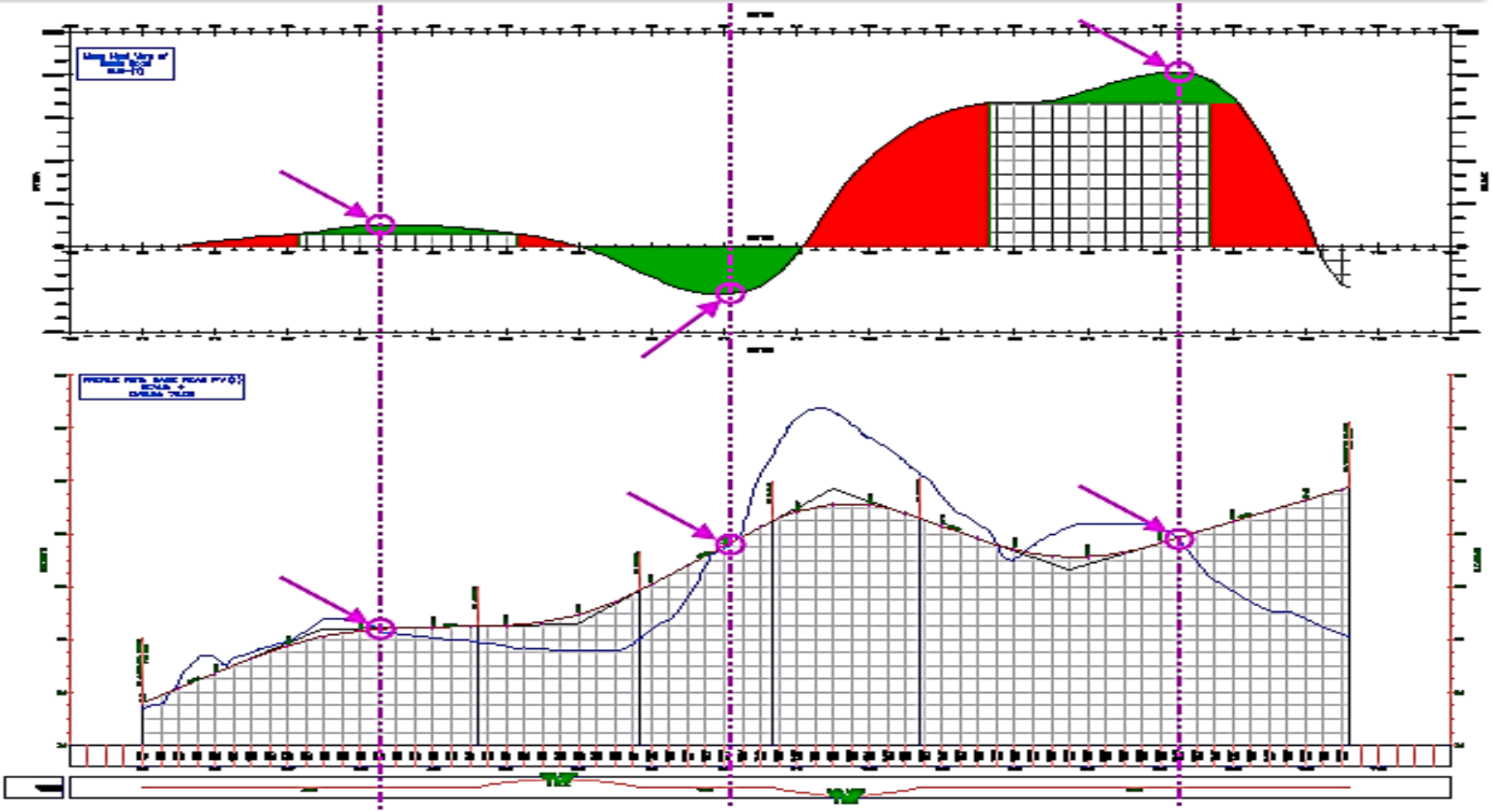
Chapter-3.
Earthwork Quantities & Mass Haul Diagram



Earthwork





Activities involve:

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















Introduction

- **Earthwork includes all clearing, grubbing, roadway and drainage excavation, excavation for structures, embankments, borrow, overhaul, machine grading, subgrade scarifying, rock fill, and all the operations of preparing the subgrade foundation for highway.**

- It is essential that considerable care is taken when quantifying and planning the way in which earth material is handled during construction.

Classification of Excavated Material

- Excavated material is usually classified as :
  - ✓ **Common excavation**- refers earth or earth with detached boulders less than ½ cu yd.
  - ✓ **Loose rock**- refers to rock which can be removed with pick and bar
  - ✓ **Solid rock**- comprises hard rock in place and boulders that can be removed only by use of drilling and blasting equipment

Areas and Volumes of Earthwork

Areas

- End area calculations are usually made by one of the following methods:

- **Planimeter Method** –
  - ✓ The original ground line and template section (cross section) must be plotted on grid paper.
  - ✓ Centerline profile grade must first be calculated for each cross section station to determine the centerline reference of each template plot. Areas of cut and fill quantities are calculated using a Planimeter, converted to square meters, and tabulated for each section.

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Areas and Volumes (cont...)

- **Electronic Computer Method** –

✓ widely used due to its versatility and speed of calculations.

