IRRIGATION AND DRAINAGE ENGINEERING

Asst. Prof.
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2016-2017
Subject: Irrigation & Drainage Engineering

<table>
<thead>
<tr>
<th>ABET Code</th>
<th>Units</th>
<th>First Semester</th>
<th>Second Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>50601305</td>
<td>4</td>
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</tbody>
</table>

50601305 Irrigation and Drainage Engineering

Irrigation: Introduction, definition, purposes, necessity, soil – water - plant relations, land grading, computation, design slope calculations, earth works calculations, Infiltration, infiltration equations, field measurements. Surface irrigation, efficiency, adequacy, uniformity, water balance concept, water front advance. Consumptive use and water requirements, net and gross depth, continuous and intermitted discharge, Irrigation scheduling, water duty.

Irrigation Canals: Classification, general layout, numbering, canal design methods.

Drainage: Definition, drainage coefficient, Darcy's Law, closed and open drains, filters, cross sectional design of open and closed drains, design of drain spacing, vertical drainage system.

Reference
4. G.L. Asawa, Irrigation and Water Resources Engineering, 2005
7. James N. Luthin, Drainage Engineering, 1973
8. هندسة النيزل, عبدالستار الدباغ.
9. هندسة نظم الري الحقيقي, أحمد يوسف حامد.
10. -Lecture notes and other handouts as well as tutorial sheets.

Asst. Prof.
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2016 - 2017
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Asst. Prof. Dr. Rasul M. Khalaf
2016-2017
Conversion of Units

Length

1 inch = 2.54 cm
1 mile = 1.6093 km
1 ft = 0.3048 m
1 yard = 3 ft = 0.9144 m
1 cm = 0.394 inch
1 km = 0.6214 mile
1 m = 3.281 ft
1 m = 1.094 yard

Areas

1 acre = 4047 m²
1 acre = 43560 ft²
1 acre = 0.001563 mile²

or 1 mile² = 640 acre

1 hectare (ha) = 10000 m²
1 ha = 10⁴ m²
1 km² = 106 m²
1 km² = 100 ha

Dona = 2500 m²
1 hectare = 4 Donums
1 hectare = 2.471 acre

Volume & Discharge

1 gallon = 3.785 Lit.

ft³/sec = CFS = 0.0283 m³/sec

m³/sec = 35.315 CFS

2 acre-ft = 1 CFS day

Volume

acre-ft = 43560 ft³

ha - m = 10⁴ m³

convert 1 mile² to hectare:

2.471 acre

2500 m²

= 640 acre hect

= 2.471 acre

= 2500 m²
Chapter one
Introduction
Chapter one
Introduction

What is the irrigation? 

Irrigation: is the application of water to the soil for purpose of supplying the moisture essential for plant growth.

purposes:

1. Add water to soil for supplying moisture for plant growth.
2. Provide crop insurance against duration drought.
3. Cool the soil and atmosphere to get best environment.
4. Wash out the salt from soil.
5. Reduce soil erosion.
6. Use it as injection of fertilizers.

Necessity of irrigation:

1. Less rainfall.
2. Non-uniform rainfall.
3. Commercial crops with additional water.
4. Controlled water supply.

Types of irrigation:

1. Total irrigation: for areas of no rainfall.
2. Supplementary irrigation: in areas with rainfall for a part of a season per year.

For both types, one can use:

1. Surface irrigation system (Border, Basin, Fawows...)
2. Ground water irrigation (by well resources).
Irrigation water resources:

1. rainfall
2. surface water
3. Subsurface (groundwater)
4. Springs (temporarily)
5. Softening of sea water (high cost)
6. waste water (should be treated)

Irrigation Network

The irrigation network for any large project can be divided into two parts:

1. Major Distribution network
2. Minor Distribution network

The MDN included water diversion stills from main resources such as D in the figure, and then conveyance using of water by main conveyance lines assigned by A, whereas the MIDS is almost located in the irrigation unit and the farm assigned B.

For small irrigation projects the main irrigation network may not include just direct diversion will occur to minor irrigation network.
Irrigation Project!

Define as: the irrigated area specified for corps production. It consists water resource one(s) such as river, lake, well, etc., main irrigation network, minor irrigation network, drainage system of open and closed drains networks as well as the all required structures which are called hydraulic structures.

Benefits of Irrigation projects

1. Employment & Income
2. Security against impoverishment
3. Reducing migration
4. Quality of life

Irrigation Unit [watercourse] 

In modern designs, the irrigation unit consists of number of farms supplied by water through one watercourse which consequently supplied by water from distributed canals. The rectangular shape is preferable for simple operation & maintenance.

