I. EARTHWORK QUANTITIES

In the geometric design of a highway, it is almost always certain that the final grade line will definitely not follow the existing ground level in order to satisfy certain design controls and criteria. Thus, there will almost always be areas of cutting away portion of the existing ground and areas of filling up some portions. The process of cutting and filling portions of the existing ground is called earthwork operations in highway.

Since earthwork operations form a substantial part of any rural highway project and probably represent the largest variable factor in constructional costs, detailed attention must be paid it.

Road Cross-Sections

Generally, road cross-sectional profiles at specified interval (e.g. 25m) are plotted to a scale of, say, 1 : 250 using spot levels taken along the center-line and at offsets of 5m, 10m, 15m, 20m and 25m to either side, or wherever there is a marked change of slope.

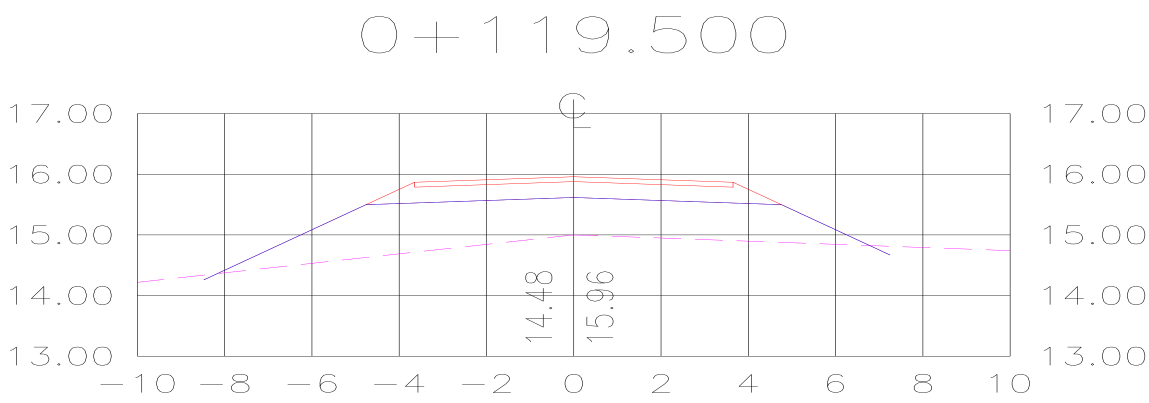


Fig. 1a – Typical cross-section profile – in embankment

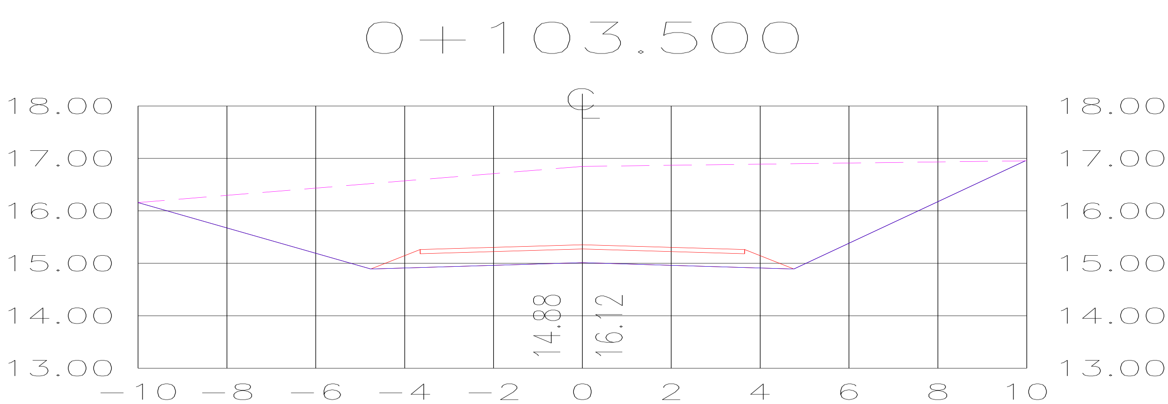


Fig. 1b – Typical cross-section profile – in cut

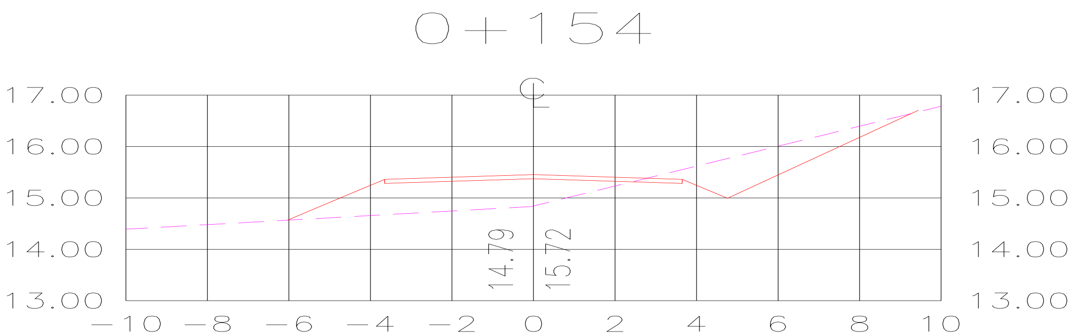


Fig. 1c – Typical cross-section profile – in both embankment and cut

Volumes are calculated by relating the cross-sectional areas to the distances between them. In order to compute the volume, it is first necessary to evaluate the cross-sectional areas, which may be obtained by the following methods:

