Chapter V
Earth Work & Quantities

Tewodros N.
www.tnigatu.wordpress.com
tedynihe@gmail.com
Introduction

- Is the phase during a highways construction when the right of way is converted from its natural condition and configuration to the section and the grades prescribed in the plans.
Earth Work Includes

• Clearing
• Grubbing - clear off roots
• Excavation of drainage channels & trenches
• Excavation of structures
• Borrows
• Haul & Overhaul
• Grading
• Preparation of Side Slopes
• Reconditioning of roadway
• Other operations for preparing the subgrade for highway or runway pavement construction (Highway Eng. II)
Earth Work Includes

Clearing

Grubbing - clear off roots
Earth Work Includes

Borrows

Excavation of drainage channels & trenches
Earth Work Includes

Preparation of Side Slopes

Grading
Earthwork Quantity

• Quantity and Cost are calculated in $m^3$ either in its original form or by allowing for shrinkage and swell.

• The rate of payment generally includes full compensation for excavation, formation of embankment, preparing of side slopes, disposal or borrowing within the free-haul distance, and the preparation and completion of the subgrade and the shoulders.

• For borrowing or disposal involving more than the free haul distance.
Classification of Excavated Material

Usually the classification is into three categories:

1. **Solid Rock**: hard rock and boulders; Volume $> 1 \text{ m}^3$; best removed by blasting

2. **Loose Rock**: detached masses or rock – $0.025 < V < 1 \text{ m}^3$; could easily be removed

3. **Common/Ordinary Excavation**: all others
Shrinkage & Swell Factors

• The process of excavation breaks up earth and makes it take up more space afterwards – *Swelling* (e.g. excavated rock occupies a larger volume in fill)

• After placing the excavated earth in a fill and compacting, volume will become less than the original. Difference b/n original volume in cut and final volume in fill – *Shrinkage*
Shrinkage & Swell Factors

- Shrinkage depends on:
  - The material’s characteristics
  - Moisture content;
  - Climatic conditions; and
  - Method of placing

Shrinkage & Swell must be taken into consideration
Shrinkage of compacted fills

<table>
<thead>
<tr>
<th>Material</th>
<th>% of shrinkage</th>
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<tbody>
<tr>
<td>Light excavated soil (on ordinary ground)</td>
<td>10 – 20%</td>
</tr>
<tr>
<td>Light excavated soil (on swampy ground)</td>
<td>20 – 40%</td>
</tr>
<tr>
<td>Heavy Excavated soil</td>
<td>Up to 10%</td>
</tr>
<tr>
<td>Excavated Rock (Swell)</td>
<td>5 – 25%</td>
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</tbody>
</table>

Amount of excavation required to make a given fill may be arrived at by:
Shrinkage: multiply the fill quantity by $1 + \%sh$
Swelling: divide the fill quantity by $1 + \%sw$
Road Bed Sections

• A highway sub-grade is usually formed with shoulders and a trench section upon which the pavement will be constructed, the finished surface being crowned to facilitate drainage.

• Ditches are provided on embankment sections to transfer water down the fill slopes into pipes or paved gutters to protect the embankment against erosion.

• On curves of 5° or sharper subgrade is banked and widened. Width of road bed in cut is wider than on fills to allow for side-ditches.
Typical Sections

Fill

Cut

Cut & Fill
## Side slopes of X-sections

<table>
<thead>
<tr>
<th>Material</th>
<th>Ht. of Slope</th>
<th>Side Slope Cut</th>
<th>Side Slope Fill</th>
<th>Back Slope</th>
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<tbody>
<tr>
<td>Soil</td>
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<td>1:4</td>
<td>1:4</td>
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<tr>
<td></td>
<td>1 – 2</td>
<td>1:3</td>
<td>1:3</td>
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<tr>
<td></td>
<td>Over 2</td>
<td>1:2</td>
<td>1:2</td>
<td></td>
</tr>
<tr>
<td>Rock</td>
<td>Any ht.</td>
<td>See standard details</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Cotton Soil</td>
<td>0 – 2</td>
<td>-</td>
<td>1:6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over 2</td>
<td></td>
<td>1:4</td>
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</tbody>
</table>
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

