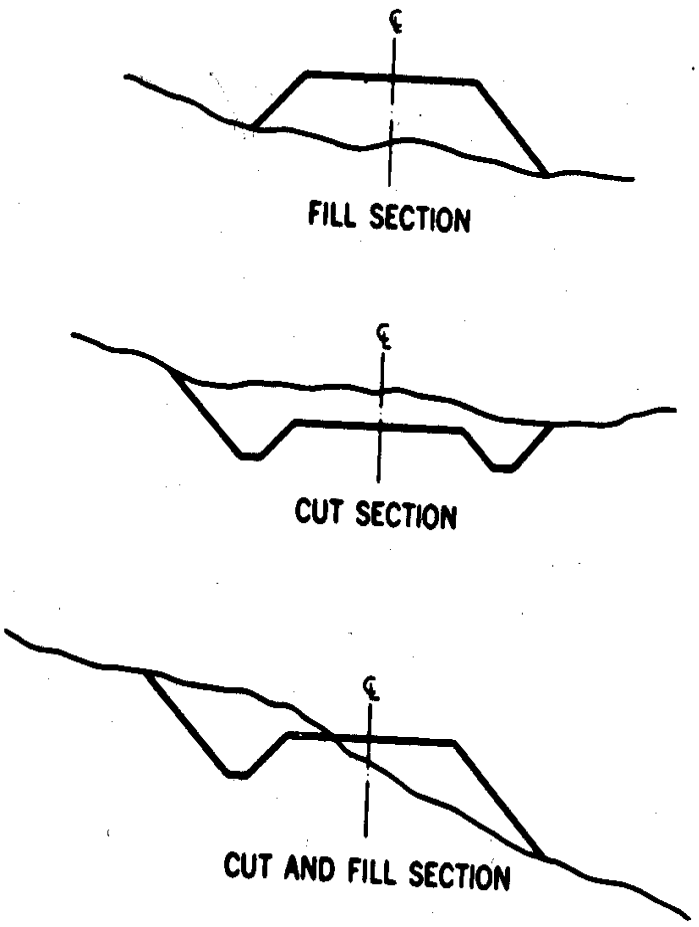


V2<V1
V2>V0

Steps in computation of earthwork quantities

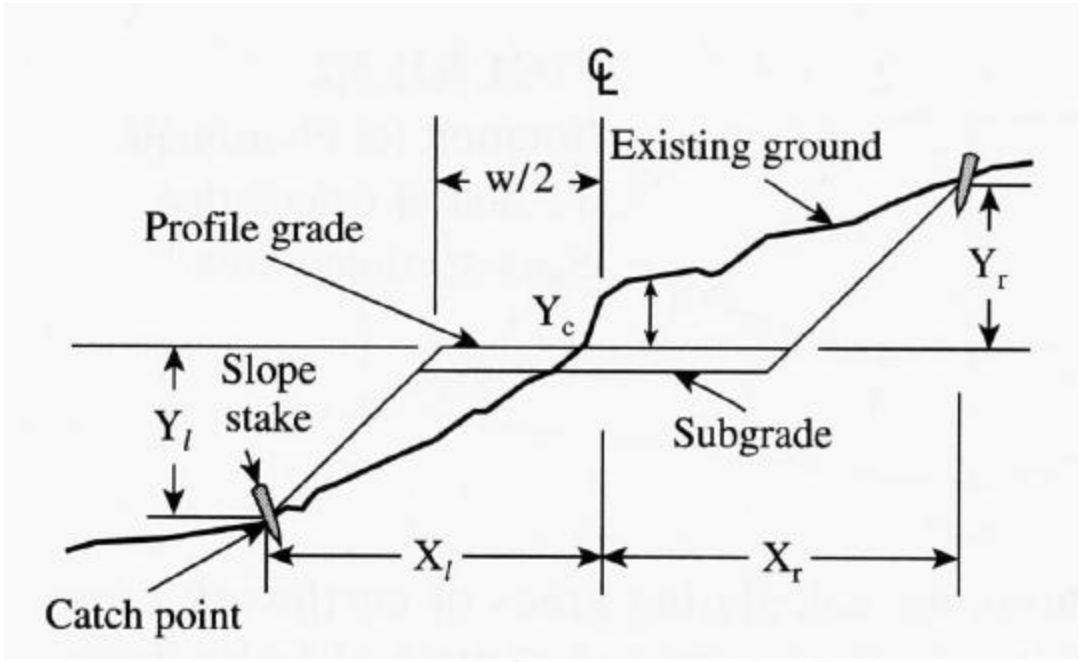
- **End area calculations**
- **Earthwork calculations**
- **Preparation of mass haul diagram**
- **Balancing earthworks using the mass haul diagram**

Cross-sections and templates



- **Each cross-section should show the location or station of the original ground section and template section, the elevation of the proposed grade at the station, and the areas of cut and fill for each section.**

Cross-Section Data Format



FY_l	CY_c	CY_r
X_l	0	X_r

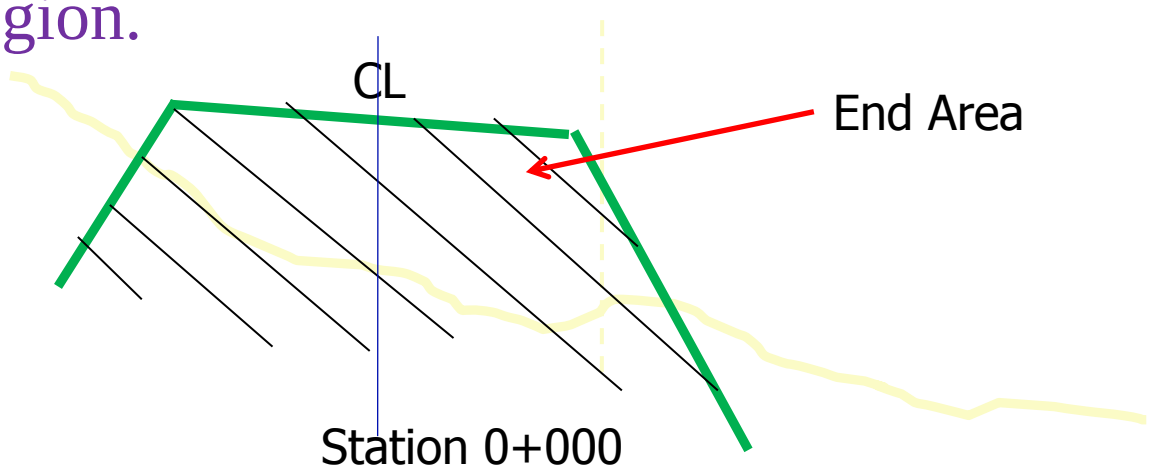
- **F – Fill**
- **C – Cut**
- **C_L – Center line**
- **X_r – Distance to the right CL**
- **X_l – distance to the leftof CL**
- **Y_c – height at the center**
- **Y_r – height at right**
- **Y_l – height at left**

End Area Calculation

- **Planimeter Method**
- **Mathematical Formula**
  - For level ground
  - For three level section
  - Coordinate method
- **Electronic Computer Method:** it employs the above methods using programs

Planimeter method

A small device called planimeter is used for measuring areas of a graphically represented planar region.

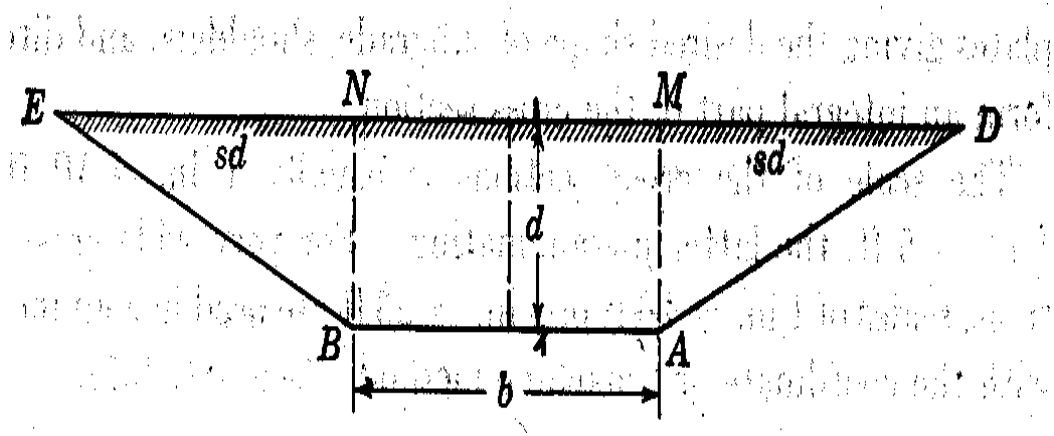


For example if your square is 300 square feet and the planimeter measures it as 1.5 square meter then

1 m2= 200 feet square

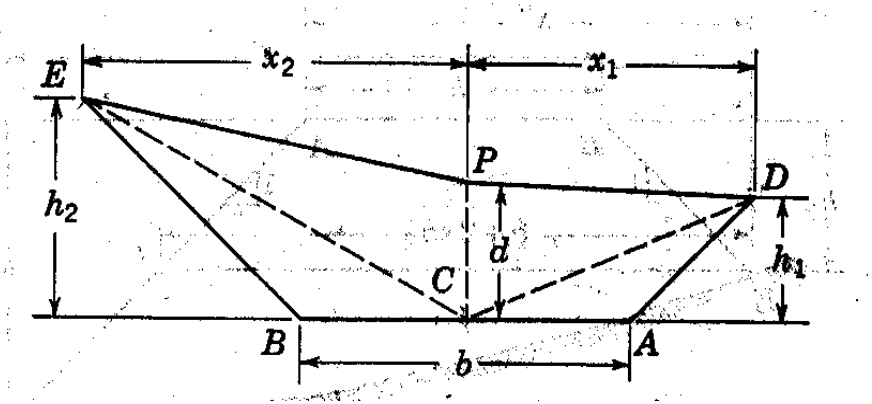
Thus multiplying the final reading of the planimeter in m2 by 2 will give you the reading in square feet.

