CHAPTER 5

Earth work quantity and mass haul diagram

CHAPTER V

Earthwork Quantities and Mass Haul Diagram

Introduction

Earthwork is excavation of material from cutting and/or construction of embankments which is required to convert right of way from natural condition and configuration to a level that is ready for pavement works as prescribed in the design of the road.

Key terms and definitions associated with this process include:

- ***Borrow*** - material not obtained from roadway excavation but secured by widening cuts, flattening back slopes, excavating from sources adjacent to the road within the right-of-way, or from selected borrow pits as may be noted on the plans
- ***Waste*** - material excavated from roadway cuts but not required for making the embankment
- Free Haul - the maximum distance through which excavated material may be transported without the added cost above the unit bid price
- ***Overhaul*** - excavated material transported to a distance beyond the free haul distance
- ***Economic Limit of Haul*** - distance through which it is more economical to haul excavated material than to waste and borrow

The activities that are undertaken in earthwork include:

- ***Clearing and grubbing***
- *Roadway excavation:* This consists of common or soft excavation, intermediate and hard rock excavation and boulder excavation.
- ***Removal and stockpiling*** of unsuitable excavated material off the right of limit.
- ***Borrow excavation and hauling*** to be used for roadway filling.
- ***Embankments constructions*** from material obtained from excavation within the right of way or borrow.
- ***Sub grade preparation***: this consists of assessment of sub grade material, removal and replacement of unsuitable material as necessary, and preparation of graded road bed for surfacing.
- ***Shoulder and side slope construction***
- ***Protection of earthworks:*** It is protection of earthworks including excavation, embankment, etc from effects of weather.

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 steps involved in the computation of earthwork quantities and the development of the optimal mass haul diagram are:

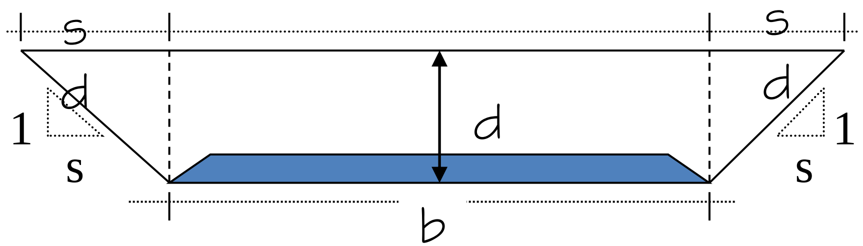
- ✓ End area calculations
- ✓ Earthwork calculations
- ✓ Preparation of mass haul diagram
- ✓ Balancing earthworks using the mass haul diagram

Areas of Cross-sections

- For the purpose of calculating the quantity of earth work, the areas of cross-sections and the distance between them must be known
- <u>Methods</u>
  - For regular/level ground $\Rightarrow$ simple geometry
  - For irregular ground, two methods
    1. Graphical or planimeter method
    2. Coordinate or other approximate method