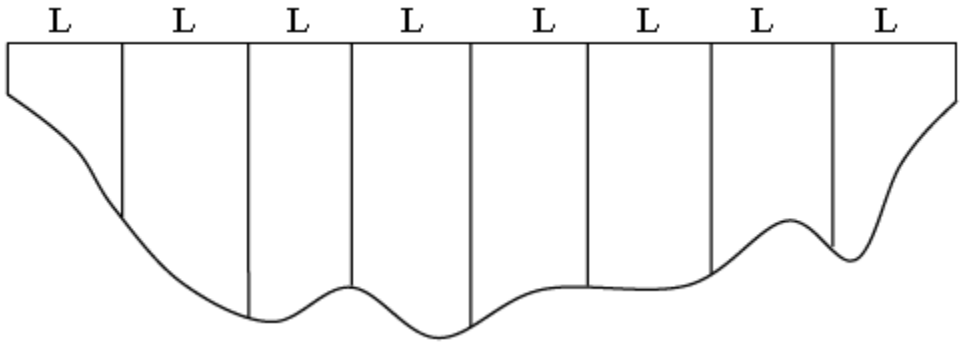
✓ The end area calculation on modern computer programs is an integral part of the alignment design program and shown on output listings along with the geometric of each section.

- If the boundary of a tract is irregular, the area is computed using offsets taken at regular interval.
- Two common methods to calculate the area enclosed by irregular boundaries are:

Areas and Volumes (cont…)

- **Trapezoidal rule**: - consider an area with irregular sides
  - The generalized trapezoidal formula can be exp

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



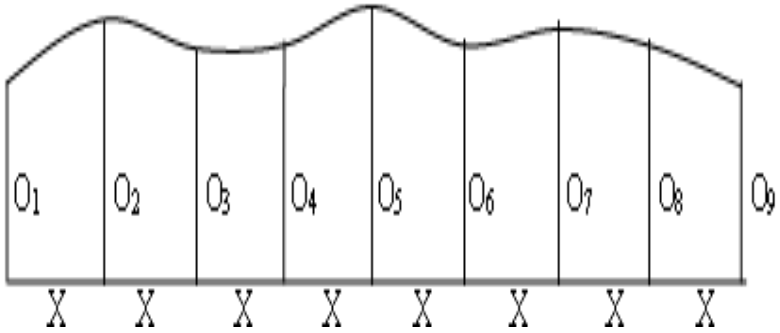
Where, L= length of each segment
O_i = Offsets heights
A = Areas of each segment

Areas and Volumes (cont…)

- **Simpson's Rule** :-

✓ It assumes that the irregular boundary is **composed of a series of arcs.**

✓ It is essential that the figure under consideration is divided into an even number of equal strips.



$$A = \frac{X}{3}[S + 2O + 4E]$$

Where S is the sum of the first and last offsets
O is the sum of remaining odd offsets
E is the sum even offsets.

Areas and Volumes (cont…)

Volumes

- The volume of earth work may be found by means of either the **average-end area** or **the Prismoidal formula**.
- Although the average-end area is less exact than the Prismoidal formula, it is generally accepted as a standard earthwork formula due to its simplicity.

Areas and Volumes (cont...)

Average-end Area Formula

- The volume of the right prism equals the average area multiplied by the length.
- Assuming the average area to be equal to the average end area,

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

where A_1 and A_2 areas of the end sections and L is the length of the solid or prism.

Areas and Volumes (cont...)

Prismoidal Formula

- A prismoid is a solid whose bases are polygons having the same number of sides and whose other faces are trapezoids or parallelograms
- The volume of a prismoid is given by:

$$V = \frac{L}{6}\left[A_1 + 4M + A_1\right]$$

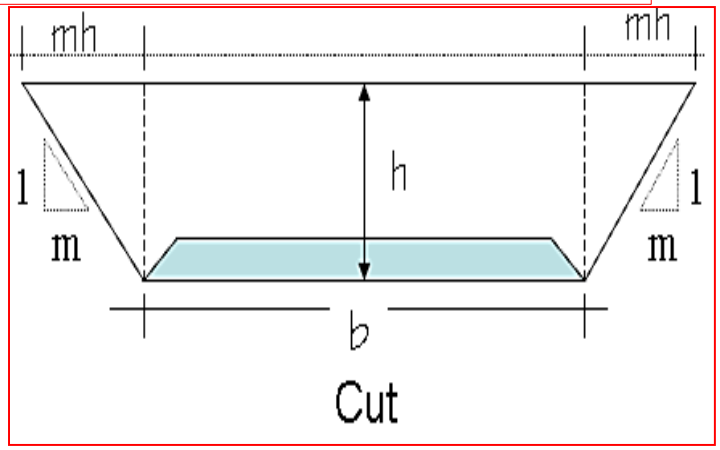
where L is the distance between the two parallel ends A_1 and A_2, and M is a section midway between the two end bases and parallel to them.

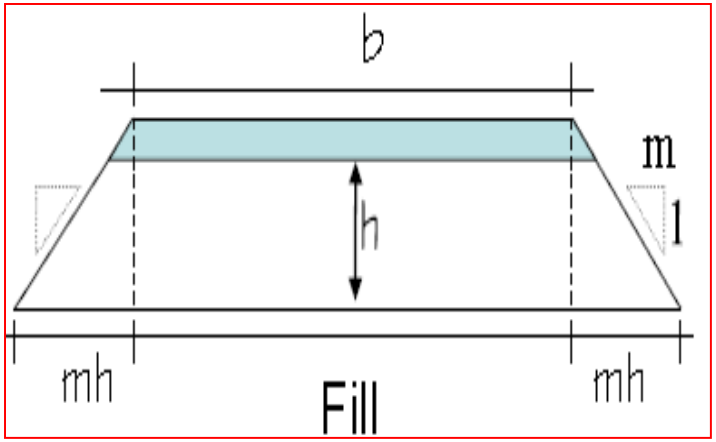
- Note: M is not an average of A_1 and A_2 but each of its linear dimensions is an average of the corresponding dimensions of A_1 and A_2.

Areas and Volumes (cont...)