End Area – for level ground

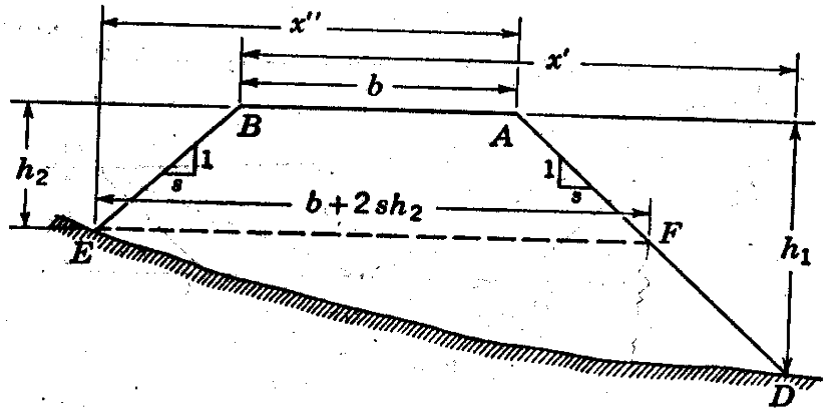


- **b = width of base AB**
- **d = center cut (or fill)**
- **s = slope of banks = MD / AM = NE / BN**
- **Area = d(b + sd)**

End Area - Three-Level Section



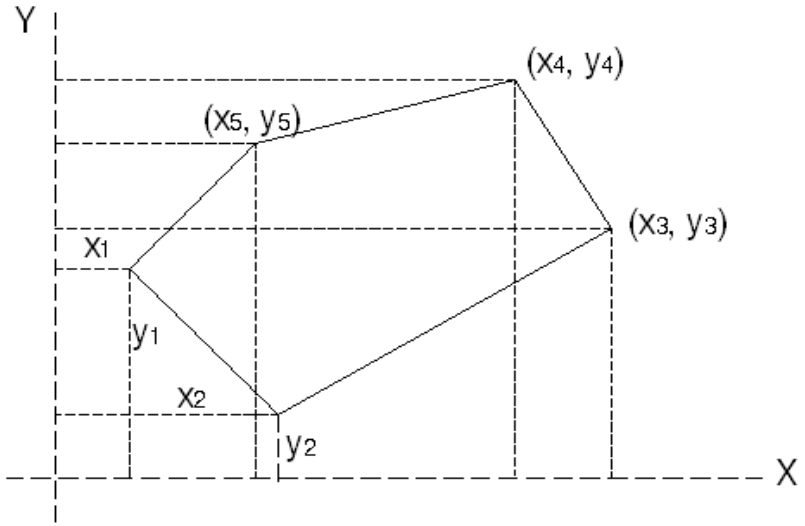
- **A = ½ [d(x1 + x2) + ½ b(h1 + h2)]**



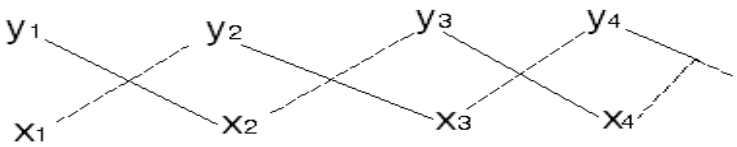
For uniform slope

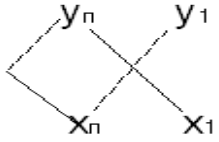
- **A = ½ (h1x'' + h2x')**

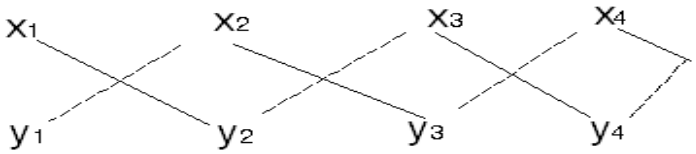
End Area – Coordinate Method

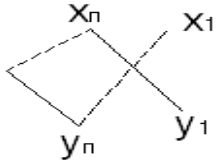


$$Areas = \frac{1}{2}\left[y_1(x_2 - x_n) + y_2(x_3 - X_1) + y_3(x_4 - x_2) + \ldots\ldots + y_n(x_1 - x_{n-1})\right]$$



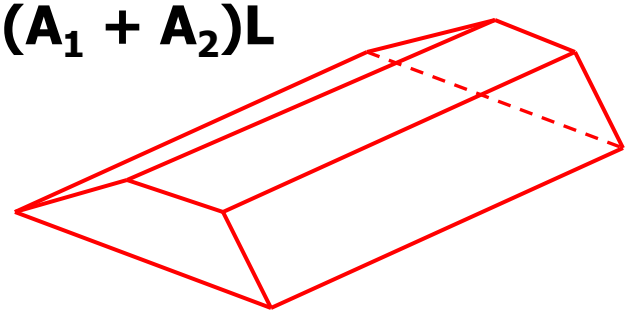




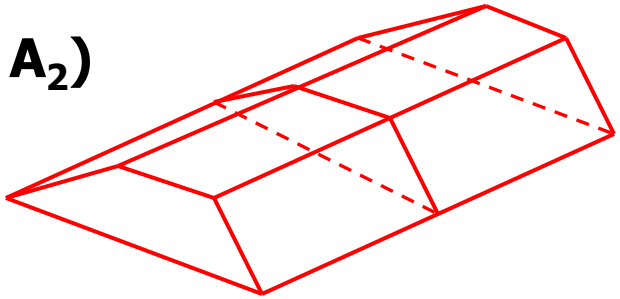


Volume of Earthwork

- **Average End Area Formula (Trapezoidal)**
  - **Volume = V = ½ (A_1 + A_2)L**



- **Presmoidal**
  - **V = L/6 (A_1 + 4A_m + A_2)**



Example 1

Given the end areas below, calculate the volumes of cut and fill between stations 351 + 00 and 352 + 50. If the material shrinks 12%, how much excess cut or fill is there?

	End areas, m^2	
Station	**Cut**	**Fill**
351 + 00		57.93
351 + 50		52.28
351 + 75	0	23.58
352 + 00	8.40	3.73
352 + 14	13.80	0
352 + 50	33.34	

Mass Haul Diagram

- The mass haul diagram is a curve in which the abscissas represent the stations of the survey and the ordinates represent the algebraic sum of excavation and embankment quantities from some point of beginning on the profile.
- The plot can be to any scale, depending on the quantities involved.
- The mass haul diagram shows excavation (adjusted) and embankment quantities from some point of beginning on the profile, considering cut volumes positive and fill volumes negative.
- At the beginning of the curve the ordinate is zero, and ordinates are calculated continuously from the initial station to the end of the project.

Uses of Mass Haul Diagram

- **The mass haul diagram can be used to determine:**
  - Proper distribution of excavated material
  - Amount and location of waste
  - Amount and location of borrow
  - Amount of overhaul in kilometre-cubic meters
  - Direction of haul.
  - Where to use certain types of equipment.

Definitions

- **Bulking:** An increase in volume of earthwork after excavation
- **Shrinkage:** A decrease in volume earthwork after deposition and compaction.
- **Haul distance (d):** The distance from the working face of the excavation to the tipping point.
- **Average haul distance (D):** The distance from the centre of gravity of the cutting to that of the filling.
- **Free haul Distance:** The distance, given in the Bill of Quantities, included in the price of excavation per cubic metre. (1000 – 2000 m)
- **Overhaul Distance:** The extra distance of transport of earthwork volumes beyond the free haul distance.

Definitions

- **Haul:** **The sum of the product of each load by its haul distance. This must equal the total volume of excavation multiplied by the average haul distance, i.e. Σ vd = VD**

- **Overhaul:** **The product of volumes by their respective overhaul distance. Excess payment will depend upon overhaul.**
- **Station Metre:** **A unit of overhaul, viz. 1 m3 x 100 m.**
- **Borrow:** **The volume of material brought into a section due to a deficiency.**
- **Waste:** **The volume of material taken from a section due to excess**

Calculation of MHD

- **Limit of Profitable (Economical) Haul (LEH):** **distance beyond which it is more economical to borrow or waste than to haul from the project**

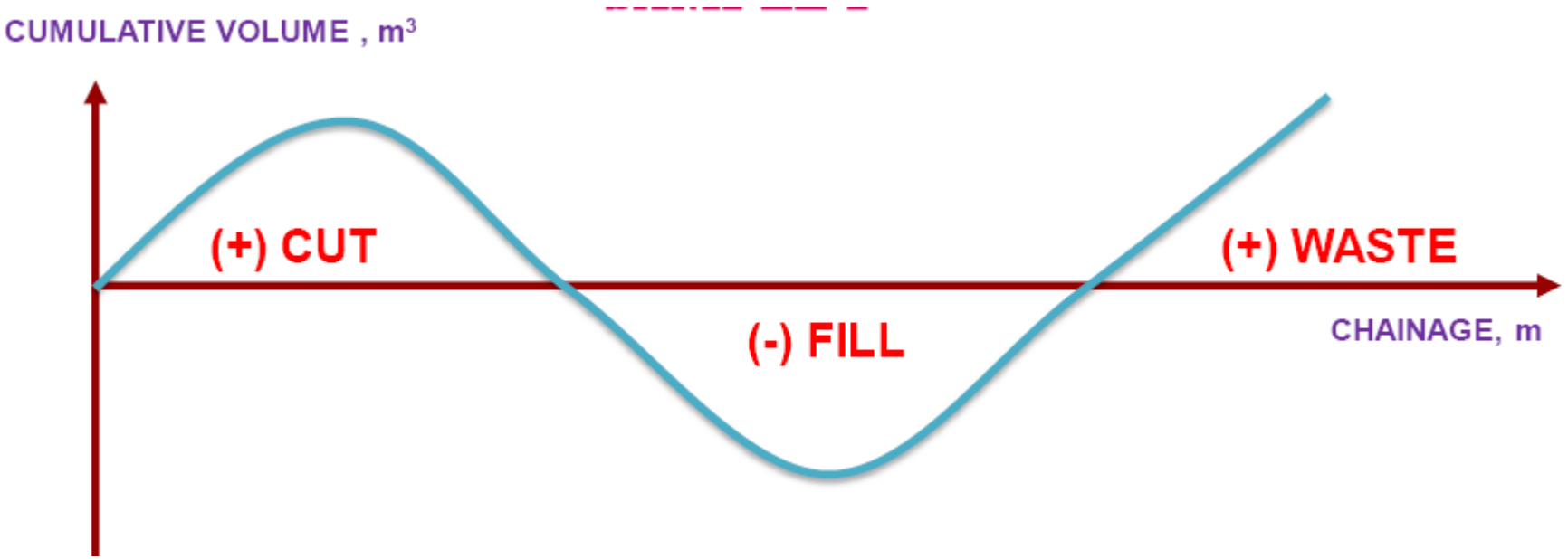
- **LEH = FHD + Ecomomic Overhaul distance**