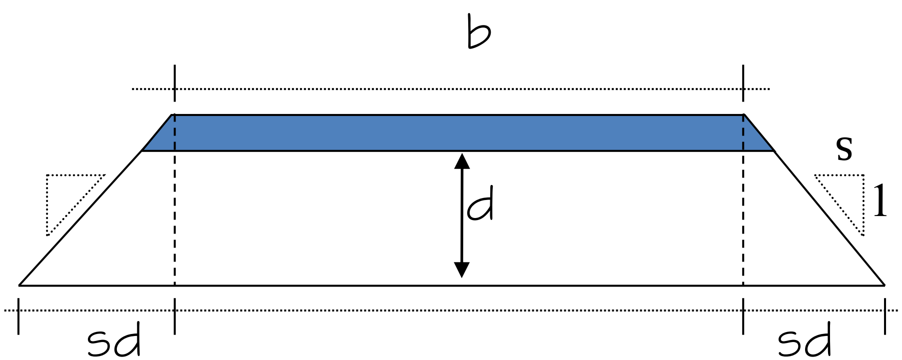
Area for Regular Ground

Area of a trapizod



Cut

$$A = bd + sd^2$$

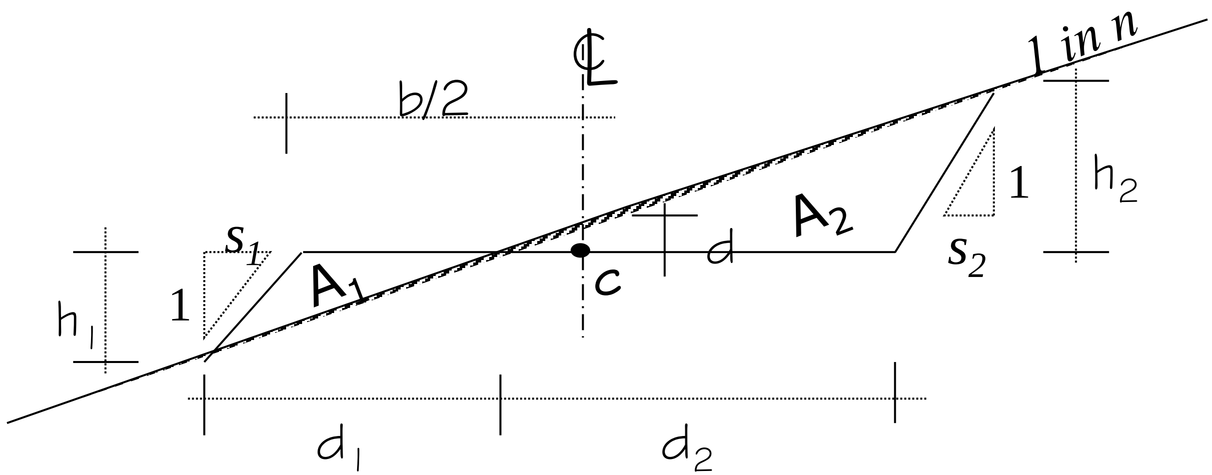


Fill

Area for (Regular) cut – fill sections

A_1=Area in cut

A_2=Area in fill



$$A_1 = \frac{(b-2nd)^2}{8(n-s_1)} \; and \; A_2 = \frac{(b+2nd)^2}{8(n-s_2)}$$

When c is to the right of the point of zero fill

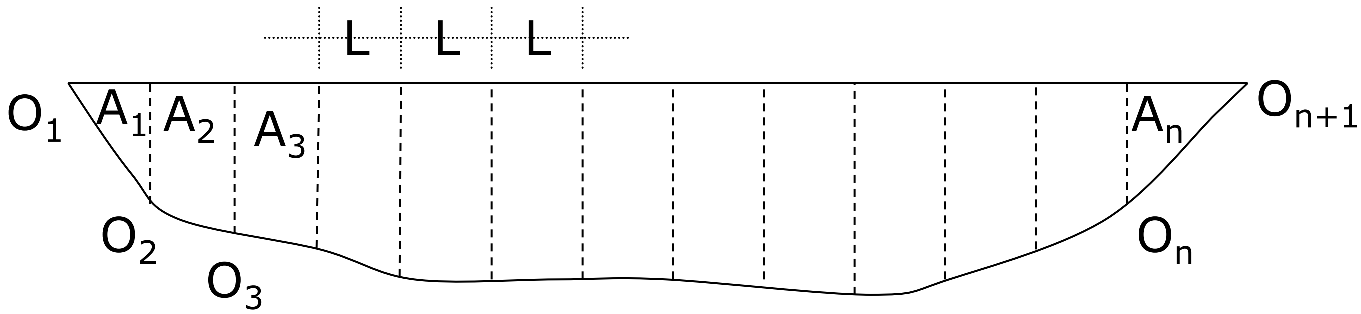
When c is to the left of the point of zero fill

$$A_1' = \frac{(b+2nd)^2}{8(n-s_1)} \; and \; A_2' = \frac{(b-2nd)^2}{8(n-s_2)}$$