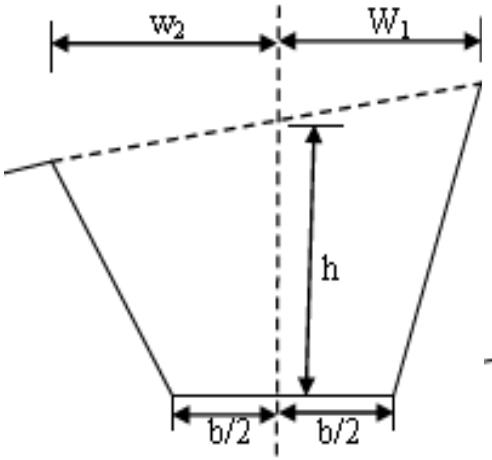
❑ Typical cut and fill sections and templates

Sections with level surfaces

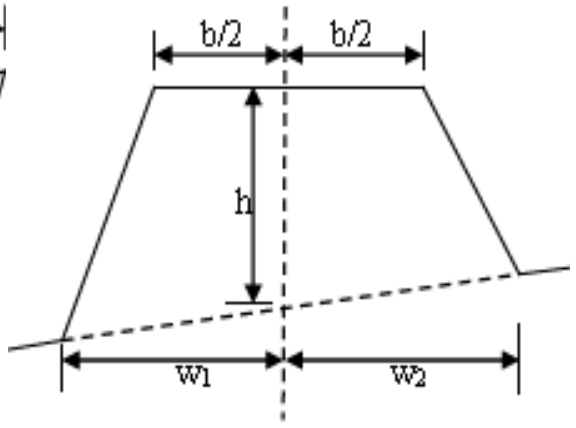




Sections with cross falls



a) Cut section

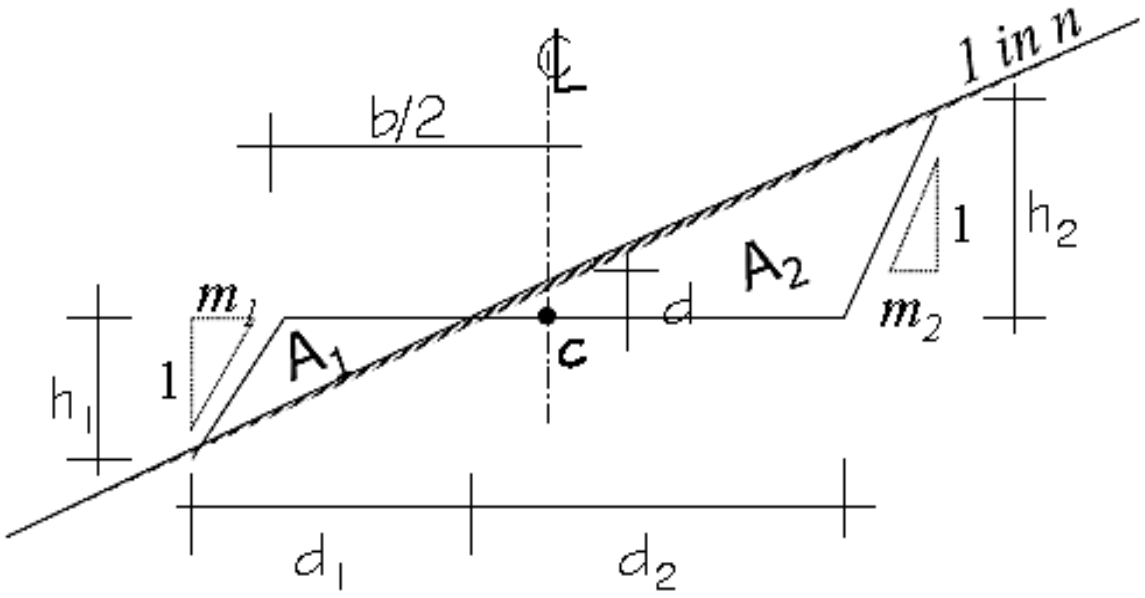


b) Embankment

For level surfaces (both cut and fill), $A = \frac{1}{2}\left[2\left(\frac{b}{2}+mh\right)+b\right]h = h(b+mh)$

Areas and Volumes (cont...)

Sections with partly in cut and partly In fill



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

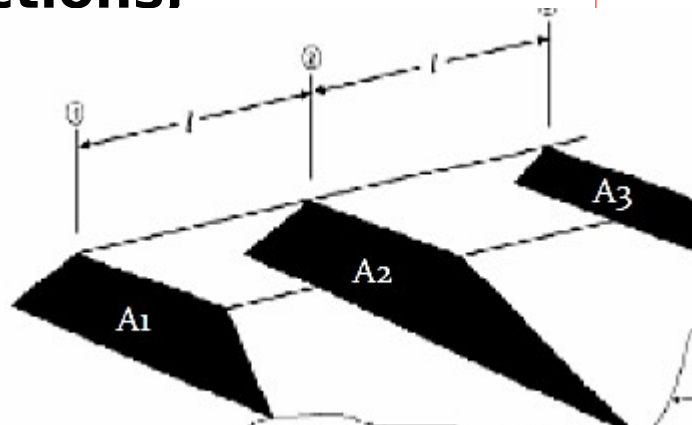
$$A_1 = \frac{(b-2nd)^2}{8(n-m_1)} \text{ and } A_2 = \frac{(b+2nd)^2}{8(n-m_2)}$$

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

$$A'_1 = \frac{(b+2nd)^2}{8(n-m_1)} \text{ and } A'_2 = \frac{(b-2nd)^2}{8(n-m_2)}$$