- **= FHD + (Cost of Borrow / Cost of Overhaul)**

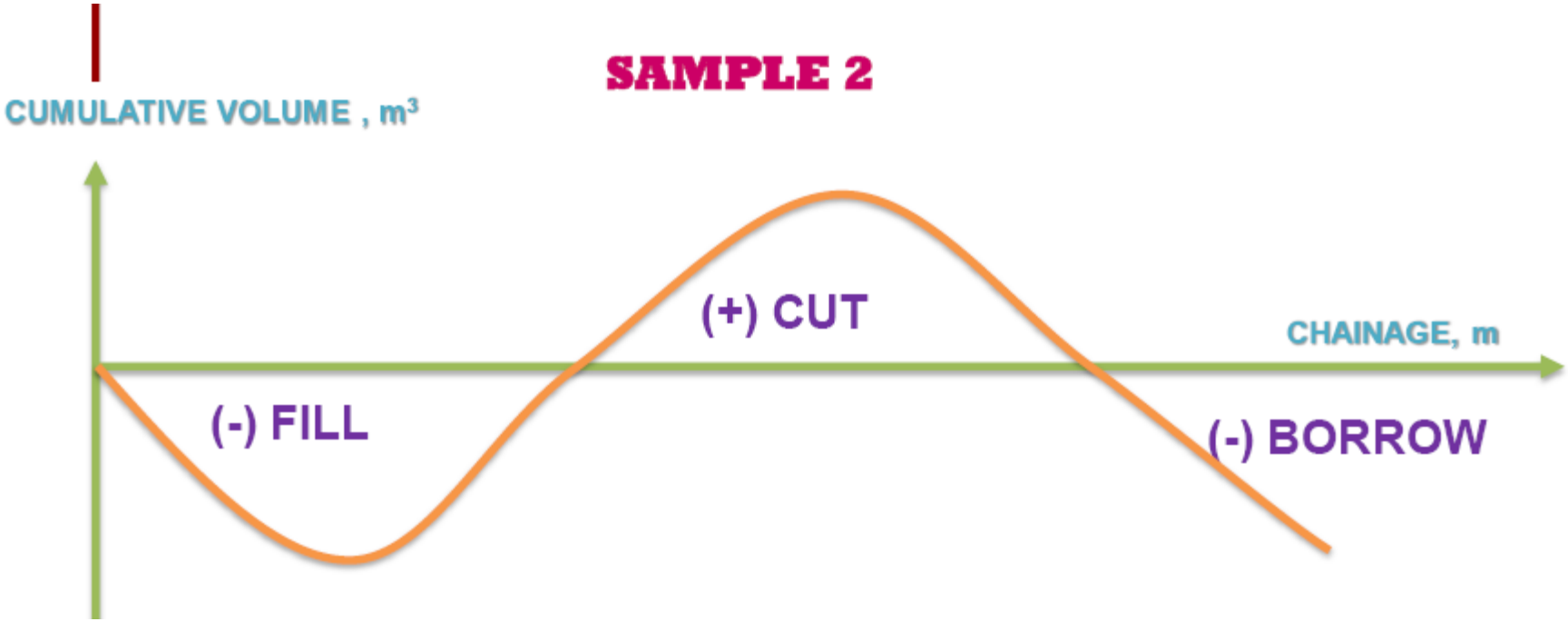
Mass Haul diagram

- **The cumulated volume of earthwork at the horizontal axis (Y=0) is 0**
- **When a horizontal line intersects two or more points along the curve, the accumulated volumes at those points are equal**
- **A negative value at the end of the curve indicates that borrow is required to complete the fill**
- **A positive value at the end of the curve indicates that a waste operation will be the net result**

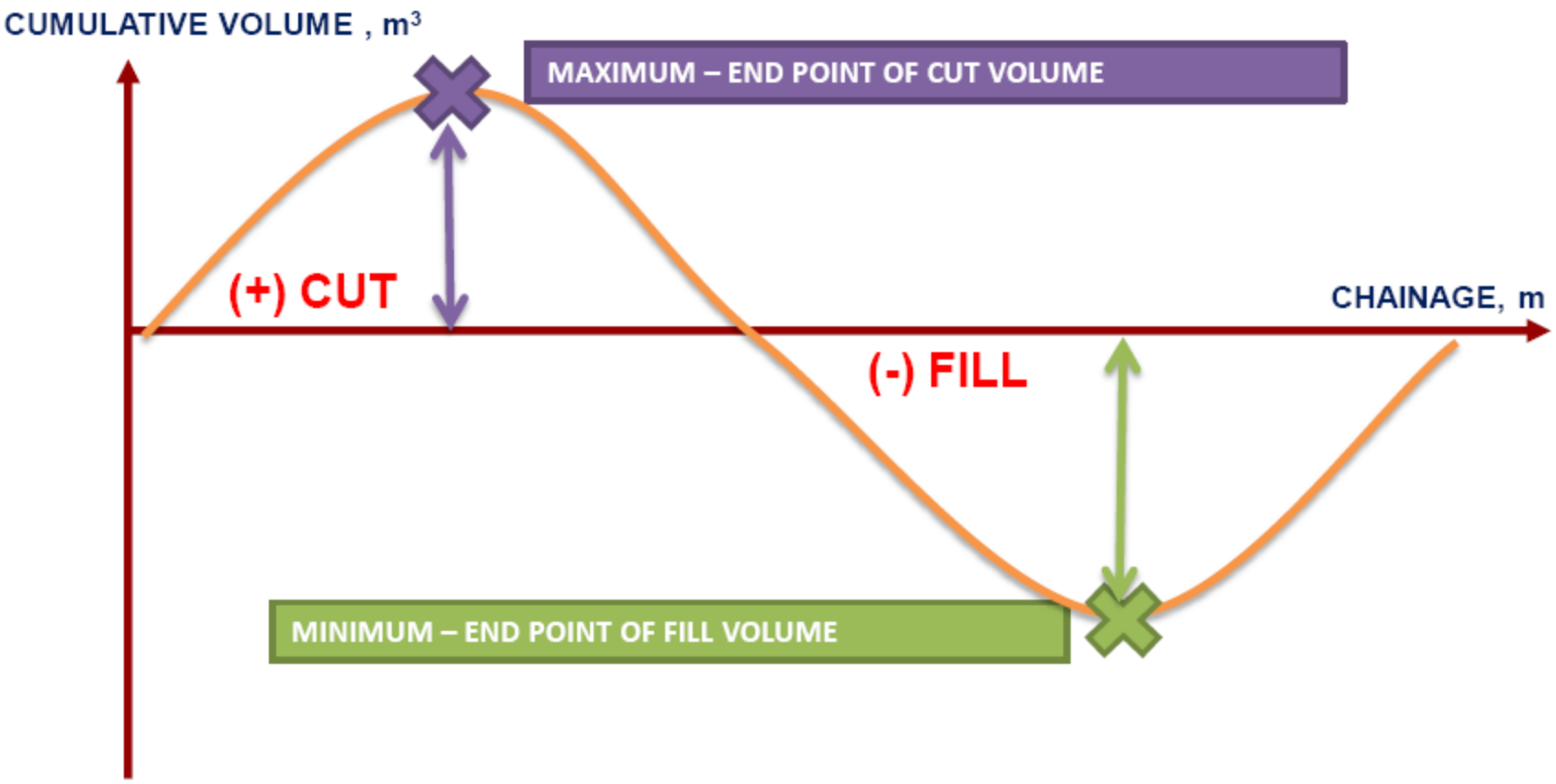
Mass Haul diagram



Mass Haul diagram



Mass Haul diagram



To construct the Mass Haul Diagram manually:

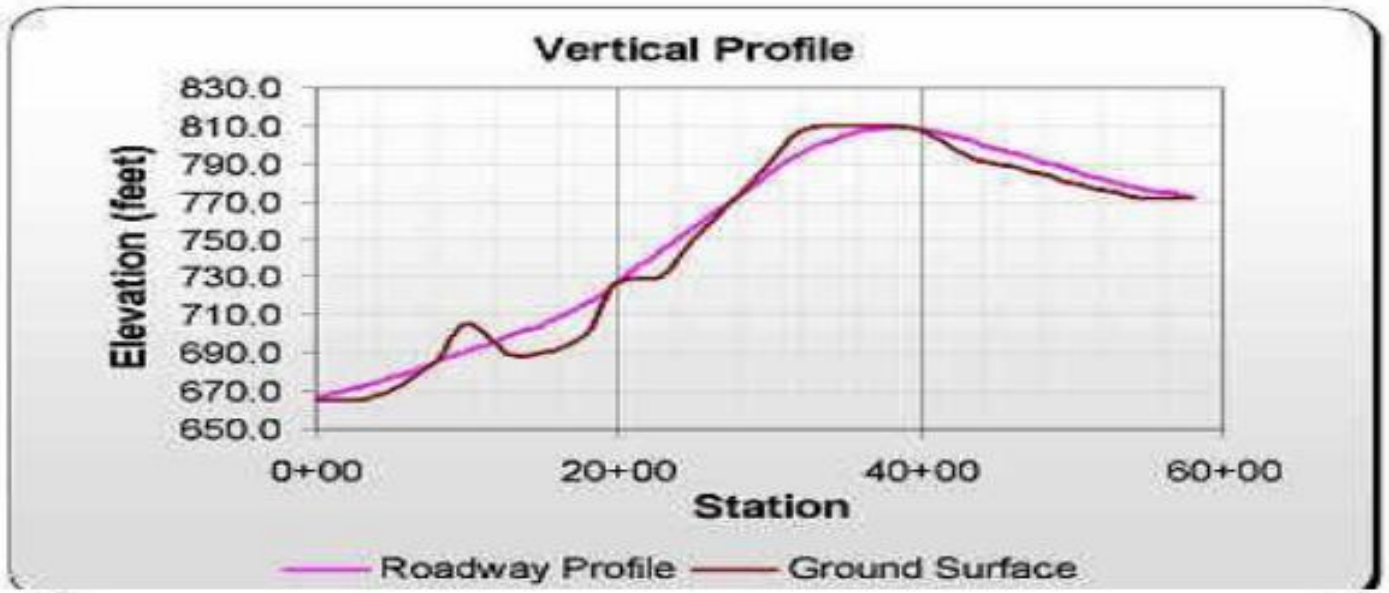
- **Compute the net earthwork values for each station, applying the appropriate shrink factor**
- **Net cuts have a positive value, net fills have a negative value**
- **The value at the first station (origin) = 0**
- **Plot the value of each succeeding station which equals the cumulative value to that point, i.e., the value at i = net cut/fill** $_{a+b+c+...i}$