Area of irregular section

Trapezoidal Rule

Assumes the boundaries could be approximated by a straight line, if the interval L between offset measurements is very small



$$A = A_1 + A_2 + \ldots + A_n$$

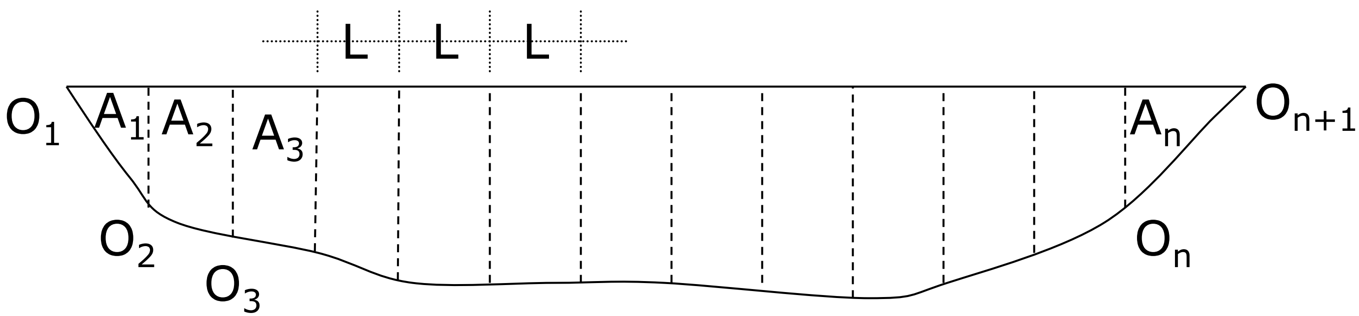
$$A = L/2\left[O_1 + O_{n+1} + 2(O_2 + O_3 + \ldots + O_n)\right]$$

Area of irregular section

Simpson's Rule

Assumes, instead, that the boundaries consist of a series of parabolic arcs

For this rule to apply, N must be an odd number



$$A_1 + A_2 = L/3(O_1 + 4O_2 + O_3)$$

$$A_3 + A_4 = L/3(O_3 + 4O_4 + O_5)$$

$$A = L/3(O_1 + O_N + 4\sum even\,offsets + 2\sum remaining\,odd\,offsets)$$

Computation of Volumes

Two methods will be discussed here:

1. Average End Area Method
2. Prismodal Formula

Average End Area Method

Volume of a right prism equals the average area multiplied by the length

$$V_{12} = \frac{A_1 + A_2}{2} l$$

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

Prismodal Formula

- A prismoid is a solid whose ends are parallel and whose sides are plane or warped surfaces
- The Volume of a prismoid is: $V_{ab} = l/6(A_1 + 4A_m + A_2)$

$$V_{13} = l/3(A_1 + 4A_2 + A_3)$$
$$V_{35} = l/3(A_3 + 4A_4 + A_5)$$
$$\Rightarrow V_{15} = l/3(A_1 + A_5 + 2A_3 + 4(A_2 + A_4))$$
$$\Rightarrow V = l/3(A_1 + A_N + 2(remaining\,odd\,areas) + 4(even\,areas))$$

- A_1 & A_3 are parallel end areas a distance l apart and A_2 the area at the mid-length, found out by interpolating the linear dimensions.