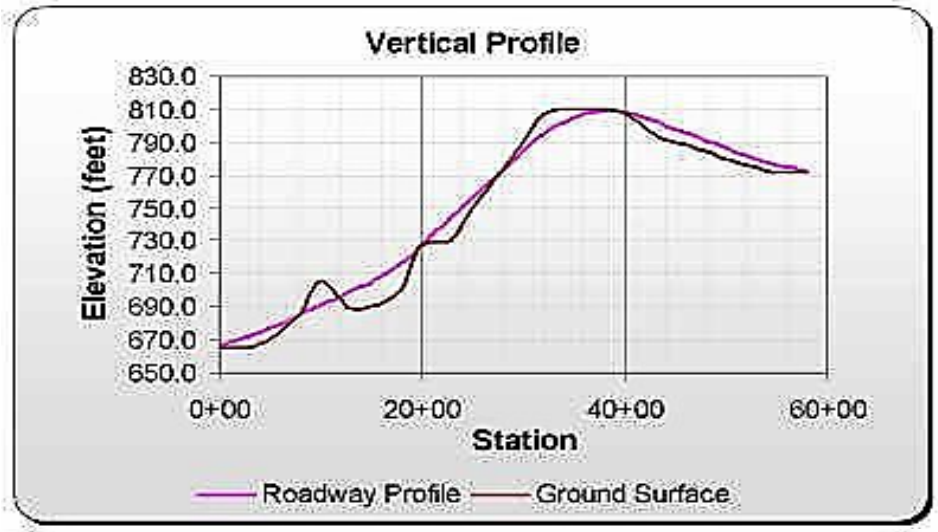
Mass-Haul Diagram

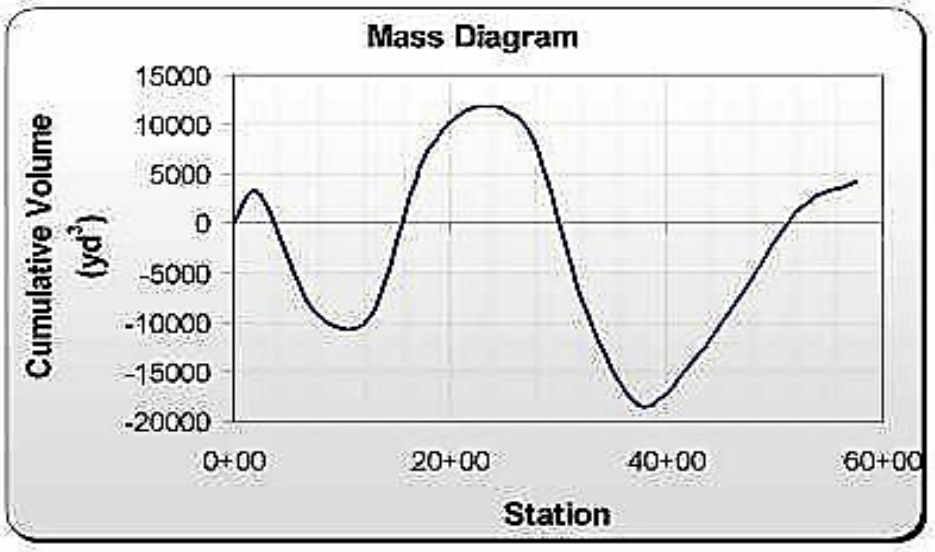
- **Earthwork includes the excavation of existing earth material and any placement of fill material required for constructing the embankment.**
- The manual method for determining earth excavation and embankment amounts involves three steps:
  - ✓ **cross sections of the proposed highway are placed on the original ground cross sections.**
  - ✓ **the areas in cut and the calculated, and**
  - ✓ **the volumes between the sectio**



Mass-Haul Diagram (cont…)

- 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.
- **It is a graph of volume against chainage.**
- **Volumes of cut are considered as +ve and volumes of fill are considered as –ve.**





Mass-Haul Diagram (cont…)

The mass haul diagram can be used to determine:

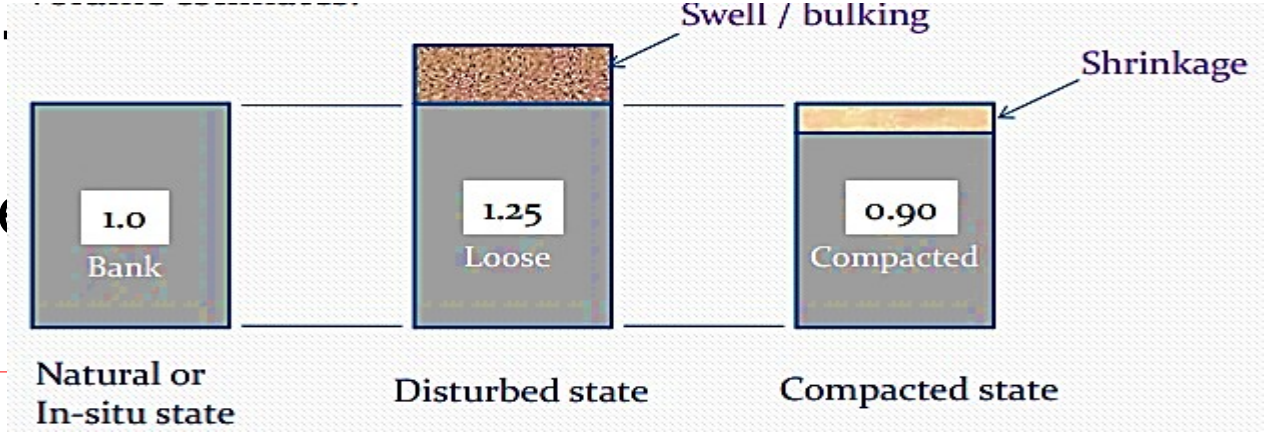
- Proper distribution of excavated material
- Amount and location of waste
- Amount and location of borrow
- Amount of overhaul in kilometer-cubic meters
- Direction of haul.