Farm

The area of the farm depends on type and nature of management, there were an individual farm owner is cooperative one. The convenient area of farm depends on Agr. density and Agr. mechanism.
Field

It is a part of farm planted by one type of crop and usually there will be more than one field planted at same time in each farm.

Surface gravity Irrigation!

It is an old irrigation method since 4000 years in Iraq, Egypt and India, and it is still used in most countries. It required to land grading to get slopes less than 6%. It is suitable for loamy-medium-soil and fine-heavy-soil. The types of surface irrigation can be divided into:

1. Border irrigation
2. Basin irrigation
3. Furrow irrigation
4. Sprinkler irrigation
5. Trickle (Drip) irrigation
Chapter Two
Soil-Water-Plant Relations
Chapter 2
Soil-water-plant relations

Soil classification
- Gravely soil > 2 mm
- Sandy soil 0.05 - 2.0 mm
- Silty soil 0.002 - 0.05 mm
- Clayey soil < 0.0002

According to USDA classification

Soil-water relations

Soil compositions
- Solid
- Water
- Air

Soil phases
- Dry
- Saturated
  - Fully Saturated
  - Partially Saturated

Voidsoil
- Soil skeleton
  - Partially Saturated
  - Fully Saturated
  - Dry soil
Volumetric relations

Void ratio $e$ is defined as:

$$ e = \frac{\text{Volume of voids}}{\text{Volume of solid}} = \frac{V_v}{V_s} $$

Porosity $\eta$ is:

$$ \eta = \frac{\text{Volume of voids}}{\text{Total volume}} = \frac{V_v}{V} $$

Volumetric moisture content $\omega$ is:

$$ \omega = \frac{\text{Volume of water}}{\text{Total volume}} = \frac{V_w}{V} $$

Degree of saturation $S$ is:

$$ S = \frac{\text{Volume of water}}{\text{Volume of void}} = \frac{V_w}{V_v} $$

For fully saturated soil, $V_w = V_v$ (no air). Thus:

$$ S = 1 = 100\% $$

Note that:

$$ \omega = \frac{V_w}{V} = \frac{V_w}{V_v} \cdot \frac{V_v}{V} $$

$$ \omega = S \cdot \eta $$

and

$$ \eta = \frac{e}{1 + e} \quad e = \frac{\eta}{1 - \eta} $$

moisture by weight

$$ W_c = \frac{W_w}{W_s} $$

(water content by weight)
Dry - 
Gs: specific gravity (relative density) 
\[ G_s = \frac{Y_s}{Y_w} \], \( Y_s = \text{solid density} = \frac{W_s}{A_s} \)

Wet - 
Gb: bulk specific gravity 
\[ G_b = \frac{Y_b}{Y_w} \], \( Y_b = \frac{W_s}{A} = \frac{Y_t}{1 + W/e} \)

\[ Y_t = \text{total density} = \frac{W}{A} = \frac{G_s + \sigma' e}{1 + e} \]

\[ Y_{buoyant (submerged)} = Y_{buoy} = Y_t - Y_w \]

\[ Y_{buoy for saturated soil} = \frac{G_s - 1}{1 + e} Y_w \]

\[ Y_{buoy for partially} = \frac{G_s - 1 - e(1 - s)}{1 + e} Y_w \]

Example 1
Determine moisture content available in a soil sample, if the wet weight of soil is 10 g and oven dried soil mass is 6.5 g.

\[ \frac{\text{weight of water}}{\text{weight of solid}} = \frac{10 - 6.5}{6.5} = 53.85\% \]

Example 2: \( Y_s = 4.8 \text{ g/cm}^3 \), \( Y_b = 2.5 \text{ g/cm}^3 \) \( \text{Find } \eta \)

\[ 1 - \eta = 1 - \frac{Y_b}{Y_s} = \frac{A - A_w}{A} = \frac{Y_s}{A} = \frac{V_s / W_s}{W_s / A} = \frac{1}{1 / Y_b} \]

\[ \text{Gb} = (1 - \eta) G_s \]

\[ 1 - \eta = \frac{Y_b}{Y_s} \Rightarrow \eta = 1 - \frac{2.5}{4.8} = 48\% \]
Subsurface water

Zone of creation Zone of saturation

Root Zone

Capillary Zone

Saturation Zone

Ground water

Impermeable stratum

Vadose Zone

Root Zone water

- Gravitational water (Rapid water)
- Capillary water (slow drainage)
- Hydroscopic water (No drainage)

Saturation (Field capacity)

Permanent wilting point (Oven dry condition)

S. I. Z. Soil moisture

R. I. Z.

Gravitational water: the water that moves in or out of the soil by gravity.