Mass Diagram

- Is a continuous curve showing the accumulated algebraic sum of the cuts (+ve) and fills (-ve) from some initial station to any succeeding station
- Ordinates of the mass curve are plotted with reference to a horizontal scale of distances
- It is convenient to tabulate the cumulative sum of cuts and fills at a station before drawing a Mass diagram

Drawing a mass-haul diagram

Procedures

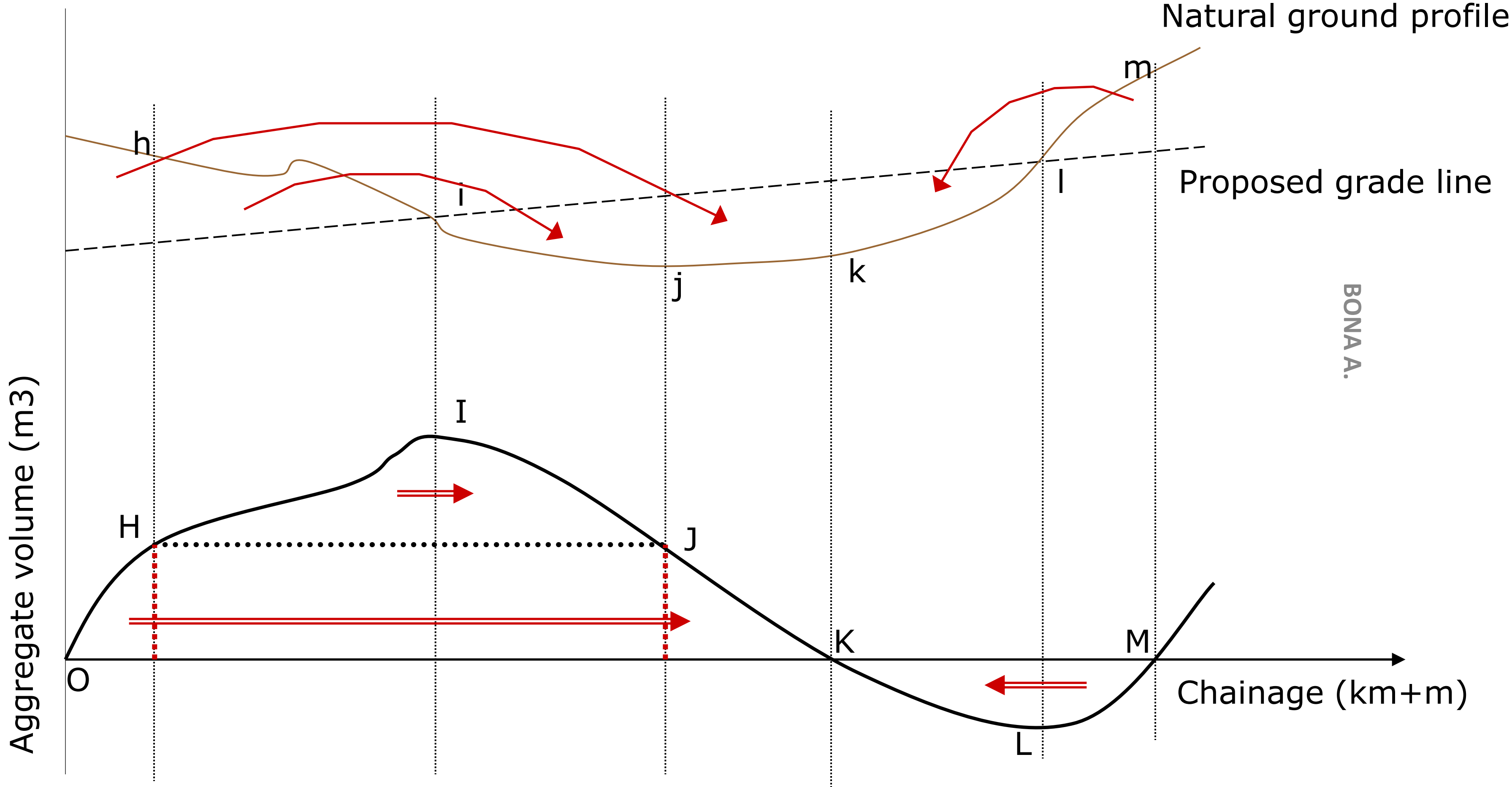
1. Calculate areas at cross-sections
2. Calculate the volume of fill and cut; cut is +ve and fill –ve.
3. Correct the volume calculated by shrinkage and swell factors
4. Tabulate the corrected aggregate volume
5. Plot the mass haul diagram
   (scale: 1:2000 H and 1:500 or 1:1000 ($cm:m^3$)V)
6. Join points by a straight line or curves