Mass-Haul Diagram (cont…)

- **Drawing of the Mass-Haul Diagram**
  - ✓ The cross-sectional areas are calculated at regular intervals along the project
  - ✓ **The volume between consecutive areas and the aggregate volume along the site are calculated.**
  - ✓ **The points are joined by curves or straight lines to obtain the finished mass-haul diagrams.**

Mass-Haul Diagram (cont…)

- **Excavated earth**, when placed in fill, will usually become compacted so that its volume is less than the space originally occupied in the embankment.
- The difference between the original volume in cut and the final volume in fill is defined as ***shrinkage***.
- **Excava** vill occupy nd the incr



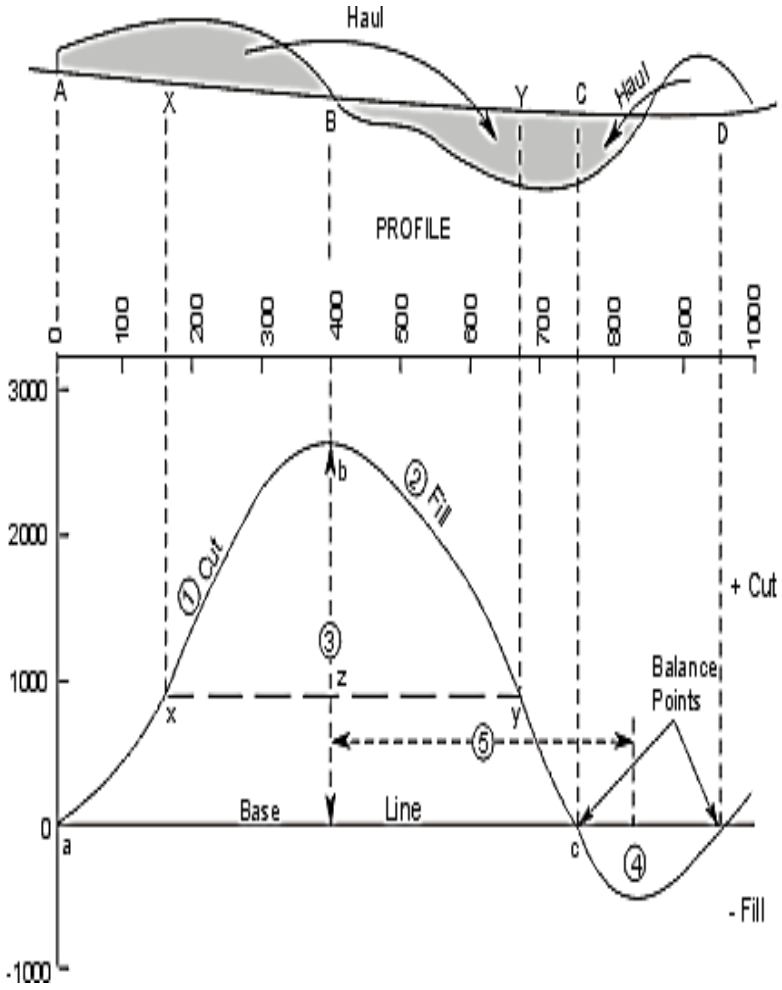
Mass-Haul Diagram (cont…)

- **Terminology**

- **Haul Distance**: - is the distance from point of excavation to the point where the material is to be tipped or unloaded.
- **Average Haul Distance**:- is the distance from the center of gravity of the excavation to the center of gravity of tip or fill.
- **Free Haul Distance**: - is the maximum distance through which excavated material may be transported without the added cost above the unit bid price.
- **Over Haul Distance**: - the distance that excavated material is transported beyond the free haul distance.
- **Borrow**: - refers to the fill material that must be brought to the proposed highway site from ***outside*** the highway corridor.
- **Waste**: - is a material excavated from roadway cuts but not required for making the embankment.
- **Economic Limit of Haul**: - is the distance through which it is more economical to haul excavated material than to waste and borrow.
- **Haul**: - This is the term used when calculating the costs involved in earth moving and is taken as the sum of the product of each volume of material and the distance through which it is moved.

Properties of Mass- Haul Diagram

- Upward slope of the curve in the direction of the algebraic summation (1) indicates excavation of cut section as the aggregate volume is increasing where as downward slope (2) indicates fill as the aggregate volume is decreasing.
- On the curve, the maximum earthworks point (3) occurs at the end of an excavation and a minimum earthwork point (4) at the end of an embankment.
- The vertical distance between a maximum point and the next forward minimum point represents the whole volume of an embankment (example 3 + 4). Similarly, between a minimum and the next forward maximum point, the whole volume of an excavation.



Properties (cont...)

- **Any horizontal line intersecting the mass curve at two or more points, similarly shows lengths over which cutting and filling are equalized and called a balancing line.**

- **When the mass curve lies above the balancing line, the excavated material must be hauled forward. When below, the direction of haul is backward.**

- **The length of balancing line intercepted by the mass curve represents the maximum haul distance in that section.**

Costing Using Mass-Haul Diagram

- Two types of charges are usually involved during earth moving.
  - ✓ **Any earth moved over distances not greater than free haul distance is costed on the excavation of its volume.**
  - ✓ **Earth moved over distances greater than the free haul distance is costed both on its volume and its volume moved over distances in excess of the free haul distance.**

Economic Limit of Haul

- **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.**
- Where there are long hauls, it may be more economical to waste and borrow materials rather than pay for the cost of overhauling