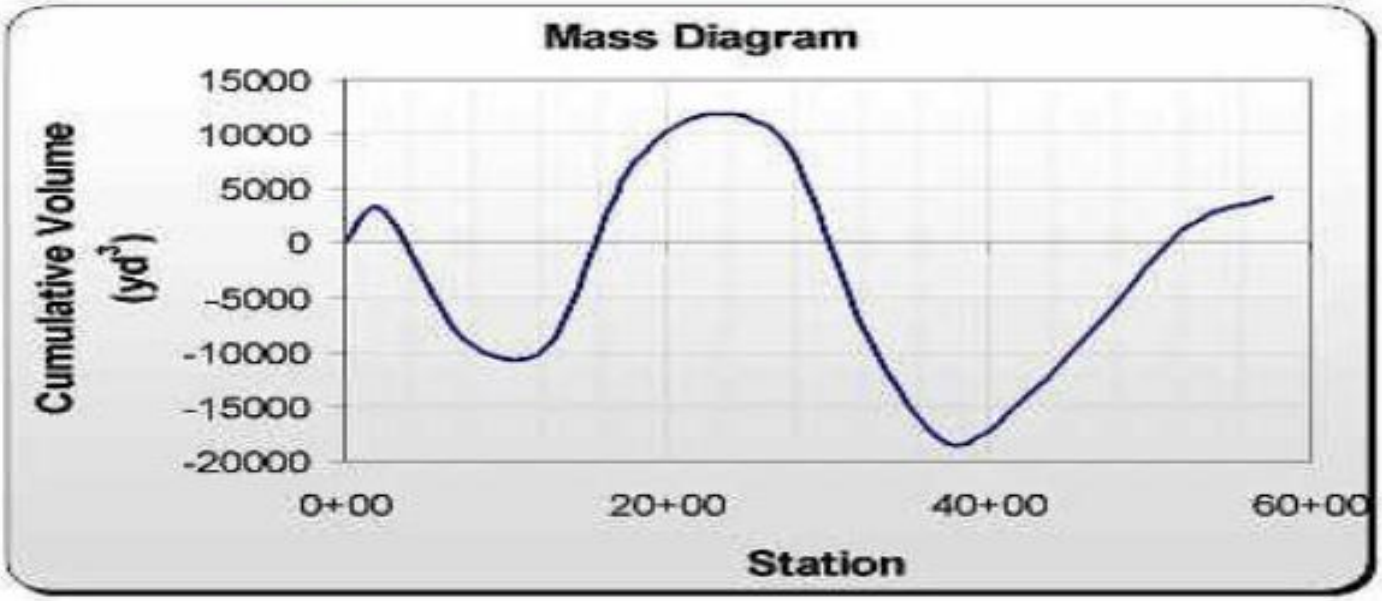
Example 2

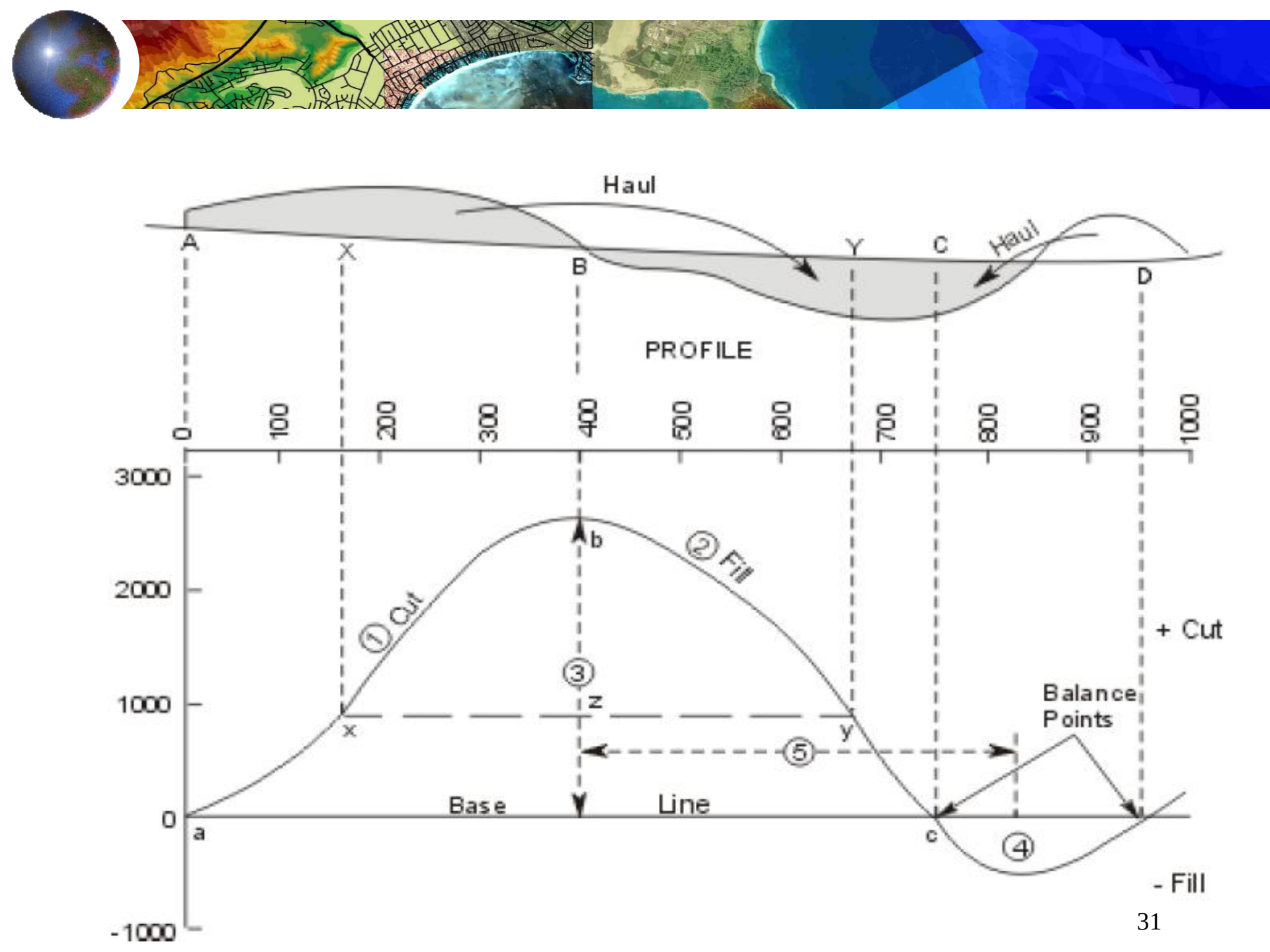
Distance (Metres)	Volume (Cubic Metres) CUT +	FILL -	Cumulative volume (Cubic Metres)
0			0
	+ 490		
100			+ 490
	+ 927		
200			+ 1 417
	+ 982		
300			+ 2 399
	+ 279		
380			+ 2 678
		- 31	
400			+ 2 647
		- 226	
500			+ 2 421
		- 654	
600			+ 1 767
		- 1 160	
700			+ 607
		- 933	
800			- 326
		- 92	
831			- 418
	+ 220		
900			- 198
	+ 428		
1 000			+ 230

Characteristics of Mass Curve

1. Rising sections of the mass curve indicates areas where excavating exceeds fill, whereas falling sections indicate where fill exceeds excavation.
2. Steep slopes reflect heavy cuts & Fills, while flat slopes indicate areas fro small amount of earthwork.
3. The difference in ordinates between any two points indicate net excess of excavation over embankment or vies versa.
4. Any horizontal line dawn to intersect two points within the same curve indicates a balance of excavation (cut) and embankment (fill) quantities between the two points.
5. Points of zero slope represent points where roadway goes from cut to fill or from fill to cut.
6. The highest or the lowest points of the mass haul diagram represents the crossing points between the grade line (roadway level) and natural ground level.


Vertical Profile
830.0
810.0
790.0
770.0
750.0
730.0
710.0
690.0
670.0
650.0
Elevation (feet)
0+00
20+00
40+00
60+00
Station
Roadway Profile
Ground Surface

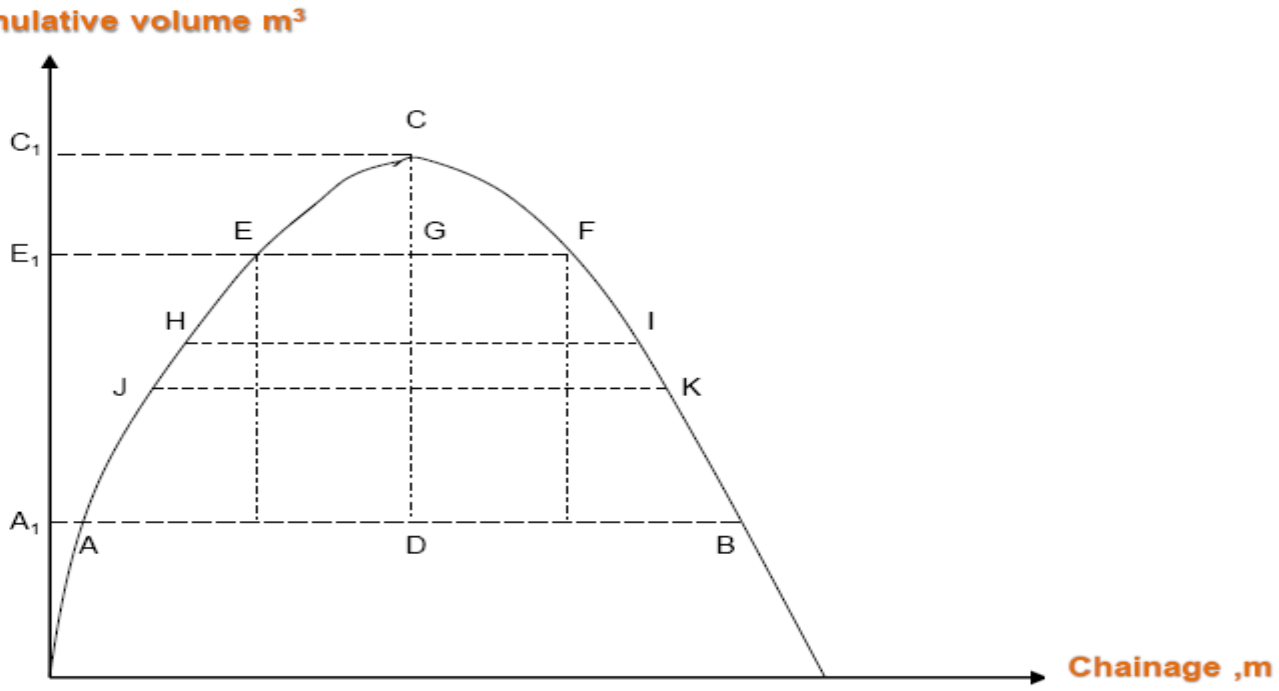

Mass Diagram
15000
10000
5000
0
-5000
-10000
-15000
-20000
Cumulative Volume
(yd3)
0+00
20+00
40+00
60+00
Station


