

CHAPTER 4- EARTHWORK QUANTITIES AND MASS HAUL DIAGRAM

- Introduction
- Cross-sectional Elements
- Calculation of Areas
- Calculation of Volumes
- Mass Diagram
- Balancing Procedures
- Computation of Costs
- Examples

INTRODUCTION

□ Earthwork

- ▣ refers to moving earth for highway construction purposes
- ▣ Involves activities such as clearing, grubbing, excavation, embankment, borrow, grading, etc.

□ Objective:

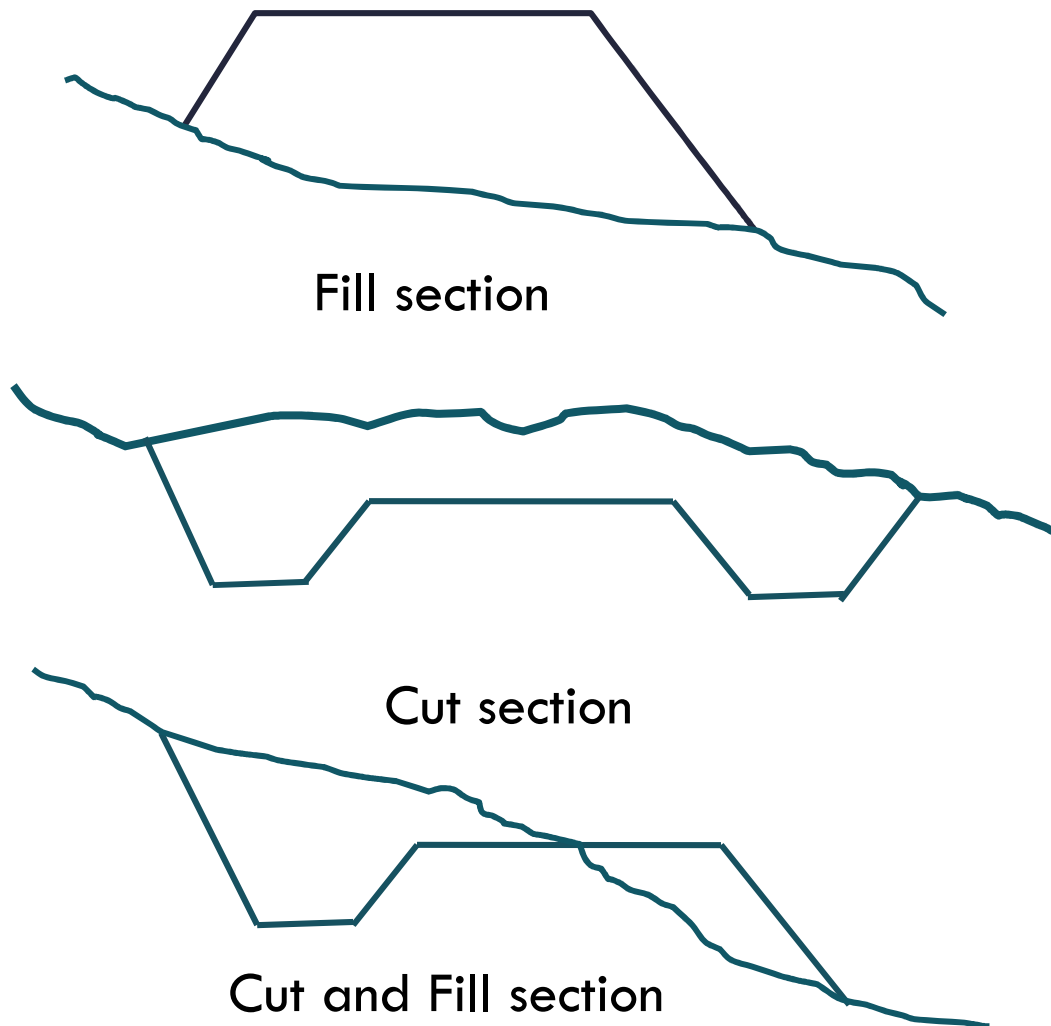
- ▣ Compute volumes of cut and fill
 - ▣ Identify location of quantities
 - ▣ Distance of earth moving
 - ▣ Estimate costs of moving earth
- ❖ Highly influenced by the geometric design of the road and type of soil.