i) By calculating using formula or from first principles, the standard cross-sections of constant formation widths and side slopes

ii) By measuring graphically from plotted cross-sections drawn to scale, areas being obtained by plannimeter or division into triangles or squares.

N.B. A plannimeter is an instrument used to directly measure areas bounded by an irregular curve. There are many different types of the instrument but all consist basically of two rods AB and BC, hinged at B (see Fig. 1d). The end labeled A is fixed, rod BC carries a wheel at B and point C is the tracer which is guided round the boundary of the figure to be measured.

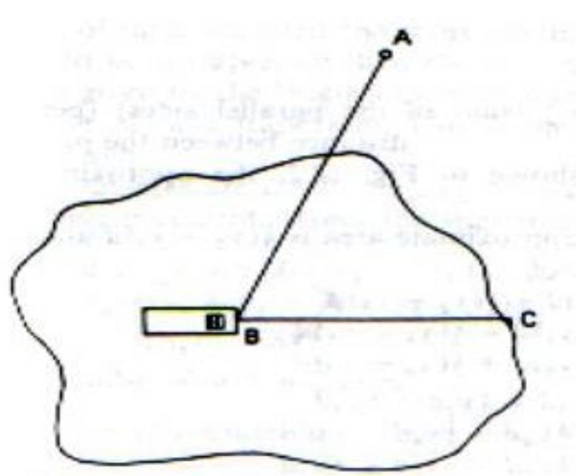


Fig. 1d – Planimeter (schematics)	**Fig. 1e** – Planimeter

BASIC METHODS OF CALCULATING EARTHWORK QUANTITIES

There are basically two standard methods of calculating earthwork quantities namely: Average End Areas (Avgendarea) method and the Prismoidial method.

A) Average End Areas Method

This is an approximate method of calculating volume and is accurate enough for most situations. In this method you essentially take the average of two areas and multiply that average by the distance between the areas using the formula:

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

where A_1 and A_2 are the cross-sectional areas distance L apart.

It should be noted that this method is exact when $A_1 = A_2$.