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

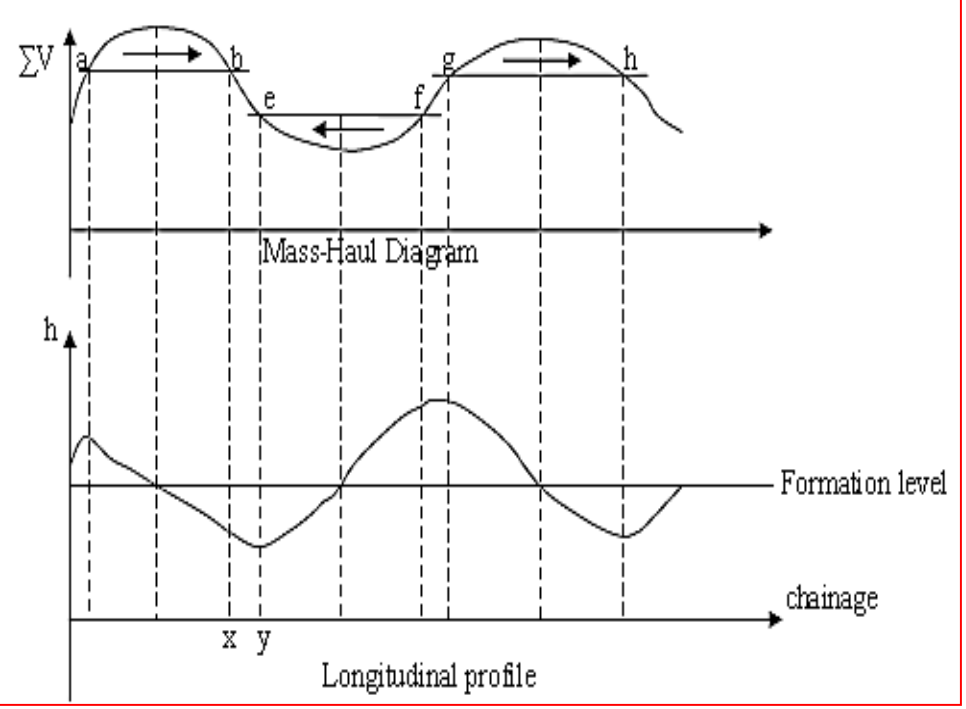
Where:

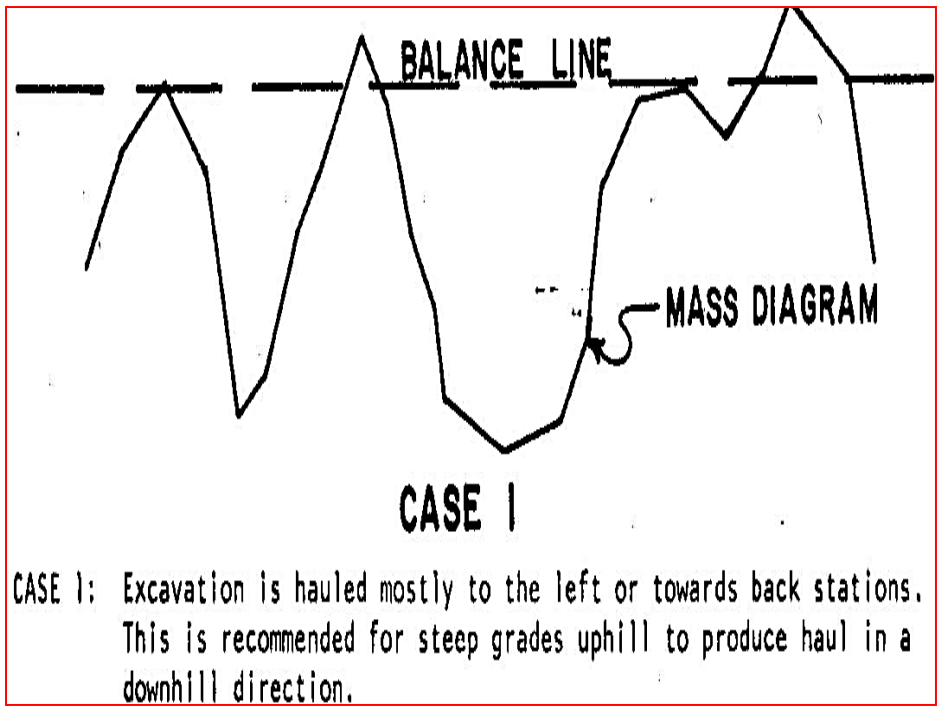
E.L.H = Economic limit of haul

F.H. = Free haul distance

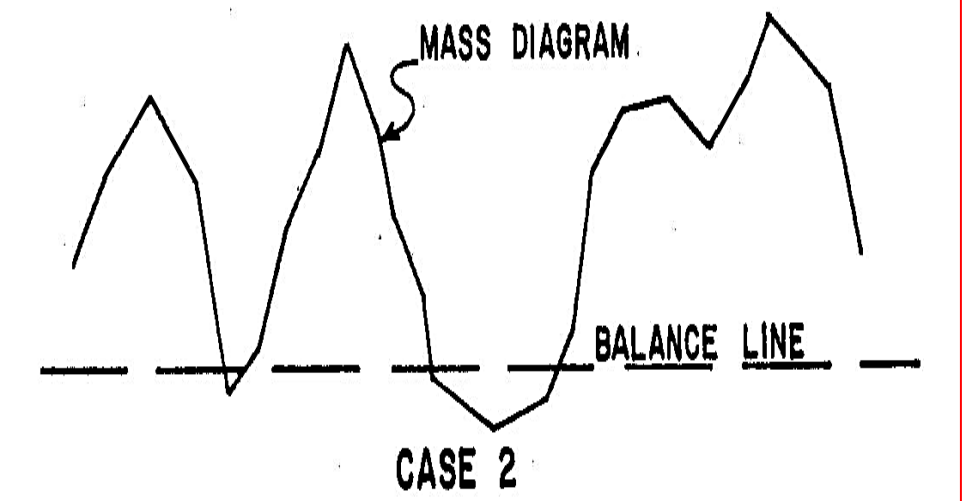
Choice of Balance Lines

- The following factors should be considered before the final choice of a scheme of balance lines is made.
  - ✓ **The uses of more than one balance line results in waste and borrow at intermediate points along the project which will involve extra excavation and transportation of materials.**
  - ✓ **Short unconnected balance lines are often more economical than one long balancing line, especially where the balancing lines are shorter than the free haul distance.**
  - ✓ **The direction of haul should be considered in the choice of balancing lines as for distances down hill hauling saves power or cost.**