INTRODUCTION

□ Definition of Terms:

- Excavation is the quantity of material in cut
- Embankment is the quantify of material in fill
- Haul is the distance a cubic unit of material is transported (st.m)
- Free-haul is distance the contractor can haul a cubit unit of material without extra cost above the cost of excavation.
- Overhaul is all haul distance beyond the free haul.
- Waste is excavated material which is not used for fill.
- Borrow: material needed for fill but not obtained from road grading.

Cross-sectional Elements



Cross-section elements show:

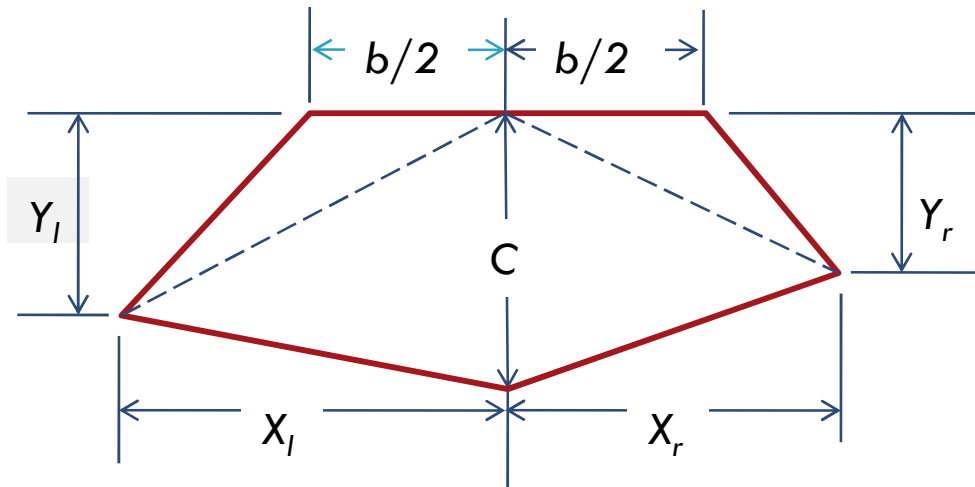
- Location/station of original ground section and template section
- Elevation of proposed grade
- Areas of cut/fill

- Computed volumes are placed between two successive cross-sections.

Computation of Areas and Volumes

Area for three-level section:

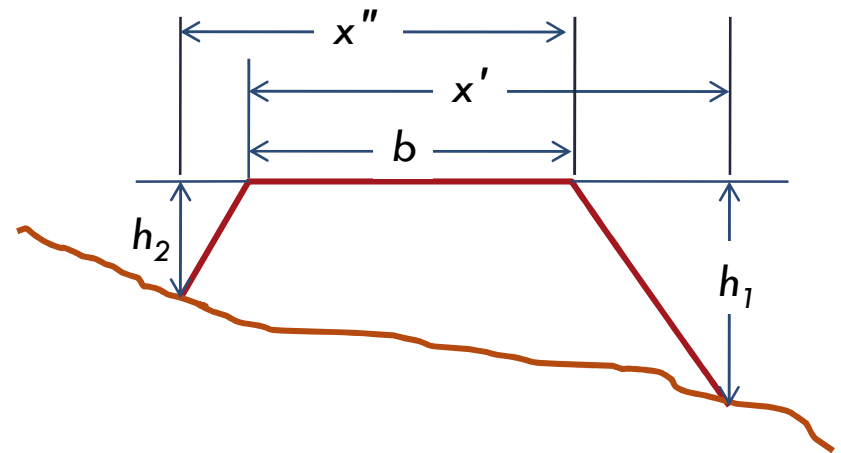
- Three reading taken from slope stakes



$$A = \frac{b}{4}(Y_l + Y_r) + \frac{C}{2}(X_l + X_r)$$

If slope stake notes are not available:

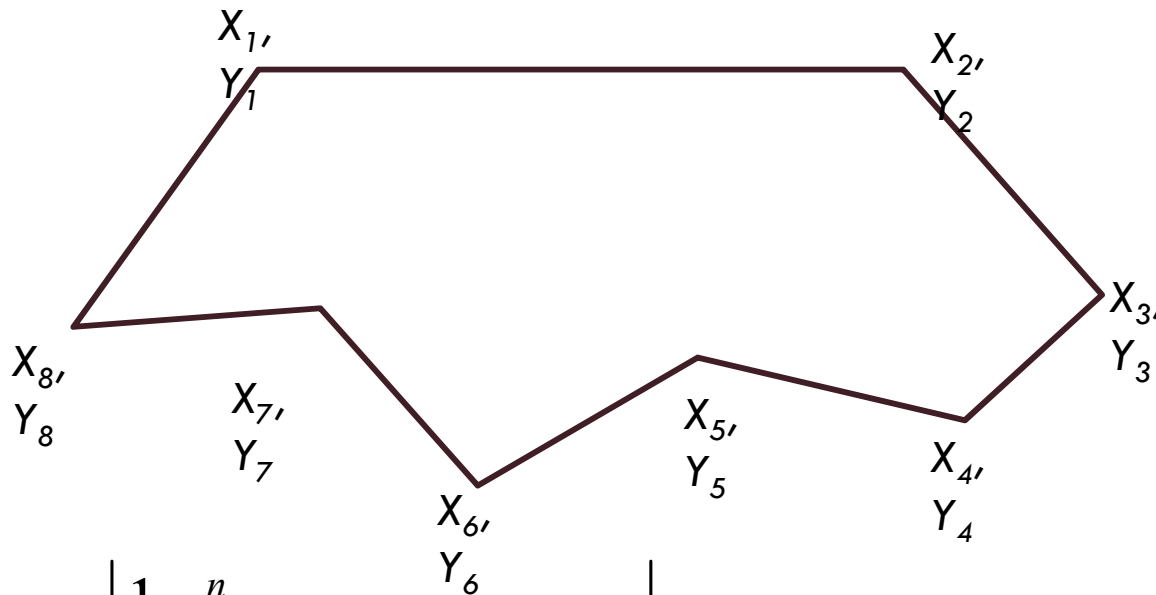
- Four field measurement



$$A = \frac{1}{2}(h_1 x'' + h_2 x')$$

Computation of Areas and Volumes

Area by coordinate method



$$A = \left| \frac{1}{2} \sum_{i=1}^n X_i (Y_{i+1} - Y_{i-1}) \right| \quad \text{where : } n+1=1; 1-1=n$$

Example 1:

- The following are notes for an irregular cross-section. Compute the cross-sectional area by dividing it into triangles and trapezoids. The roadway is 14 m wide and the side slopes are 1:2.

F4.00	F8.20	F6.60	F8.10	F6.76
15	6.2	0	17.9	20.52

Example 2:

- The following are notes for an irregular cross-section. Compute the cross-sectional area. The roadway is 12 m wide and the side slopes are 1:2.

C3.50	C2.87	C1.33	C3.53	C4.77	C6.20
13.0	7.73	2.80	0	13.13	18.40

Computation of Areas and Volumes Contd.

Volume by average end-area method

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

- Less accurate than the prismoidal formula
- Generally accepted approach

Volume by prismoidal formula

$$V_p = \frac{L(A_1 + 4A_m + A_2)}{6}$$

- The sides of A_m are average of the corresponding sides of A_1 and A_2

- Prism

If one of the end areas is zero

$$V = \frac{AL}{3}$$

Distribution Analysis and Mass Diagram

□ Distribution analysis:

- ▣ determining balance points along the roadway center line between cut and fill.
- ▣ Mass diagram is used on larger projects

□ Mass Diagram

- ▣ a continuous graphical display of cumulated cut and fill volumes plotted as ordinates versus stations along the center line as abscissas.
- ▣ Cut is positive and fill is negative
- ▣ Plotted above or below centerline profile

Mass Diagram contd.