Sta	Individual volume		Bulking/ Shrinkage factors	Corr. Indiv. volumes		Aggregate Vol.
	Cut	Fill		Cut	Fill	

Mass-Haul Diagram - Characteristics

i. The Ordinate at any point represents the cumulative material to that point on the profile
ii. With in the limits of a single cut, the curve rises from left to right; within the limits of a single fill, it falls from left to right
iii. Sections where the profile changes from cut to fill correspond to a maximum (and the opposite for ch. from fill to cut). Evidently the maximum and minimum points on the mass diagram occur at or near grade points on the profile
iv. Any horizontal line cutting a loop of a mass curve, intersects the curve at two points b/n which the cut is equal to the fill (adjusted for shrinkage); such a line is called a BALANCE LINE
v. The loop convex upward indicates that the haul from cut to fill is to be in one direction

Mass-haul Diagram - Example



Distribution Analysis of Earthwork Terminologies

- Haul Distance: distance from point of excavation to point where the material is to be tipped
- Average Haul Distance is the distance from the centre of gravity of the excavation to the centre of gravity of the tip
- Free-haul Distance: is the distance (usually specified in the contract) over which a charge is paid only for the volume of earth excavated and not for its movement (300m). *Free-haul is part of the haul which is contained within the free haul distance.*
- Over-haul Distance: is the distance in excess of the free-haul distance, over which it is necessary to transport material. An extra charge will be paid for transport. *Over-haul is part of the haul which remains after the free haul has been removed.*
- Haul: is the sum of the product of each volume of material and the distance through which it is moved. On the mass-haul diagram, it is the area contained b/n the curve and the balance line

Distribution Analysis of Earthwork Terminologies (cont.)

- Waste: is the volume surplus or unsuitable material which must be exported from a section of the site.
- Borrow: is the volume of material which must be imported in t a section of the site due to deficiency of suitable material

Cont…

- ✓ Of note is the fact that most current highway design computer programs will produce the mass haul diagram as part of the output when typical sections and horizontal and vertical alignments are inputs.
- ✓ A final stage of geometric design is then usually to make adjustments to the alignments in the interests of balancing or minimizing the earthwork quantities.

General steps to be following for determining mass haul diagram are:

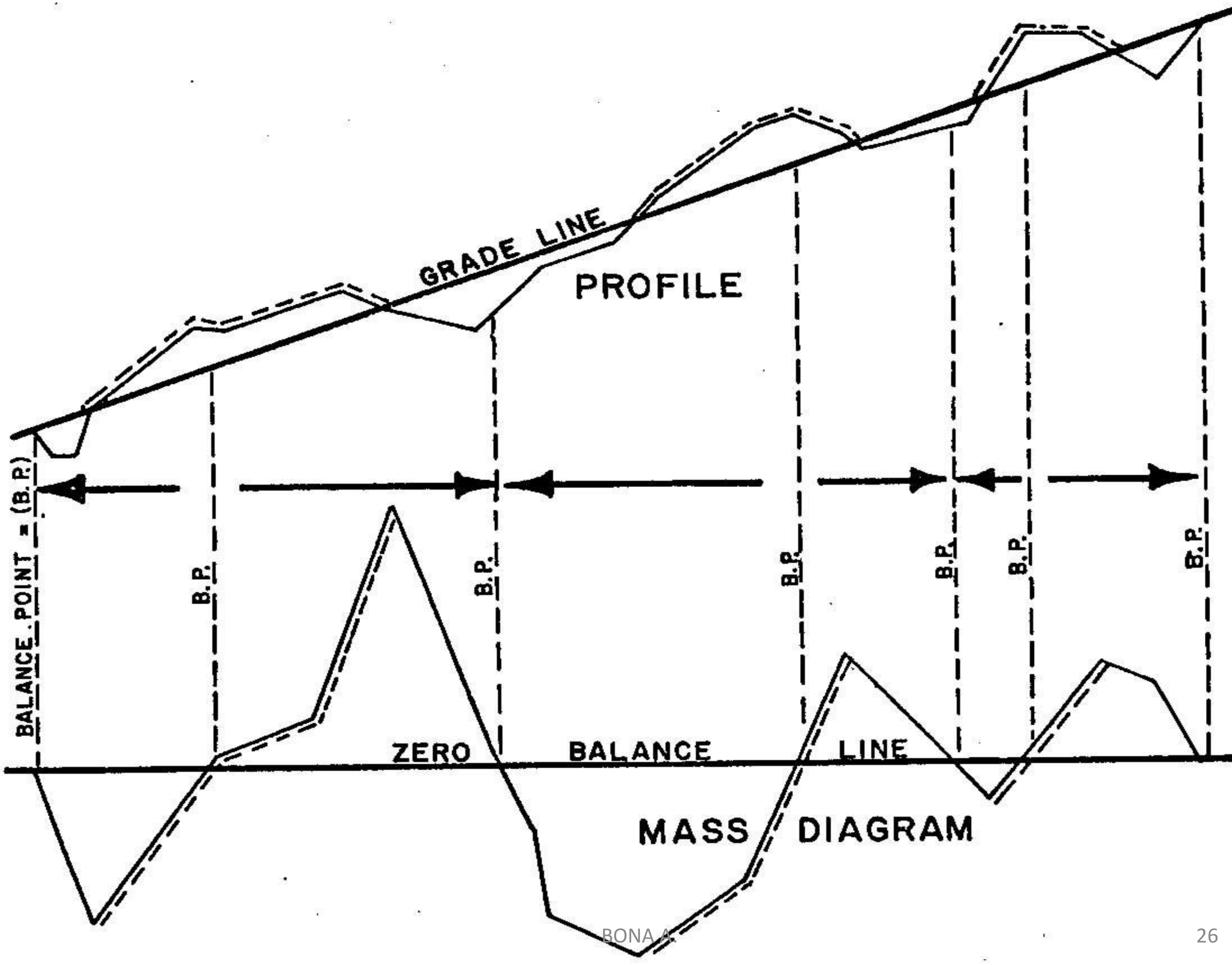
- Calculate fill and cut volumes separately
- Correct the volumes calculated for swell and shrinkage
- Tabulate the corrected cut and fill volumes, and aggregate volumes in the following format
- Plot the Mass-haul diagram with stations in x-coordinate and aggregate volumes in y-coordinate.

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 kilometer-cubic meters
- Direction of haul.

Note that properties of mass haul diagrams are as follows:

- An upward slope on the mass curve indicates excavation, and conversely, a downward slope indicates embankment.
- The maximum ordinate of the mass curve occurs at the point where excavation ends and embankment starts. Similarly, the minimum ordinate occurs at the point where embankment ends and excavation starts.
- Cut and fill quantities between the points at which any horizontal line cuts off a loop of the mass curve will exactly balance. Such horizontal lines are called balance lines.
- Areas below the balance line indicate that hauling of excavation to embankment is from right to left, whereas areas above the balance line indicate that the haul is from left to right.
- The area between a balance line and its corresponding loop of the mass curve is a measure of haul (product of the volume and distance in station-meters).
- The ordinate at any station represents the accumulated amount of surplus or deficit of material at the station. It does not indicate the amount of cut or fill volume at that station.