Haul
A
X
B
Y
C
Haul
D
PROFILE
0
100
200
300
400
500
600
700
800
900
1000
3000
2000
1000
0
-1000
b
① Cut
② Fill
③
z
x
y
⑤
Base
Line
a
c
④
+ Cut
Balance
Points
- Fill

Analysis of MHD

- **Identify the resulting balanced sections, which are bounded by points that intersect the X-axis**
- **Draw a horizontal line midway between the peak or valley and the X-axis. The scale length of that line 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**

Analyze the MHD

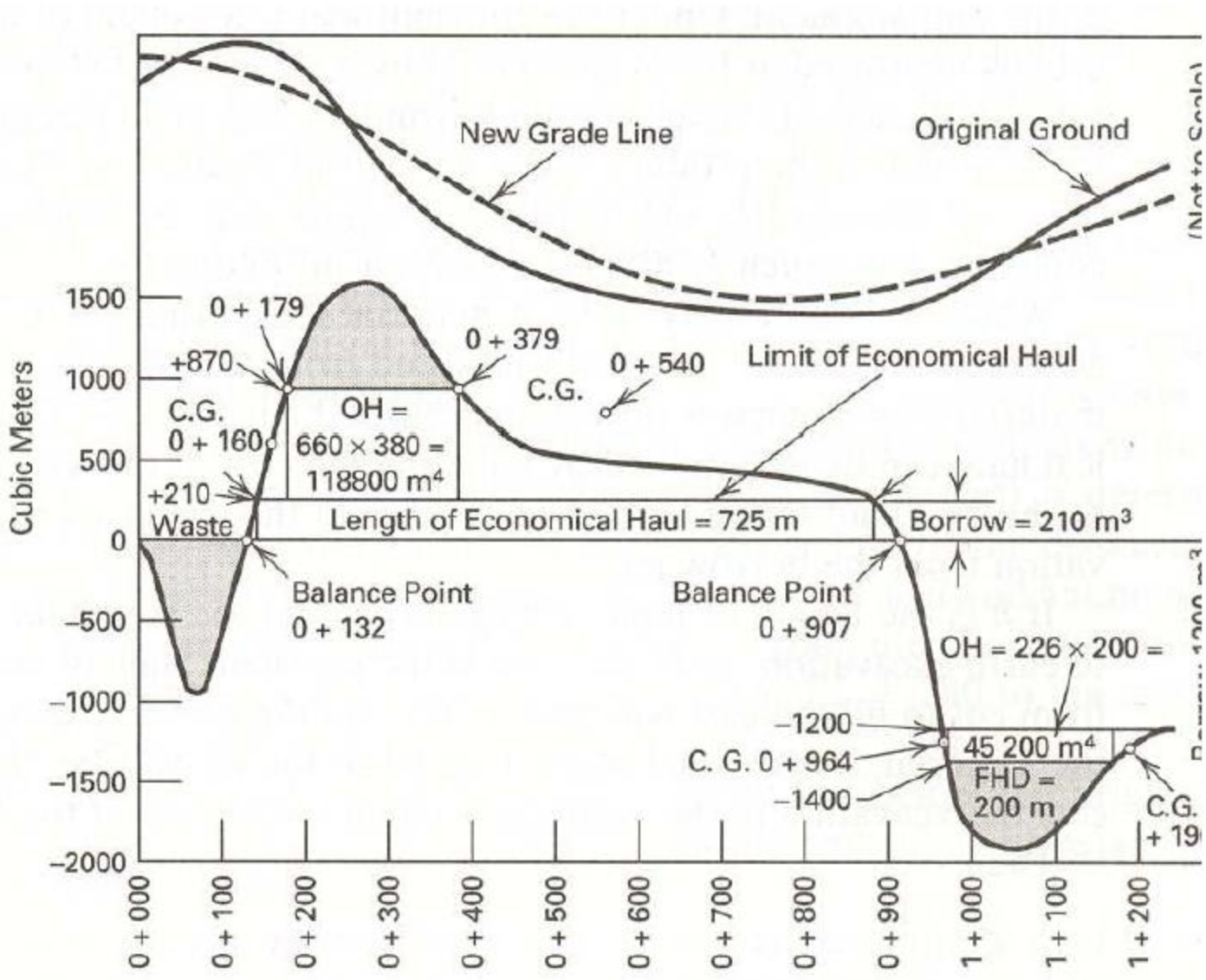


From the graph,

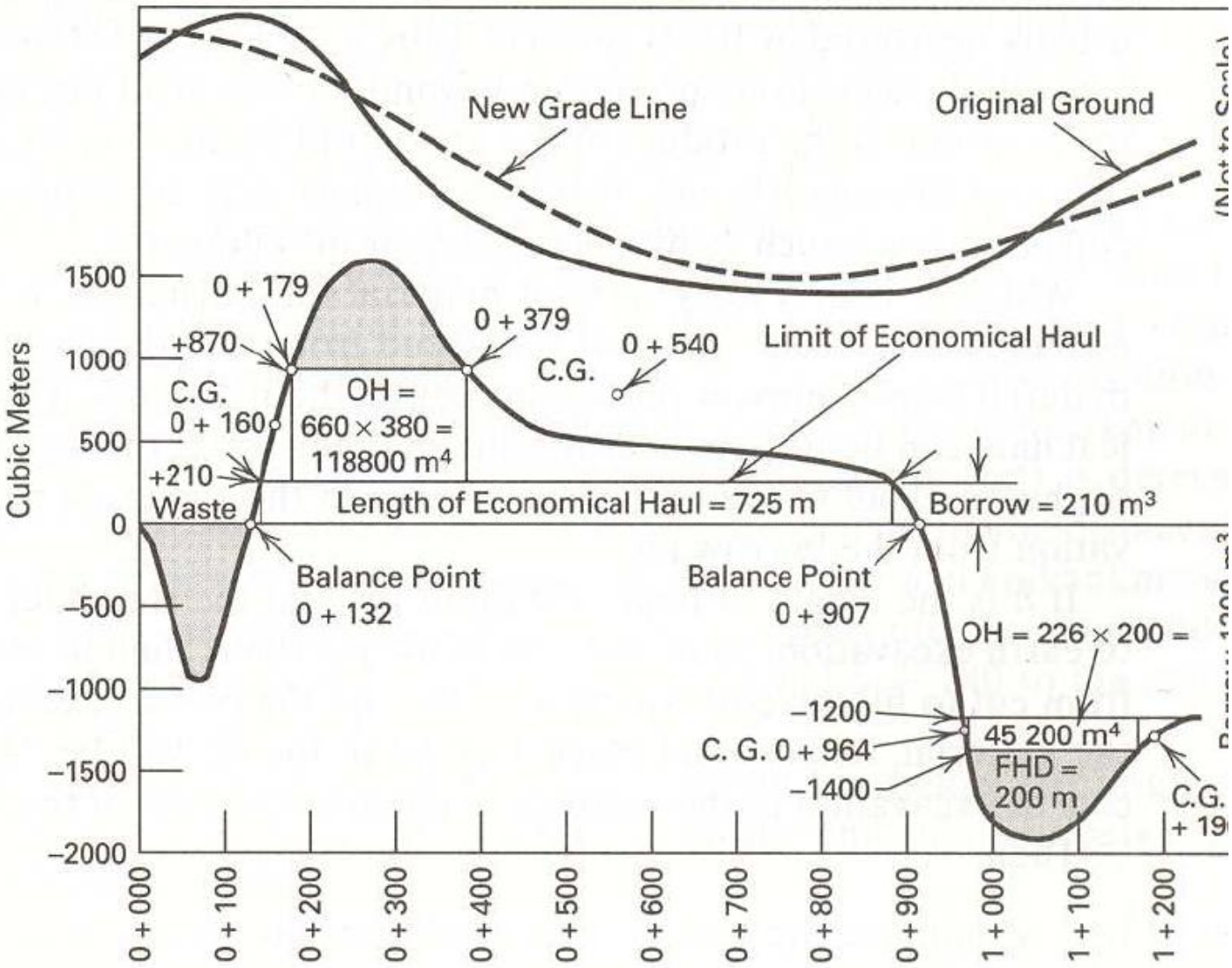
Line	Description
EF	Freehaul distance
CG	Freehaul volume
CD	Haul volume
HI	Average haul distance – centre line of CD
GD	Overhaul volume
JK	Average overhaul distance - centre line of GD

Calculation of total cost of earthworks:

- **Cost of free haul = cost of free haul per m3 * Volume of free haul.**
- **Cost of borrow = cost of borrow per m3 * Volume of borrow.**
- **Cost of waste = cost of waste per m3 * Volume of waste.**
- **Cost of overhaul = [cost of free haul per m3 * volume of overhaul] + [cost of free haul per m3.station * volume of overhaul * {average hauling distance-free haul distance}].**