For a volume comprised of several sections you sum them up:

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

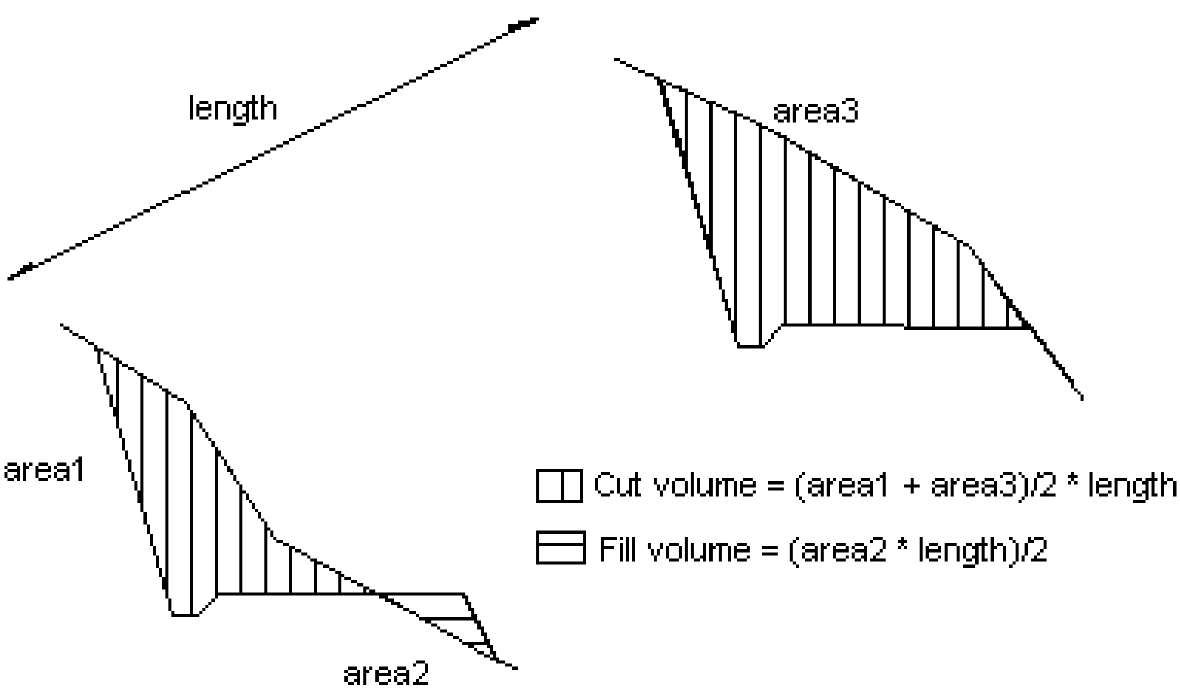


Fig. 1f – Typical Cross-sectional Areas

B) Prismoidal formula

A prismoid is defined as any solid having two plane parallel faces, regular or irregular in shape, which can be joined by surfaces either plane or curved on which a straight line may be drawn from one of the parallel ends to the other. Examples of prismoids are shown in Figure 1g.