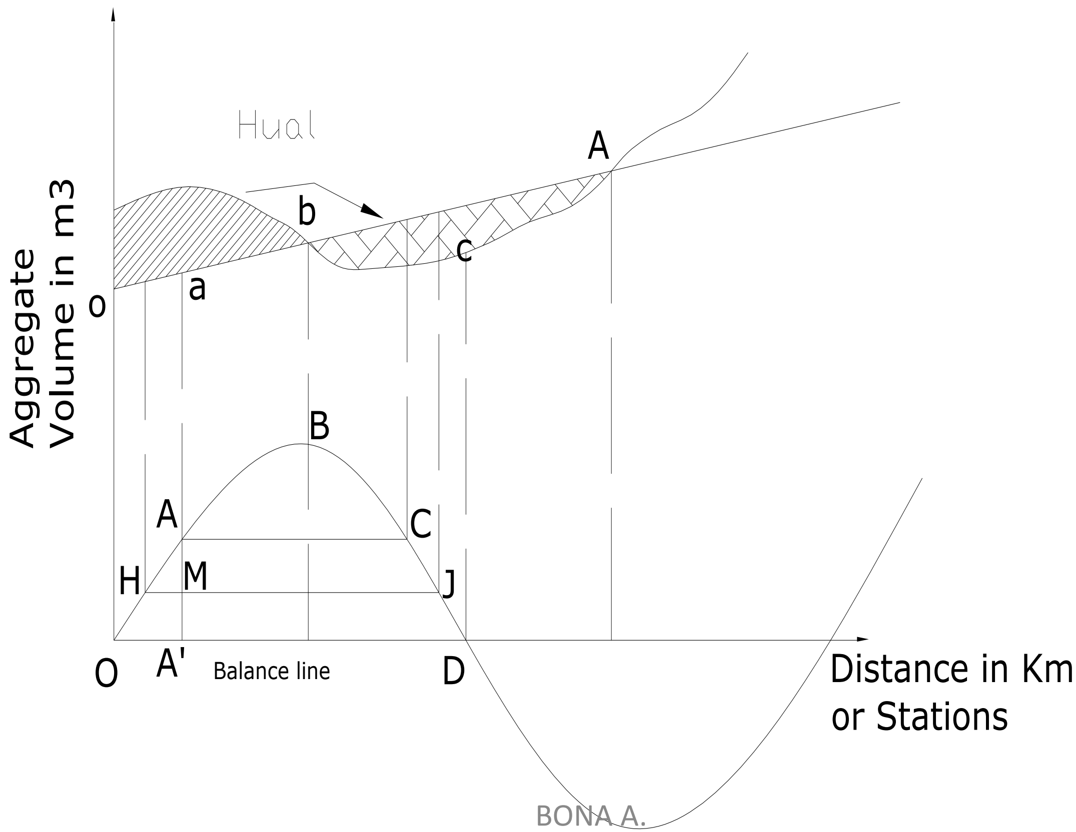

GRADE LINE
PROFILE
BALANCE POINT = (B.P.)
B.P.
B.P.
B.P.
B.P.
B.P.
B.P.
ZERO BALANCE LINE
MASS DIAGRAM

Earthwork Analysis

- Assume a free haul distance and find by trial a horizontal line to intersect the curve at **A** and **C** such that the length of line **AC** equals the assumed free haul distance. The quantity of material above line **AC** will be hauled at no extra cost. Off note is the fact that this material is a measure of ordinate from line **AC** to point **B** and it is the volume of material to be cut from **ab** to be filled in **bc**.
- Considering the volume of material above the balance line **OD**. A study of the mass haul and the corresponding profile shows that the cut from **o** to **b** makes the fill **b** to **d**. Since the part above line **AC** is included in the free haul, the remaining part between line **OD** and **AC** which is measured by the ordinate **AA'** is subjected to overhaul unless wastage and borrow takes place that is the excavation from **C** to **A** may be overhauled to make the fill **CD**.
- The average distance of overhaul of the material **o** to **a** to make the fill **a** to **c** is the distance between the center of gravity of cut **o** to **a** and fill **c** to **d**.
- The approximate gravity lines are found as follows

Bisect AA’ at M and draw a horizontal line intersecting the curve at H and J. These points are assumed to be vertically below the desired center of gravity. Therefore, the average haul distance is given by the distance HJ and the over haul distance can be obtained by subtracting the free haul distance.