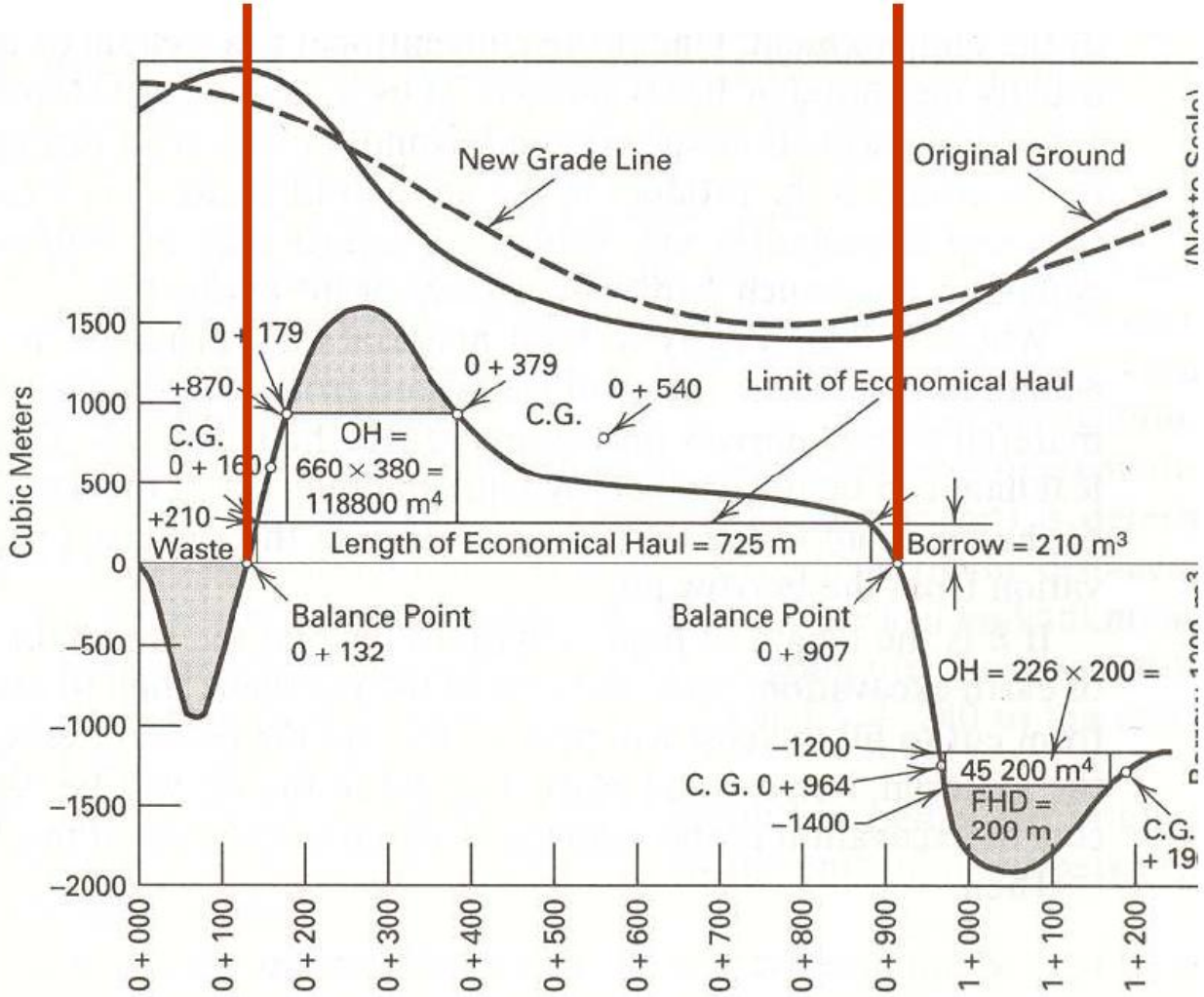


Assumption:
FHD = 200 m
LEH = 725 m



Between Stations

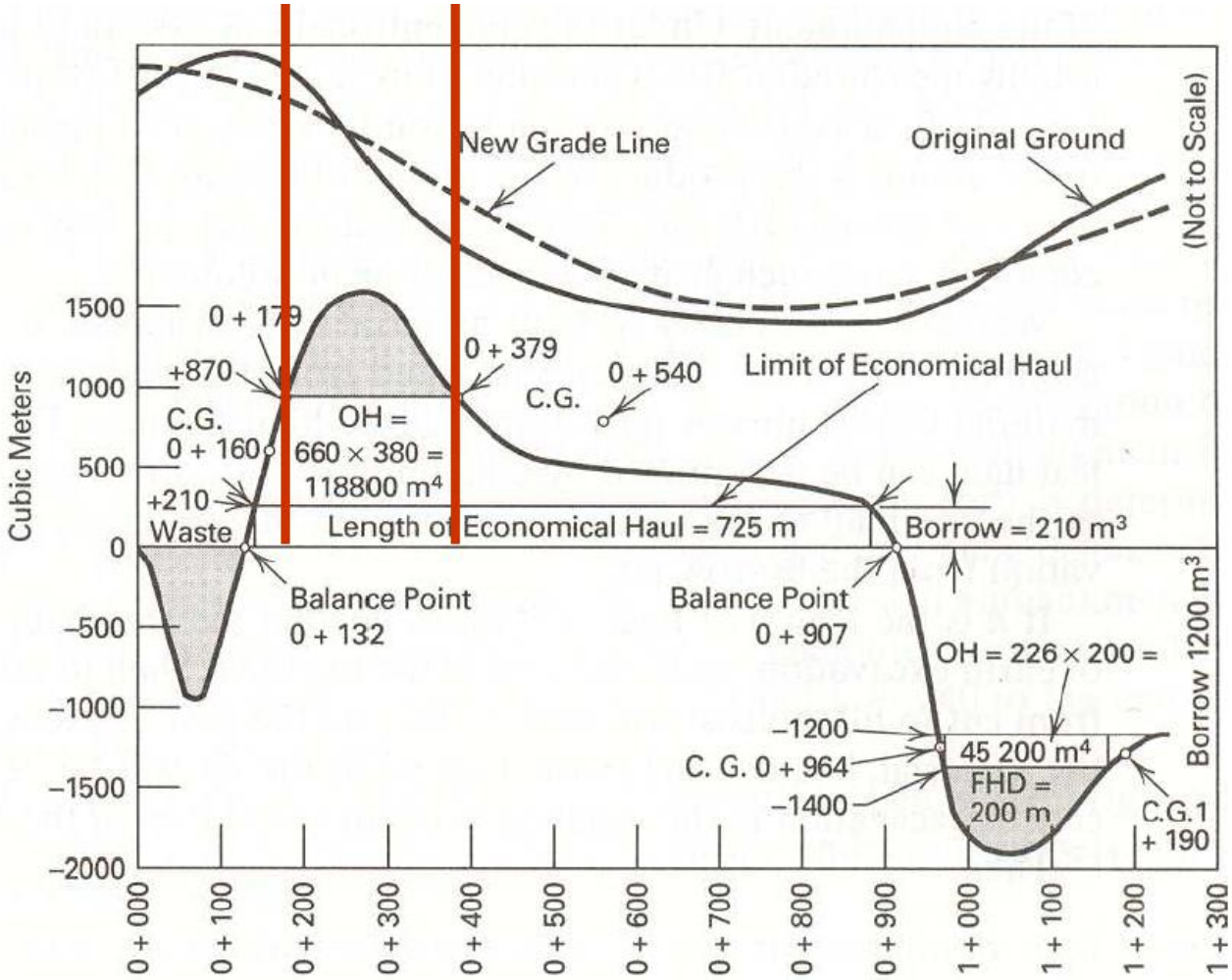
0 + 00 and 0 + 132, cut and fill equal each other, distance is less than FHD of 200 m



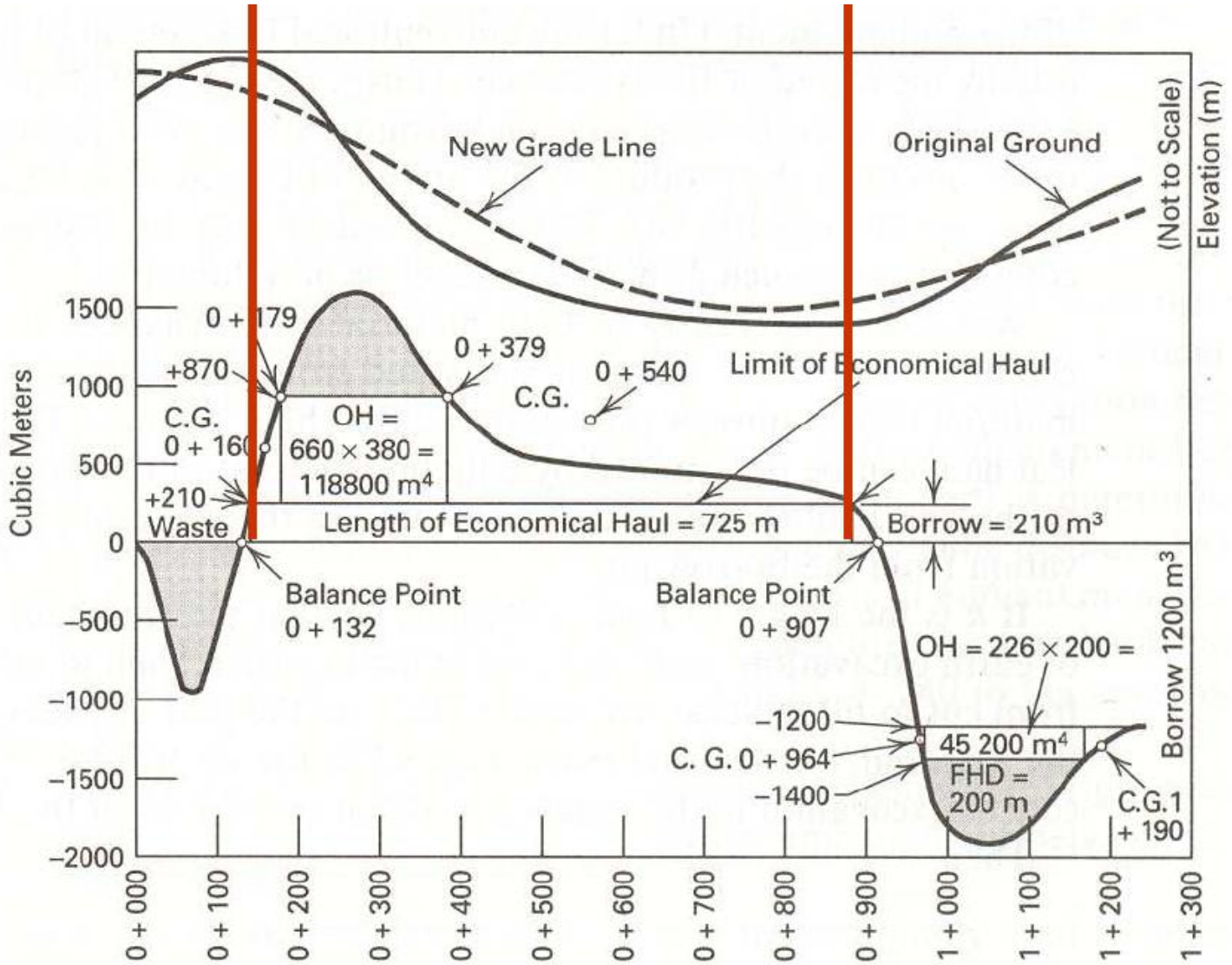
Between Stations 0 + 132 and 0 + 907, cut and fill equal each other, but distance is greater than either FHD of 200 m or LPH of 725 m