Capillary water: is the water that remains in the soil after draining of gravitational water. It permits plants to survive through droughts.

Hydroscopic water: is the water held very tightly by the soil particles. It is unavailable to plants.
Field Capacity (Fc): the water remaining in the soil after excess water (gravity water) was drained away and the rate of downward movement has decreased, after 2-3 days (after irrigation depends on texture & structural of soil).

Perennial Wilting point: Permanent Wilting point (PWP) is the moisture content beyond which the plants can no longer extract enough moisture and remains wilted unless water is added to the soil.

moisture tension at PWP (15 atm)
moisture tension at Fc (1/3 atm pressure)
PWP → Fc. (1/3 - 15) atm pressure
(30 kPa - 1500 kPa)
Available water (capillary water)
\[ AW = FC - PWP \]

Readily available water (RAW) is the water which can be removed from the soil with minimal energy required.

\[ RAW = \text{Percent of } AW \]

Allowable Depletion (AD) is the allowable amount of water that can be withdrawn from the soil between two successive irrigations without stressing the plant.

\[ RAW = AD \times AW \]

Soil moisture deficit (SMD) is the amount of water required to recover the soil moisture at field capacity.

\[ SMD_{max} = RAW \quad (SMD \leq RAW) \]

If \( SMD = 0 \), then water content is at FC.
moisture distribution after irrigation (immediately)

relation between water content and the crop production
Ex: For a soil: $F_c = 28\%$, by dry weight.

$PWP = 18\%$, by volume.

$AD = 50\%$, find Readily available water by volume, $Gb = 1.85$.

And Readily AV by weight.

Sol: $RAW = AD \times AW$

$= AD \times (F_c - PWP)$

$W$ by volume $= \frac{W_v}{V}$

by $V$ in terms of $Gb$: $V = \frac{W_s}{Gb \times W_v}$

$\Rightarrow W$ by volume $= \frac{V \times W_v}{W_s / Gb \times W_v} = \frac{W_v \times W_s}{W_s} Gb$

$= \frac{W_s}{Gb}$

$\Rightarrow W$ by volume $= W$ by weight $\times Gb$

$RAW = \frac{50}{100} \times (28 \times 1.85 - 18) = 9.9\%$ by vol.

$RAW = 9.9/1.85 = 5.33\%$ by weight.

Ex: For given Soil: $Gs = 2.46$, weight = 184 g.

dry weight = 153 g. Find $Gb$?

Sol: $Gb = \frac{W_s}{V \times W_v}$, $Gs = \frac{W_s}{V \times W_v}$ $\Rightarrow V_s = \frac{153}{2.46} = 62.5 cm^3$

$W_s = 184 - 153 = 31 g$.

$V_w = \frac{31}{W_v} = 31 cm^3$

$V = 62.5 + 31 = 93.5 cm^3$

$Gb = \frac{153}{93.5 \times 1} = 1.64$
Ex: A layered soil has the following:

Top layer: F.C. = 40\%  
PWP = 18\%  
Depth of soil = 50 cm  
Initial water content = 26\% by volume  
AD = 35"

Bottom layer: F.C. = 38\%  
PWP = 20\%  
Depth of soil = 60 cm  
Actual water content = 30\% by vol.  
AD = 55"

Find the required depth of irrigation "d_n".

Sol.:  
Top layer:  
SMD = (F.C. - Initial content) \times Depth  
= \left(\frac{40 - 26}{100}\right) \times 50 = 7 cm

RAW = (F.C. - PWP) \times AD \times Depth  
= \left(\frac{40 - 18}{100}\right) \times 50 \times 0.35 = 3.85 cm

\Rightarrow SMD > RAW ?

But SMD should be less or equal to RAW

Bottom layer

SMD = \left(\frac{38 - 30}{100}\right) \times 60 = 4.8 cm

RAW = \left(\frac{38 - 20}{100}\right) \times 60 \times 0.55 = 5.94

SMD < RAW 0.1 cm

d_n = 7 + 4.8 = 11.8 cm

d_{n \text{ max}} = 3.85 + 5.94 = 9.79 cm
For a soil: F.C. = 20%, PWP = 12% (all by weight), Gs = 1.2, R.T. = 80 cm, AD = 50% if SMD > RAW by 20%. If 40 cm of water is added to the soil immediately, find SMD after adding the water.
Chapter Three
Irrigation and Drainage Engineering
Land Grading
Chapter-3
Land Grading

Land grading is the process of forming the surface to a predetermined grades so that the water easily flow to irrigate and to drain. It is involving cutting and fill.

The land grading permits uniform and efficient application of irrigation water without excessive erosion and at same time provides adequate surface drainage.