• Methods
  – For regular/level ground ⇒ simple geometry
  – For irregular ground, two methods
    1. Graphical or plan meter method
    2. Coordinate or other approximate method
Area for Regular Ground

Area of a trapezoid

\[ A = bd + sd^2 \]
Area for (Regular) cut - fill sections

\[ A_1 = \frac{(b - 2nd)^2}{8(n - s_1)} \quad \text{and} \quad A_2 = \frac{(b + 2nd)^2}{8(n - s_2)} \]

When \( c \) is to the right of the point of zero fill

\[ A'_1 = \frac{(b + 2nd)^2}{8(n - s_1)} \quad \text{and} \quad A'_2 = \frac{(b - 2nd)^2}{8(n - s_2)} \]

When \( c \) is to the left of the point of zero fill
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

$$A_1 + A_2 = L/3 (O_1 + 4O_2 + O_3)$$
$$A_3 + A_4 = L/3 (O_3 + 4O_4 + O_5)$$
$$A = L/3 (O_1 + O_N + 4 \sum \text{even offsets} + 2 \sum \text{remaining odd offsets})$$
Computation of Volumes

Two methods will be discussed here:

1. Average End Area Method
2. Prismatic Formula
Average End Area Method

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

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

\[ V = l / 2[(A_1 + A_n) + 2(A_2 + A_3 + ... + A_{n-2} + A_{n-1})] \]
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: \( V_{ab} = \frac{l}{6}(A_1 + 4A_m + A_2) \)

- \( V_{13} = \frac{l}{3}(A_1 + 4A_2 + A_3) \)
- \( V_{35} = \frac{l}{3}(A_3 + 4A_4 + A_5) \)

\[ \Rightarrow V_{15} = \frac{l}{3}(A_1 + A_5 + 2A_3 + 4(A_2 + A_4)) \]
\[ \Rightarrow V = \frac{l}{3}(A_1 + A_N + 2(\text{remaining odd areas}) + 4(\text{even areas})) \]

- \( A_1 \neq A_3 \) 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-haul 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.
Mass-haul Diagram

- Cut
- No Cut and Fill
- Fill

• Chainage
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:m³)V)
6. Join points by a straight line or curves

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<tbody>
<tr>
<td></td>
<td>Cut</td>
<td>Fill</td>
<td></td>
<td>Cut</td>
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Mass-Haul Diagram

Characteristics

I. The Ordinate at any point represents the cumulative material to that point on the profile

II. Within 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

Natural ground profile
Proposed grade line

Aggregate volume (m³)

Chainage (km+m)
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 to a section of the site due to deficiency of suitable material
Limit of Economical Haul

• For long haul distances, it may be economical to waste and borrow materials rather than pay for cost of overhauling

Compare Cost of overhauling vs. Cost of waste + borrow
Limit of Economical Haul

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

Cost to excavate 1 m\(^3\) 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 1 m\(^3\) material in fill
\[ = C_b + C_e \quad (2) \]

Equating (1) & (2):
\[ C_e + C_{oh} L_e = C_b + C_e \Rightarrow L_e = \frac{C_b}{C_{oh}} \]

Total Distance, \( D = L_e + F \)
where: \( F = \text{free haul distance} \)
Example

If the cost of roadway excavation, $C_e$, is 800 cents/m³, cost of borrow, $C_b$, is 700 cents/m³, and cost of overhaul, $C_{oh}$, is 12 birr/m³-station, what is the economical length of overhaul? The free haul distance is 1.5km and a station is 100m long.

Ans: $L_e = 1558$m
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 1.1 km. Use a shrinkage factor of 0.9.
## Example

<table>
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<td></td>
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<td></td>
<td>Cut</td>
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Thank You!