□ Features of the mass diagram

- ▣ A rising curve indicates a cut, as from A to C;
- ▣ A falling curve indicates fill, as from C to B;
- ▣ A maximum point on the curve, as at C, indicates a change from cut to fill
- ▣ A minimum point as at D indicates a change from fill to cut in the direction of stationing;
- ▣ A horizontal line intersects the curve of the mass diagram at balance points.
 - Ex. AB in the Fig. is a balance line

Mass Diagram contd.

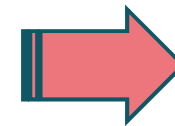
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Mass Diagram cond.

aa' (1 cubic unit of cut)

bb' (1 cubic unit of fill)

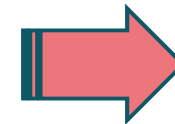


$\text{Vol} \cdot x = \text{Area}$
($AA'BB'$)

Move $aa'c$



Place at $bb'c$



$\equiv \text{Area } b/n$
ACB and AB

If $AB=F$

$aa'c$ excavated
and placed at $bb'c$
at the unit price of
excavation

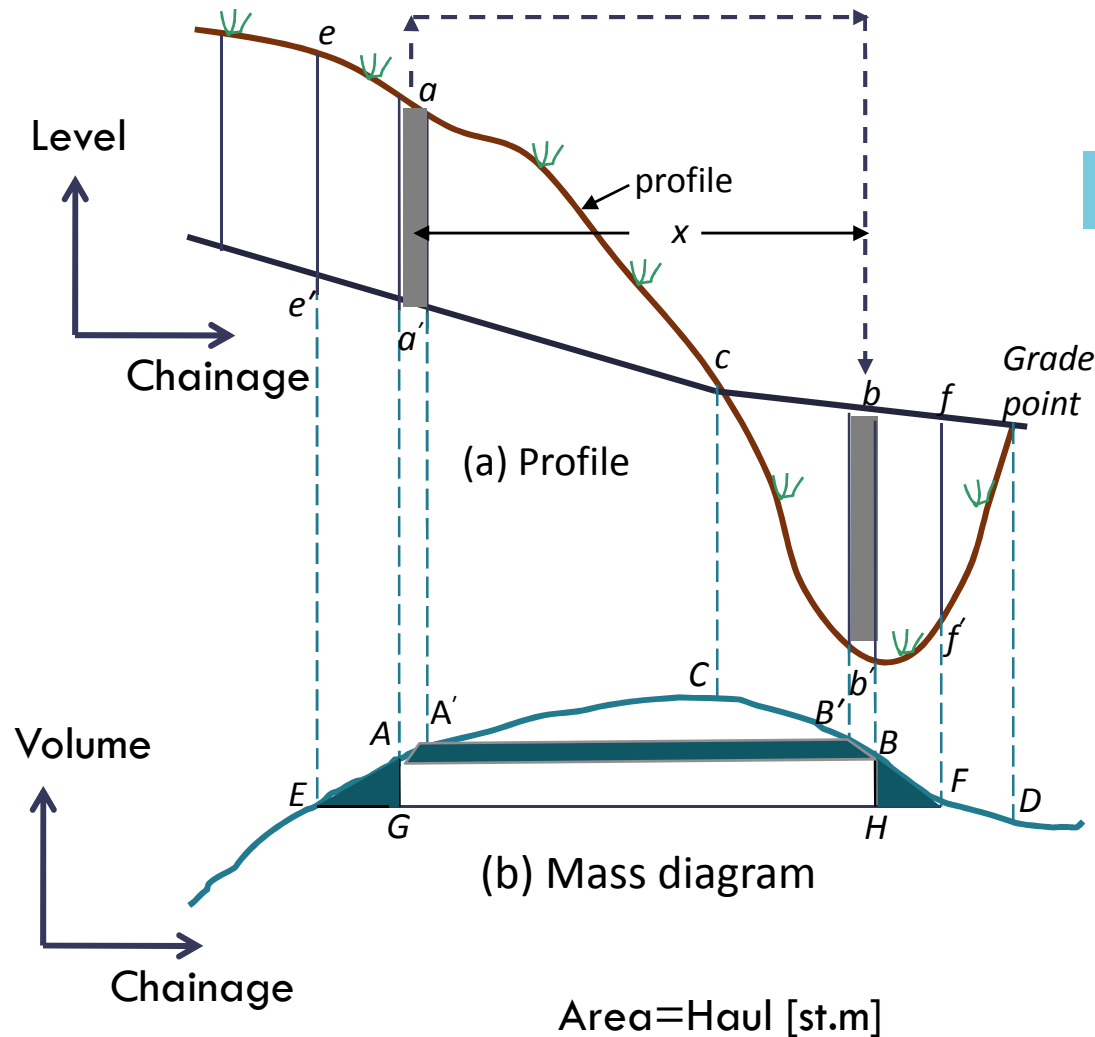