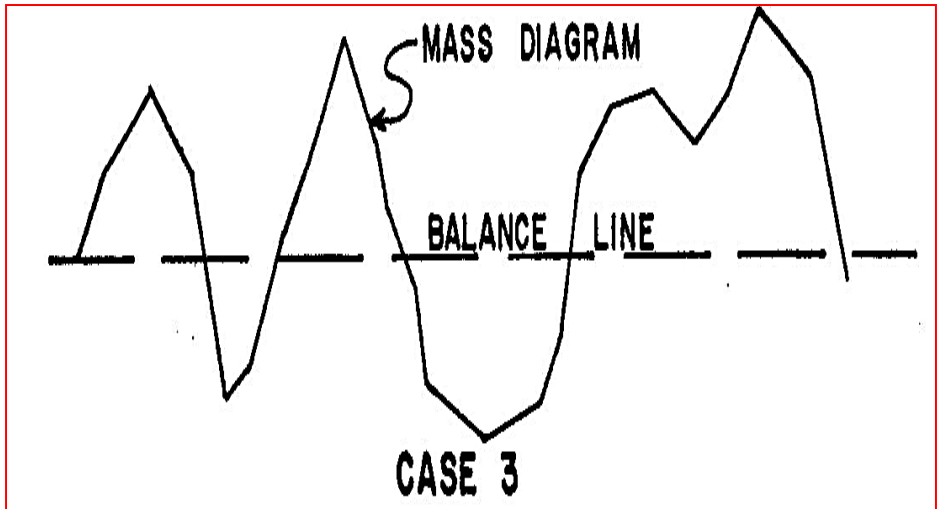




CASE 1: Excavation is hauled mostly to the left or towards back stations. This is recommended for steep grades uphill to produce haul in a downhill direction.



CASE 2: Excavation is hauled mostly to the right or towards forward stations. This is not recommended for steep grades uphill but can be used on downhill grades providing balance distances are not too long.



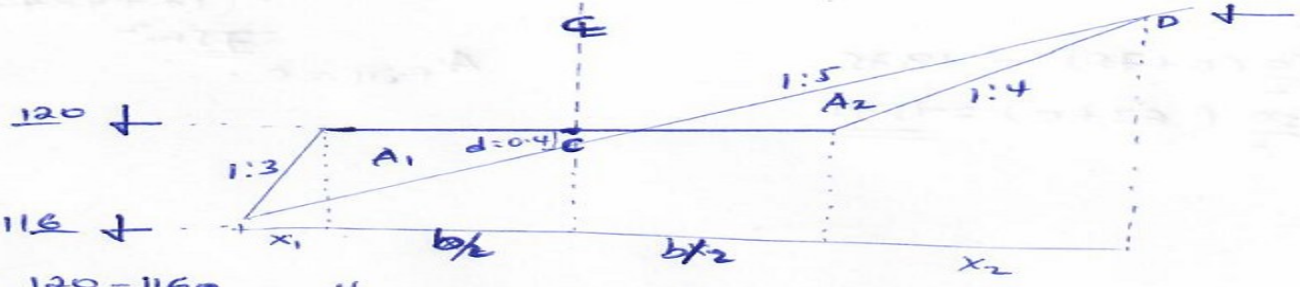
CASE 3: Excavation is hauled equally to left and right. This is optimum situation for most road construction where grades do not exceed 5%.

Example At a 0+050m station of the selected route corridor the formation level of elevation 120m is located 0.4m above natural ground slope of 1 in 5. The elevation on the left hand side of the highway is 116m. The slope of excavation and embankment is 1 in 4 and 1 in 3 respectively. However at a 0+100m station the earth work is totally fill section of 3 m depth on levelled surface with same side slope of previous fill section. At 0+150m station the earth work is totally cut section of 4.5 m depth on levelled surface with same side slope of previous cut section. Compute the following.

a. Area of cut and fill section at each stations
b. The highest elevation of back slope at 0+050 station cross section.
c. Volumes of cut and fill between given stations
d. Draw the mass haul diagram for the given 150m roadway and indicate the direction of hauling.

@ 0+000 There is no Area and Volume of cut and fill -

@ 0+050 m



$\frac{V}{H} = \frac{1}{3} = \frac{120-116.0}{x_1} = \frac{4}{x_1} \Rightarrow x_1 = 12\,m$

$\frac{120-0.4-116}{b/2+x_1} = \frac{1}{5} = \frac{3.6}{b/2+12} \Rightarrow b/2 = 18-12 = 6m \Rightarrow b = 12m$

elevation of right end point of the highway (point D) is calculated by

$\frac{Del_2-116}{x_2+b+x_1} = \frac{1}{5} = \frac{Del_2-116}{x_2+24} = \frac{1}{5}$ ..... (*)

$\frac{Del_2-120}{x_2} = \frac{1}{4} \Rightarrow x_2 = 4Del_2 - 120\times4 = 4Del_2 - 480$

from eq(2) (*):

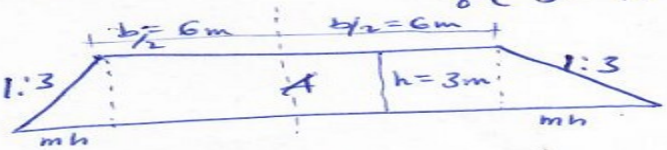
$5Del_2 - 580 = x_2 + 24 = 4Del_2 - 480 + 24$

$Del_2 = 580 - 480 + 24 = 124m$

Therefore $A_1' = \frac{(b+2nd)^2}{8(n-m_1)} = \frac{(12+2\times5\times0.4)^2}{8(5-3)} = 16\,m^2$ → fill area