Distance =

[0 + 907] – [0 + 132] = 775 m



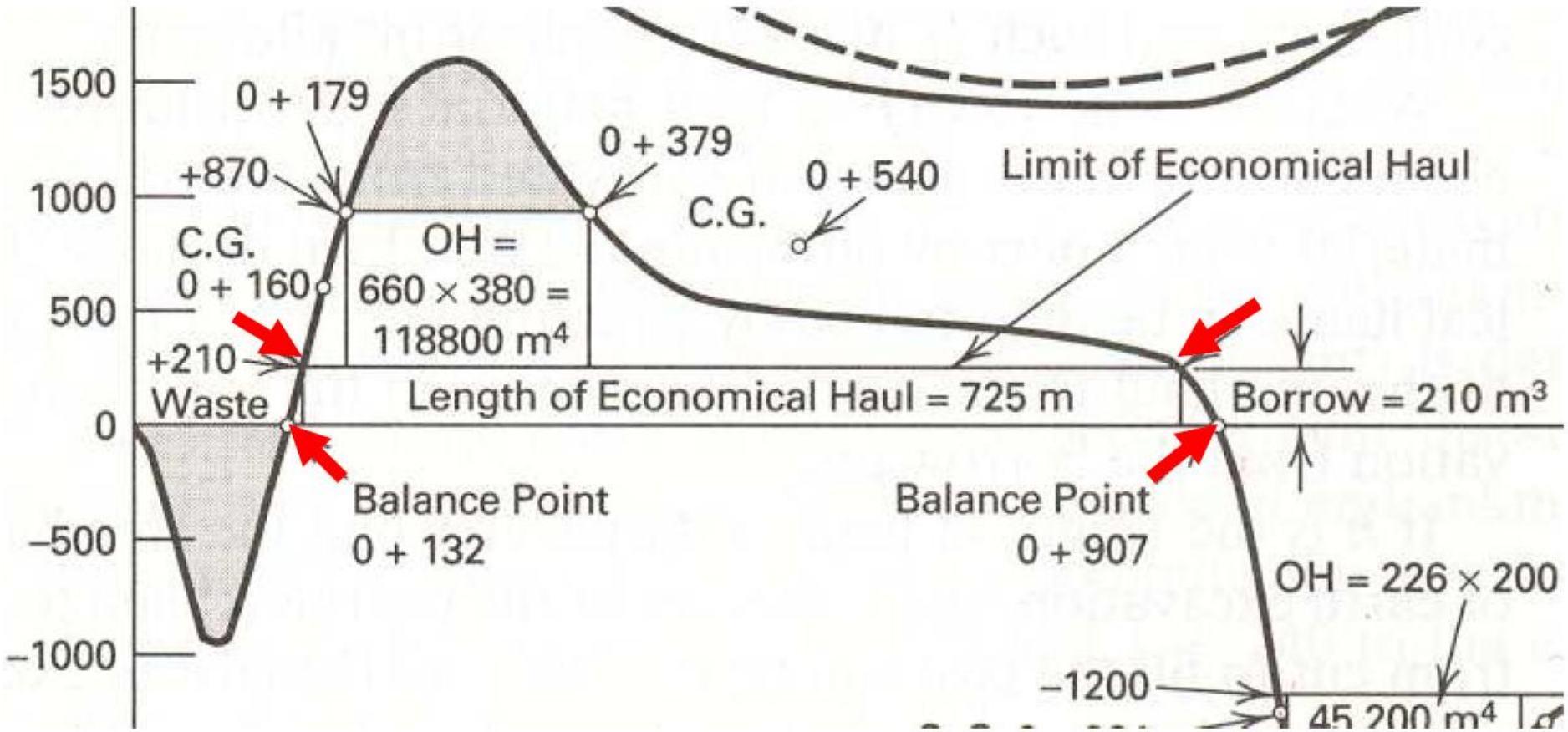
Between Stations 0 + 179 and 0 + 379, cut and fill equal each other, distance = FHD of 200 m
Treated as freehaul