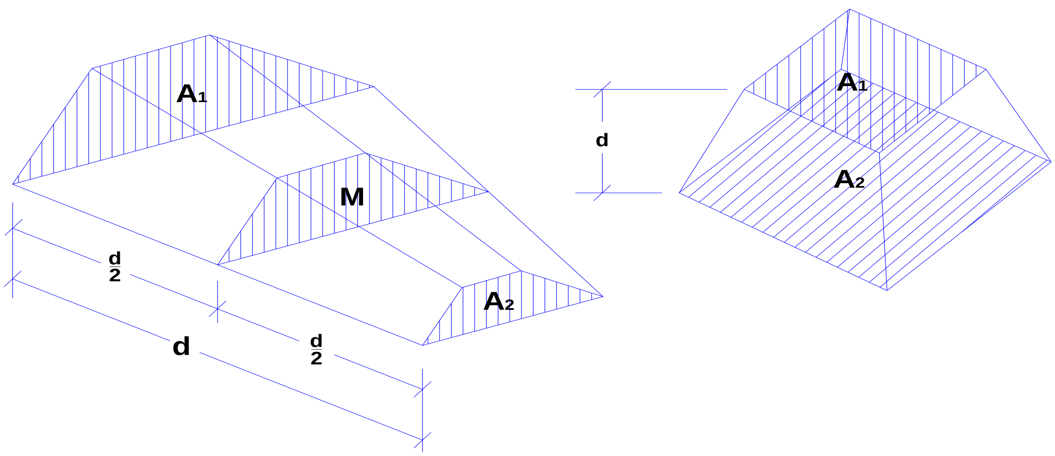


Fig. 1g – Examples of prismoids

In the prismoidal method, the volume is calculated using the two end areas and a middle area obtained from the average of linear dimensions. The following formula gives the volume of a prismoid based on the end and middle areas:

$$V = \frac{1}{6}L(A_1 + 4M + A_2)$$

where A_1 and A_2 are the cross-sectional areas distance L apart, and M is the area of a section mid-way between the two ends (*Note: M* is not necessarily the mean of A_1 and A_2)

J. MASS HAUL DIAGRAM (MHD)

Mass-haul diagrams (MHD) are used to compare the economics of the various methods of earthwork distribution on road or railway construction schemes. With the combined use of the MHD plotted directly below the longitudinal section of the surveyed centre-line, one can find:

i) The distances over which ‘cut and fill’ will balance.

ii) Quantities of materials to be moved and the direction of movement.

iii) Areas where earth may have to be borrowed or wasted and the amounts involved.

1. <u>BULKING AND SHRINKAGE OF MATERIAL</u>

Some materials such as rock and chalk increase in volume when excavated and subsequently compacted to form an embankment and this phenomenon is termed <u>*bulking*</u>. Other materials such as gravel, sandy soils, and clays show a decrease in volume as a result of more thorough compaction and this is termed <u>*shrinkage*</u>.

The shrinkage factor is the term used to describe the relationship between the excavated volume and the volume of fill. Excavated quantities can therefore be converted to volume of compacted fill by the use of this shrinkage factor, which could be taken as 1.2, thus:

$$V_{excv.} = 1.2\, V_{fill}$$

2. <u>HAULAGE OF MATERIAL</u>

The cost of any earth-moving operation depends not only on the volume and nature of the materials to be handled but also on the distance which these materials have to be carried from the point of excavation to the point of tipping and compaction.

In road schemes, the earthworks are usually planned so that, <u>where suitable</u>, material excavated from a cutting can be used to form an embankment further along the road. As this may entail carting (or hauling) the material over a considerable distance, the cost of haulage is taken into account by the contractors making allowance for haulage in the rates quoted for the item(s) covering excavation in cutting and forming of embankments.

3. EARTHWORK TERMINOLOGIES

a) **Haul distance (d)** – This is the distance from the working face of the excavation to the tipping point.

b) **Average haul distance (D)** – The distance from the centre of gravity of the cutting to that of the filling.

c) **Haul** – This is the volume of material multiplied by the distance through which it is moved. It is usually expressed in station metre. (Haul = Volume X Distance)

d) **Freehaul and Overhaul** – On certain road contracts, the Bill of Quantities may be drawn up so that the items relating to general excavation and compaction of material include haulage only within a specified distance, called the *freehaul distance*. Haulage over and above this distance is paid for under an additional item, and the extra distance is termed the *overhaul distance*. The amounts of material involved under these items are termed the *freehaul* and *overhaul* respectively, and these volumes can be ascertained by reference to the mass haul diagram.