$A_2' = \frac{(b-2nd)^2}{8(n-m_2)} = \frac{(12-2\times5\times0.4)^2}{8(5-4)} = 8\,m^2$ → cut area

@ 0+100



$A_F = \frac{1}{2}(b_1+b_2)h$

$= \frac{1}{2}(b+b+2mh)h$

$= (b+mh)h$

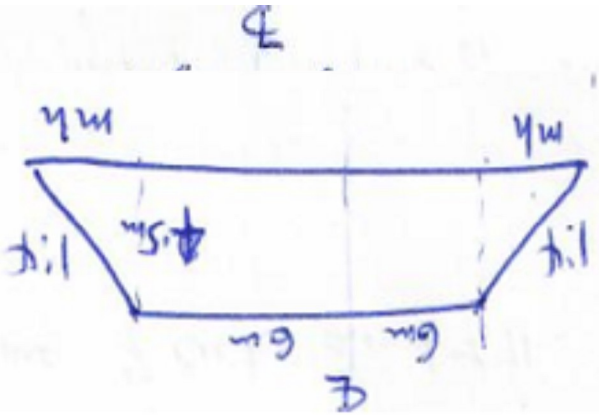
$= (12+3\times3)3 = 63\,m^2$

$A_C = 0$

From the above calculation we can calculate the volume as tabulated below -

@ 0+000 $V_{cut} = \frac{L}{2}(A_1+A_2) = \frac{50}{2}(0+8) = 200\,m^3$

@ 0+150



$A_{cut} = \frac{1}{2}(b+b+2mh)h$

$= (b+mh)h$

$= (12+4\times4.5)4.5$

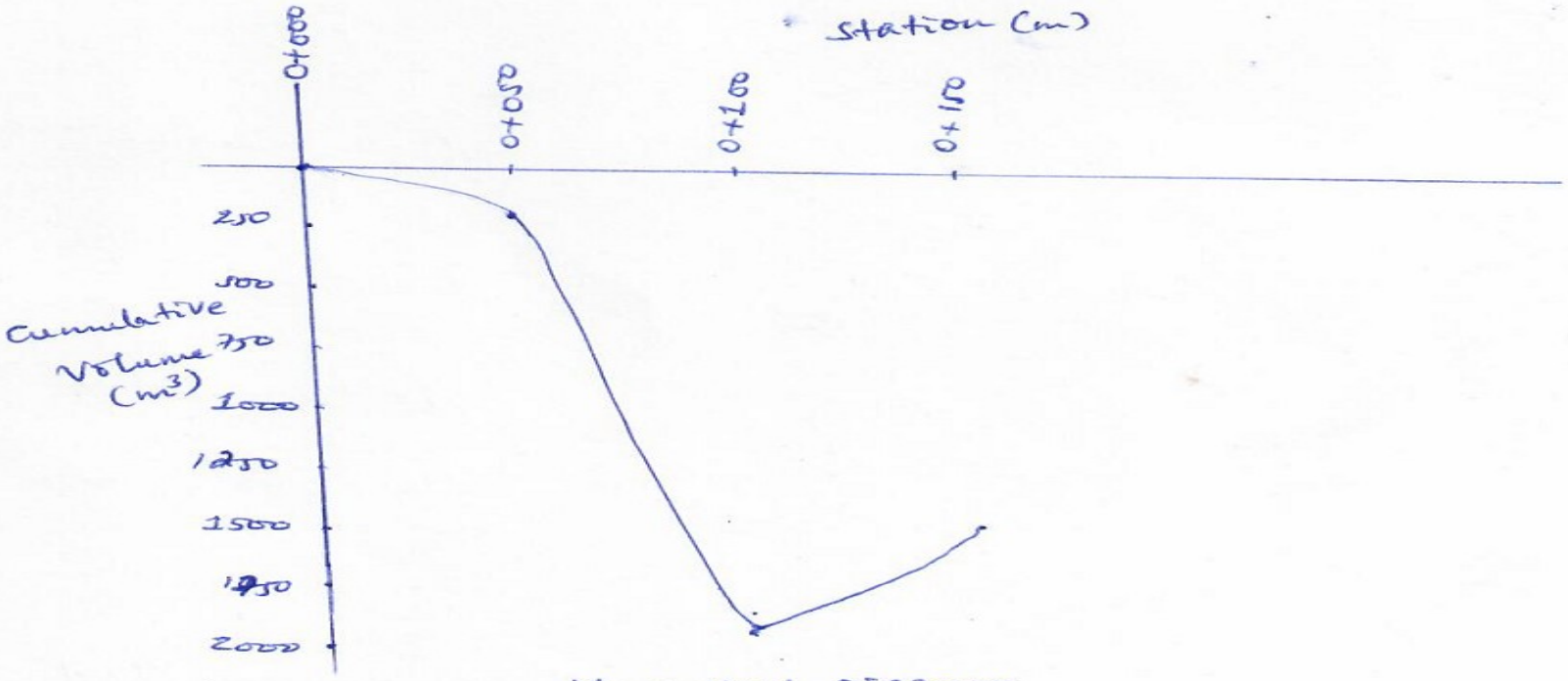
$= 75 m^2$

$A_{fill} = 0$

$V_{cut} = \frac{50}{2}(0+75) = 1875$

$V_{fill} = \frac{50}{2}(63+0) = 1575$

Station	A_{Cut} (m^2)	A_{Fill} (m^2)	Cut Volume (m^3)	Fill Volume (m^3)	Cumulative Volume (m^3)
0+000	–	–	–	–	0
0+050	8	16	200	-400	-200
0+100	0	-63	200	-1875	-1875
0+150	75 m^2	0	1875	-1575	-1675



Mass-Haul Diagram