Move $ea'a'e'$



Place $bff'b'$

**OVER
HAUL**

$\equiv \text{Area of}$
EAG + BFH



Mass Diagram contd.

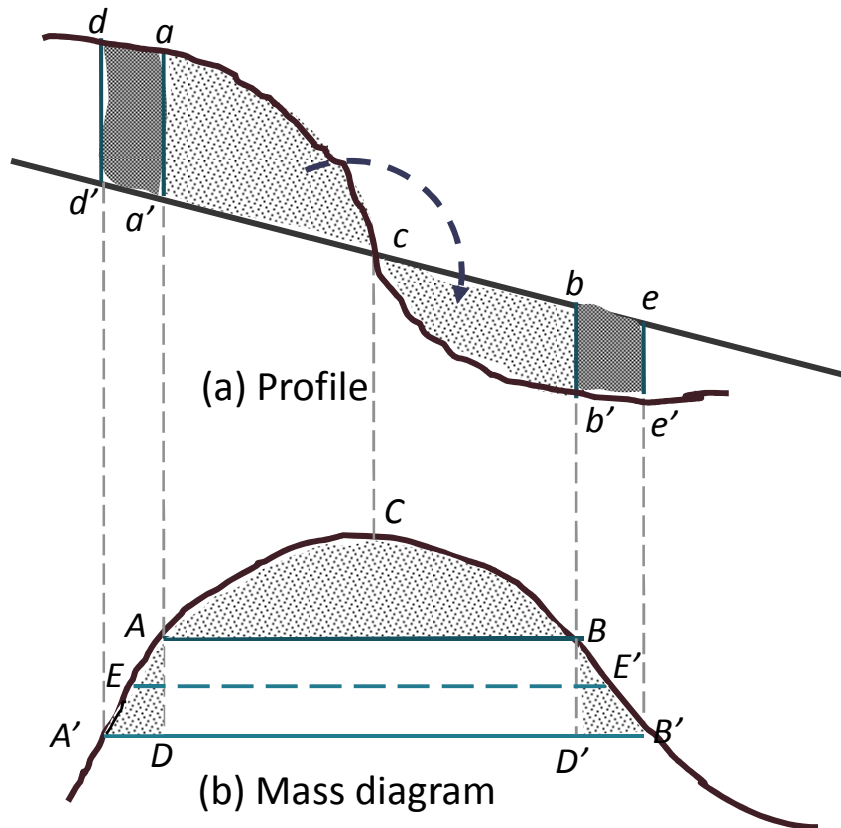


Fig. Free-haul and Overhaul

Assume:
 $AB = F$ and
 $A'B' = LEH$

Move $aa'd'd$



Place $bb'e'e$

**OVER
HAUL**

$\equiv$ Area of
 $AA'D + BB'D'$
 $= AD * (EE' - AB)$

If AA' and
 BB' are
 straight

EE' will be
 midway b/n
 AB and $A'B'$

Mass Diagram contd.

□ Limit of Economic Haul

$$C_B = C_{OH} (LEH - F)$$

$$LEH = \frac{C_B}{C_{OH}} + F$$

Where:

C_B =cost to borrow 1 unit volume

C_{OH} =cost for overhaul per station unit

F =free-haul distance, stations

L.E.H.=limit of economic haul, stations

• Shrinkage and swell

$$V_F = (1 + s) V_C$$

$$V_C = \frac{V_F}{1 + s}$$

Where:

V_C =Volume of cut

V_F =Volume of fill

s =shrinkage or swell factor

(+ve for swell, and -ve for shrinkage)

• Upto $\pm 30\%$

• Apply appropriate swell shrinkage factors.