Overhaul distance = HJ – AC



Economical analysis

The economical limit of haul is defined as the distance through which it is more economical to haul excavated material than to waste and borrow. The following formula is presented as a guide to assist the designer in determining the economic limit of haul:

$$E.L.H. = F.H.\ distance + \frac{\text{Unit Price of Borrow}}{\text{Unit Price of Overhaul}}$$

Where:

E.L.H = Economic limit of haul

F.H. = Free haul distance

Example: Assume F.H. Distance = 1500 meters

Borrow U.P. = ETB 8.00/m3

Overhaul U.P. = ETB 5.00/100/meter/m3

$$E.L.H = 15 + \frac{8}{.5}$$

$$E.L.H = 15 + 16 = 3100m$$

Limit of Economical Haul

Let: C_e=cost of excavation per unit volume (including free haul)
C_b=cost to excavate borrow pit (including free haul)
C_{oh}=cost of overhaul per m^3m
L_e=Economical Length of over-haul

Cost to excavate $1m^3$ of material from cut and move to fill

$$=C_e+C_{oh}L_e \quad (1)$$

Cost of excavate from cut, waste, borrow and place 1m3 material in fill

$$= C_b+C_e \quad (2)$$

Equating (1) & (2): $C_e+C_{oh}L_e= C_b+C_e \Rightarrow L_e=C_b /C_{oh}$

Total Distance, $D=L_e+F$

where: F=free haul distance

Example

If the cost of roadway excavation, C_e, is 800 cents/m^3, cost of borrow, C_b, is 700 cents/m^3, and cost of overhaul, C_{oh}, is 12 birr/m^3-station, what is the economical length of overhaul? The free haul distance is 1.5km and a station is 100m long.

Example

For the tabulated volume of cut and fill data given below:

1. draw the mass-haul diagram, and
2. estimate the total cost of excavating and moving earth

if, the cost of excavation is 6birr/m3, cost of borrow is 6 birr/m3, cost of overhaul is 12birr/station-m3, and the free haul distance is 1.1km. Use a shrinkage factor of 0.9.

Example

Sta km+m	Indiv. volume 10^3 m^3		Bulking/ Shrinkage factors	Corr. Indiv. Volumes 10^3 m^3		Agg. Vol.
	Cut	Fill		Cut	Fill	
0+000						
	2.00	-	0.9	1.80		1.80
0+100						
	1.2	-	0.9	1.08		2.88
0+200						
	0.8	-	0.9	0.72		3.60
0+300						
	0.15	-	0.9	0.14		3.74
0+400						
	-	0.65			0.65	3.09
0+500						
	-	1.50			1.50	1.59
0+600						
	-	2.00			2.00	- 0.41
0+700						
	-	1.80			1.80	- 2.21
0+800						
	-	1.60			1.60	- 3.81
0+900						
	2.00	-	0.9	1.80		- 2.01
1+000						
	1.80	-	0.9	1.62		0.39
1+100						
	1.60	-	0.9	1.44		1.05
1+200						
	-	1.00			1.00	0.05
1+300						
	-	1.00			1.00	- 0.95
1+400						
	3.00	-	0.9	2.70		1.75
1+500						
	1.00	-	0.9	0.90		2.65
1+600						

Listed below are a few considerations in determining the best earthwork design:

- Right-of-way restrictions may necessitate importing borrow material for the required embankments.
- Where large quantities of inferior or deleterious material are encountered in the excavation, it will be necessary to waste this material, which is unsuitable for use as embankment.
- Special conditions through deep cuts, such as sloughing, sight distance requirements, or sand drift conditions may require very flat back slopes resulting in large amounts of excavation and no large embankments within a reasonable haul distance.
- The need to carry the road level considerably above the existing ground for extended distances through flood plain areas will generally require borrow excavation.