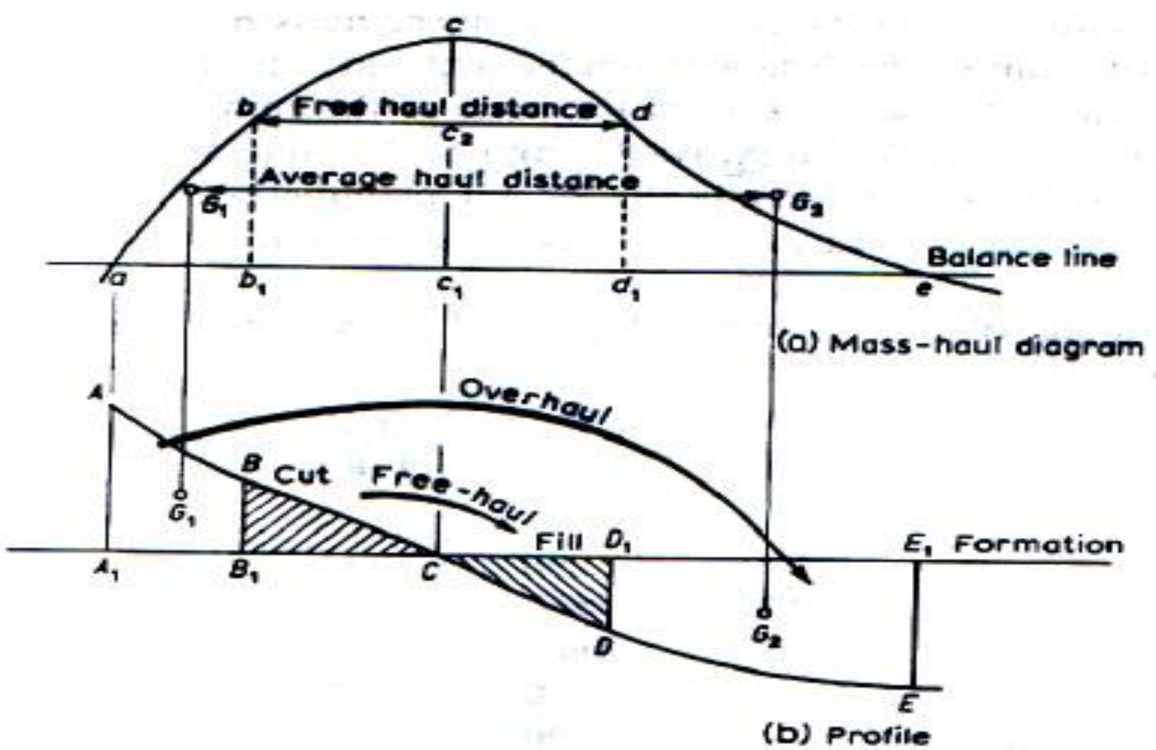


Figure 2a – Freehaul and Overhaul

e) **Economic Haul** – When the contractor is faced with large haul distances, it is more economical for him to waste material within the entire area of construction and borrow material from nearby areas than to pay for the expensive overhauling. On any given scheme, the economic haul distance will vary considerably as it depends both on the availability of suitable borrow material and of nearby sites where excavated material can be wasted.

The economic distance of haulage is termed the *Economic Haul* and can be determined by equating the cost of roadway excavation plus overhaul and tipping in embankments with the cost of borrow pit material (include original cost as well as cost of excavation, hauling and tipping borrow in embankment) plus excavation, haul and wasting of roadway material within the freehaul distance.

f) **Waste and Borrow** – Materials excavated from cuts along the roadway but not used for embankment fill are called *waste*. *Borrow*, on the other hand is the material used for fill, which is not obtained from roadwork excavation but excavated elsewhere.

g) **Station Metre** – A unit of overhaul, viz. 1 m^3 x 100m.

4. THE MASS HAUL DIAGRAM

The mass haul diagram (Fig. 2) is related to the longitudinal profile of the road and shows the net cumulative volume, adjusted for bulking and shrinkage, up to any chainage along the center-line. Excavated volumes in cutting are positive while volumes of embankments are negative.