Balancing Procedures

Two loops

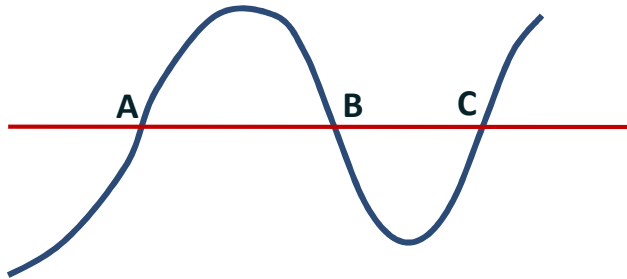


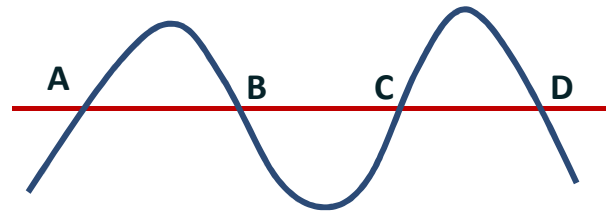
Fig. Balancing Procedures. (a) Two loops

$$\begin{aligned} AB, BC &< LEH \\ \text{And} \\ AB &= CB \end{aligned}$$

Even # of loops

$$\begin{aligned} \sum (\text{segments cutting concave or} \\ \text{convex loops}) &= \\ \sum (\text{segments cutting loops in} \\ \text{opposing direction}) \\ \text{AND} \\ \text{Each segment} &< LEH \end{aligned}$$

Three loops



(b) Three loops

$$\begin{aligned} (AB + CD) - BC &< LEH \\ \text{And} \\ AB, CD, BC &< LEH \end{aligned}$$

Odd # of loops

$$\begin{aligned} \sum (\text{segments cutting concave or convex} \\ \text{loops}) - \\ \sum (\text{segments cutting loops in opposing} \\ \text{direction}) &= L.E.H. \\ \text{AND} \\ \text{Each segment} &< LEH \end{aligned}$$

Computations of Costs

Excavation Costs = $\sum$ “cut” columns on the summary sheet

- Excavation prices > in terms of “cut-meters”
- Do not include correction for swell or shrinkage

Quantities of Over Haul

- Estimate the areas representing OH in each loop on the mass diagram
- Commonly using planimeter
- Pay haul excludes the FHD (F): $OH = V(M - F)$

Quantities of borrow

- Determined from the mass-diagram
- $\sum$ (vertical dimensions of all areas of fill outside the balance line)

Example:

- Given the end areas below, calculate the volumes of cut and fill between stations 351+00 and 342+50. if the material shrinks 12%, how much excess cut or fill is there? Express excess cut or fill in m^3 .

	End Areas, m^2	
Station	Cut	Fill
351+00		57.93
351+50		52.28
351+75	0	23.58
352+00	8.4	3.73
352+14	13.8	0
352+50	33.34	

	End Areas, m^2		Volumes, m^3			
Station	Cut	Fill	Chainage, m	Length, m	Excavation	Embankment
351+00		57.93	0			
				50		2755.25
351+50		52.28	50			
				25		948.25
351+75	0	23.58	75			
				25	70	341.38
352+00	8.4	3.73	100			
				14	155.4	17.41
352+14	13.8	0	114			
				36	848.52	
352+50	33.34		150			

Total: 1073.92 4062.28

Excess Fill (m³ of fill)=

4062.28-1073.9(1.00-0.12)=*

3117.23

Example:

• Volumes in m³ of excavation (+) and fill (-) between successive sections 100 m apart on a 1300 m length of a proposed roadway are given below. Draw a MHD for this length. If earth may be borrowed at either end, which alternative would give the least haul? Show on the diagram the forward and backward free hauls if the free haul distance is 500 m, and give these volumes.

Section	0		1		2		3		4		5		6	
Vol (m ³)		-1000		-2200		-1600		-500		200		1300		2100

Section	7		8		9		10		11		12		13	
Vol (m ³)		1800		1100		300		-400		-1200		-1900		