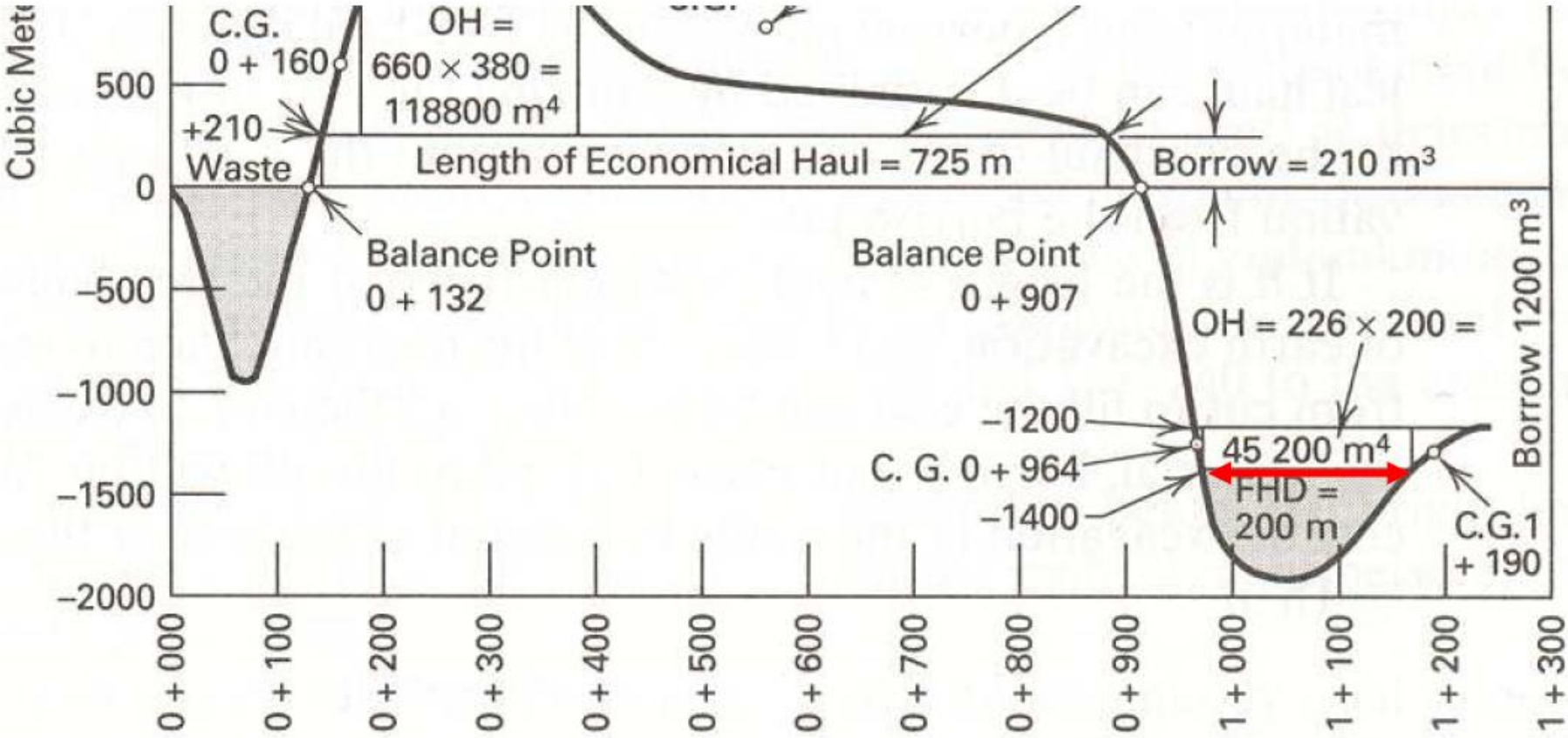
Between Stations

0 + 142 and 0 + 867, cut and fill equal each other,

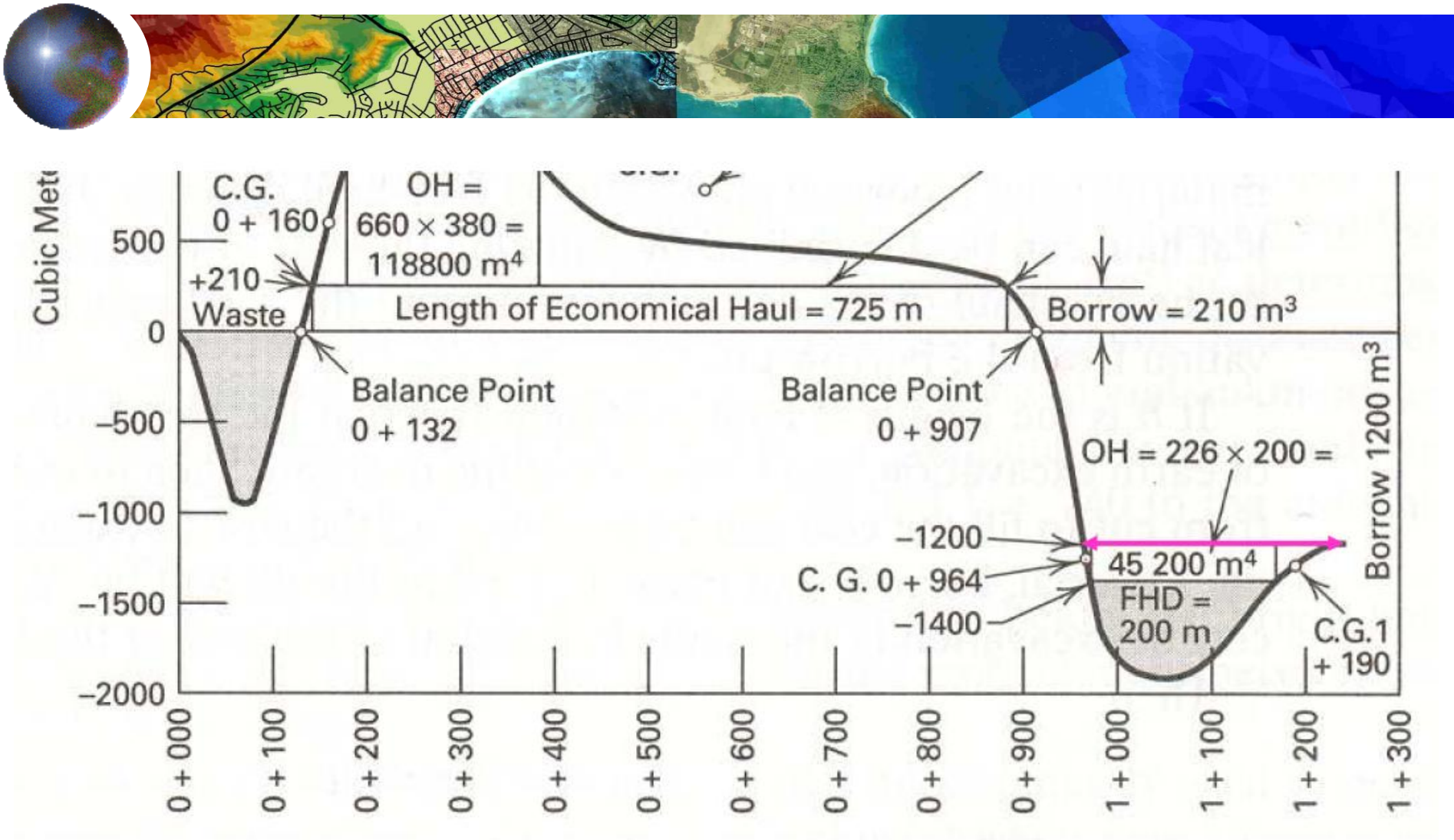
distance = LEH of 725 m



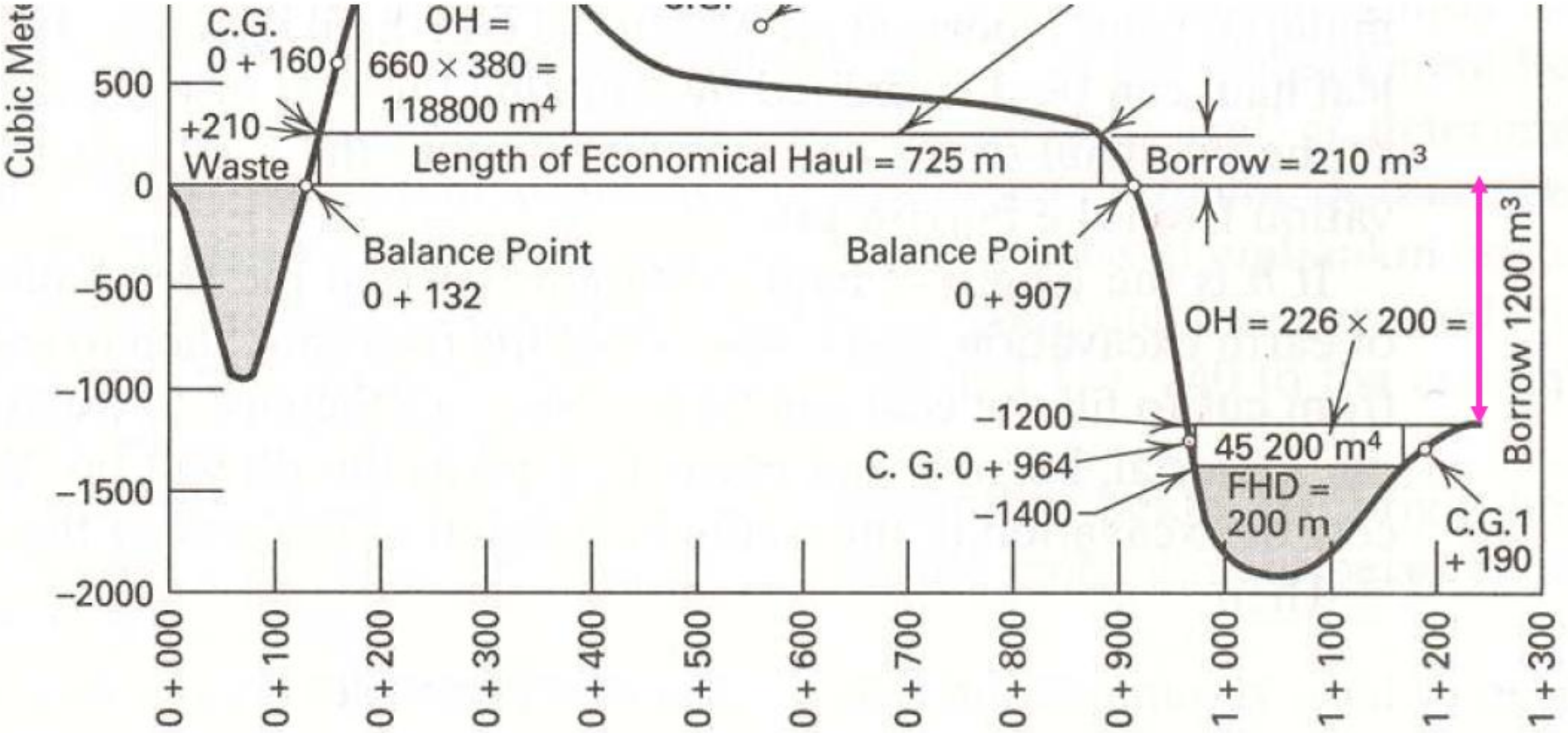
Material between Stations 0 + 132 and 0 + 142 becomes waste and material between stations 0 + 867 and 0 +907 becomes borrow



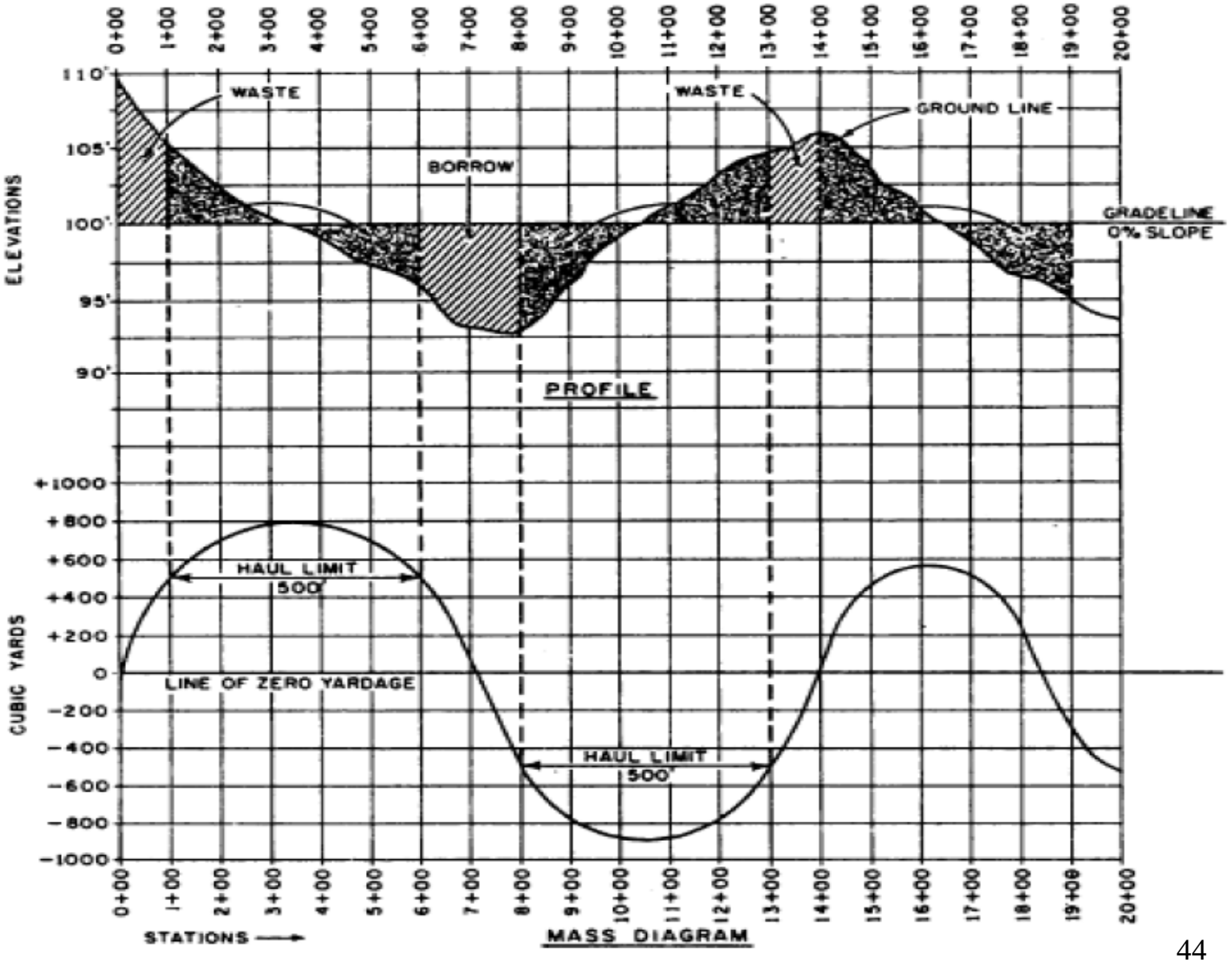
Between Stations 0 + 970 and 1 + 170, cut and fill equal each other, distance = FHD of 200 m



Between Stations 0 + 960 and 1 + 250, cut and fill equal each other, distance is less than LEH of 725 m



Project ends at Station 1 + 250, an additional 1200 m^3 of borrow is required


0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
9+00
10+00
11+00
12+00
13+00
14+00
15+00
16+00
17+00
18+00
19+00
20+00
110'
105'
100'
95'
90'
ELEVATIONS
WASTE
BORROW
WASTE
GROUND LINE
GRADELINE
0% SLOPE
PROFILE
+1000
+800
+600
+400
+200
0
−200
−400
−600
−800
−1000
CUBIC YARDS
HAUL LIMIT
500'
LINE OF ZERO YARDAGE
HAUL LIMIT
500'
STATIONS
MASS DIAGRAM

Example 3

Chainage	Distance	Volume of (m^3)		
		Cut	Fill	
732+20	0	0	0	
732+40	20	1600		
732+55	15	572.8		
732+85	30	355.91	69.83	
733+00	15		114	
733+20	20	18.72	321	
733+40	20	18.72	1156	
734+00	60		6731.1	

Find the cost of the earth work, allowing 15% shrinkage for material excavated and placed in embankment. Borrow should be expressed in fill meters and waste in cut meters.

Unit cost and additional information

Take

Free haul distance= 300 m

Excavation costs (including 300 m free haul) = (Free haul cost)= 60 Birr /m^3.

Borrow (including cost of hauling)= 73 Birr/m^3.

Cost of overhaul= 0.4 Birr/m^3.stn

Cost of waste = 57 Birr/m^3

1 station = 20 m

QUESTIONS?