The diagram has the following characteristics:

a. If at any chainage the diagram is above the base line, then the net volume up to that section is positive; i.e. a surplus of cut. Below the base line denotes a deficit of fill.
b. A rising gradient on the diagram means that the road is in cutting at that section. A falling gradient denotes embankment.
c. A maximum point occurs at the end of a cutting and a minimum point occurs at the end of an embankment.

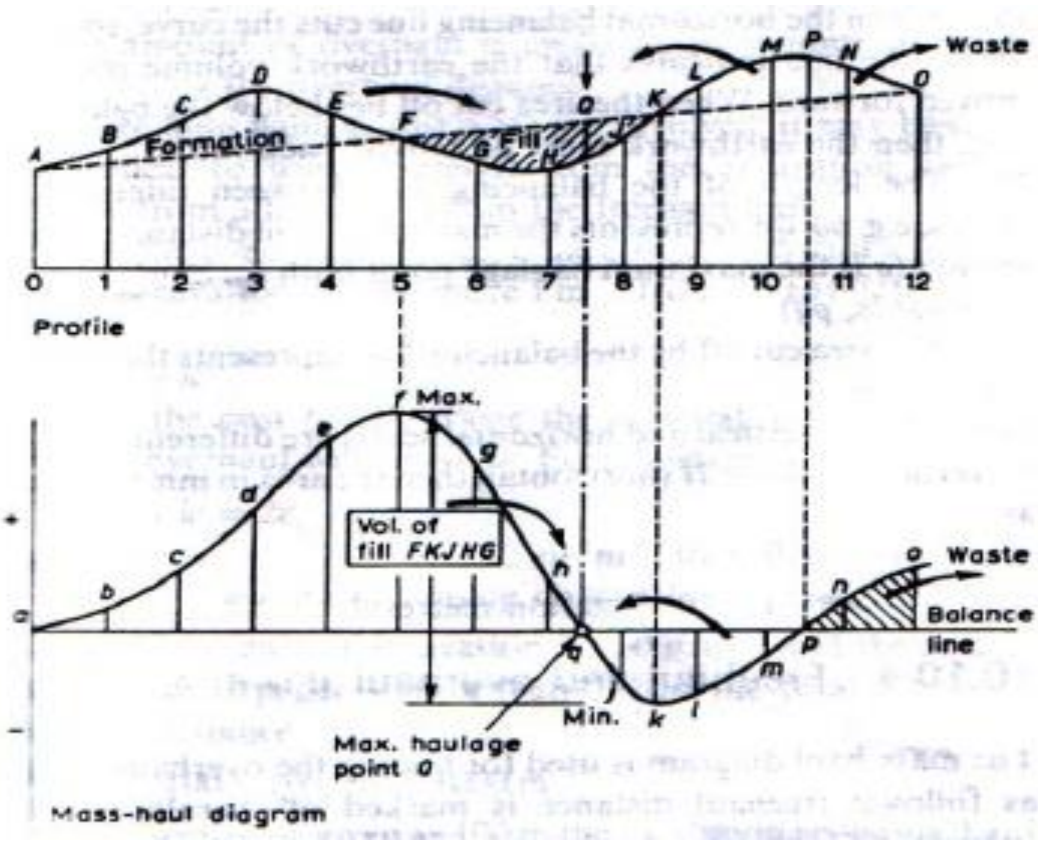


Figure 2a – Mass Haul Diagram

d. The vertical distance between any two points on the diagram is measure of the net volume of earthworks between these sections.

e. Any horizontal line on the diagram, including the base line, cuts the diagram at sections between which earthworks are balanced.

f. The length of any such balance line represents the maximum haulage distance between the sections.

Example:

Volumes of cut and fill along a length of proposed road are as follows:

Chainage	0	100	200	300	400	500	600	700	800	900	1000	1100	1200
Cut	290	760	1680	620	120								
Fill						20	110	350	600	780	690	400	120

a) Draw a mass-haul diagram and exclude the surplus excavated material along this length.

b) Determine the overhaul if the freehaul distance is 300.

Solution:

Chainage	0	100	200	300	400	500	600	700	800	900	1000	1100	1200
Cut	290	760	1680	620	120								
Fill						20	110	350	600	780	690	400	120
Aggregate Volume	+290	+1050	+2730	+3350	+3470	+3450	+3340	+2990	+2390	+1610	+920	+520	+400

Total Cut = 3470, Total Fill = 3070, Check = 3470 – 3070 = 400

i. As the surplus of 400 m^3 is to be neglected, the balancing line is drawn from the end of the mass-haul curve, parallel to the base line, to form a new balancing line ***ab***.

ii. As the freehaul distance is 300m, this is drawn as a balancing line ***cd***.

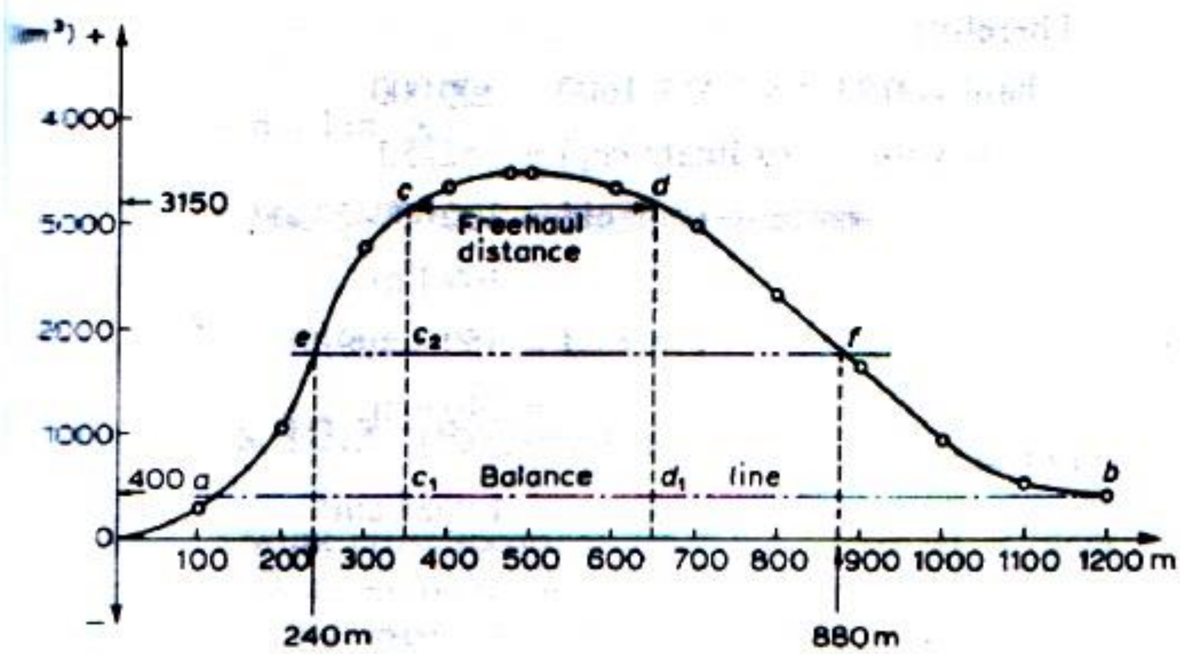
iii. From ***c*** and ***d***, draw ordinates cutting the new base line at c_1d_1.

iv. To find the overhaul:

a) Bisect cc_1, to give c_2 and draw a line through c_2 parallel to the base line cutting the curve at ***e*** and ***f***, which now represent the centroids of the masses acc_1 and dbd_1.

b) The average haul distance is the centroids of the masses acc_1 and dbd_1.

c) The overhaul distance = the haul distance – the free haul distance



The Mass-Haul Diagram for the example