Sometimes land grading includes land planning which is the process of smoothing the land surface with a land planner to eliminate minor depressions and irregularities with changing the general topograph.

The land grading is very important in saving the water resources in an optimum way, however it caused a destroy and demolition in soil structure and fertility. This was due to the cut and fill process. Thus, some land grading criteria must be considered.
1. **Soil profile condition**

- Make survey to obtain information about the thickness of the soil suitable for planting (the datum layer).

- Disadvantage of soil damage can be reduced by removing the fertile surface and placing it away, then after spreading it again through land grading process. Although it is conservative step, but it is still of high cost process.

2. **Land slope**

   For land of steep slope or has complex topography or the planting depth is small, it cannot be able to make the surface of uniform slope. This type of slope or soil is preferable to leave without land grading, otherwise the dividing of the land into subareas each one has a certain slope to reduce the cut and fill works. The limitations of the slopes in the direction of irrigation are specified the range of the slope from $\frac{1}{20}\%$ to $\frac{1}{2}\%$ with min. $\frac{1}{200}\%$ but for drainage requirement the more convenient slope is $(0.1 - 0.2)\%$. For furrow slope, it is less than $2\%$.

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>Slope in Irrigation and Drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy soil</td>
<td>$0.05% - 0.25%$</td>
</tr>
<tr>
<td>Loam soil</td>
<td>$0.2% - 0.4%$</td>
</tr>
<tr>
<td>Light soil</td>
<td>$0.25% - 0.65%$</td>
</tr>
</tbody>
</table>
3. Plot size for grading

It may be considered as unit, farm or even field depending on topography of the land and the method of irrigation. In Iraq, the land grading is preferable at farm level and rarely at field level.

4. Crop type

Valuable crop → high degree of accuracy for L.G.
Other crop → has no need for this type of L.G. (ie fodder)

5. Irrigation methods

For each method, there will be limitations concerned for irrigation slope and transverse slope. If more than one type of irrigation used in same field, it will expected to be also more restrictions for L.G.

6. Other requirements

Cut & fill works from drainage canals construction can be used for fill works (i.e., canals, dikes, binder levees, and field ways) since the drainage system is constructed during L.G.

Preparatory steps

The first steps of L.G. is:
1. Define the plot size of grading.
2. Staking, use stake (1m × 1m × 4cm).
3. Determination of elevation at each stake point. Close to 1 cm, all structures, electric lines, drains, roads, water resources, must be assigned.
Staking

The natural ground surface elevations and the values of cut and fill works must be found at certain points where the stakes are fixed at equal spacing ranged from 15 to 30m from station to station, thus a network of squares or rectangles are created as shown in the following illustration:

for nonuniform field, the stakes are extended to cover any area within a dimension of 15m or greater.

Typical layout for staking area required to grade

Land Grading Computations:

1. Locating the centroid

For uniform shape (rectangles, triangles, etc.) it is easy to locate the centroid, while the nonuniform (irregular) shapes are posed a problem. The area, hence, divided into uniform shape of known centroid and calculate it as:

\[ X_c = \frac{\Sigma a_i x_i}{\Sigma a_i} \quad (3.1) \]
Same formula was held for $Y_c$.

For more accuracy, it is recommended to divide the farm into small areas as in network of land elevations with neglecting the parts of cell (if it exists), see figure below. Also the procedure shown in table below.

<table>
<thead>
<tr>
<th>Distance for column centroid from $Y$-axis by No. of interval $L_1$</th>
<th>Number of cells in the column $i$ $N_i$</th>
<th>Moment about $Y$-axis $i*N_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>25</td>
</tr>
</tbody>
</table>

$x_c = \frac{75}{25} = 3L_1$

or $x_c = 3(20) = 60 \text{ m} \quad \text{[say } L_1 = 20 \text{ m}]$
In general:

\[ x_c = \left[ \frac{\sum_{i=1}^{m} (n_i \times i)}{\sum_{i=1}^{m} n_i} \right] \times L_1 \quad (3.2) \]

\[ y_c = \left[ \frac{\sum_{j=1}^{n} (m_j \times j)}{\sum_{j=1}^{n} m_j} \right] \times L_2 \quad (3.2) \]

2) Determination of average field levels

The average of field levels \( \bar{H} \) can be found by dividing the sum of levels in the center of cells (i.e., \( \sum H_{ij} \)) by the total number of cells (\( \sum_{i=1}^{m} \sum_{j=1}^{n} N_{ij} \)). Thus

\[ \bar{H} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} (H_{ij})}{\sum_{i=1}^{m} \sum_{j=1}^{n} N_{ij}} \quad (3.3) \]

where \( \sum_{i=1}^{m} \sum_{j=1}^{n} N_{ij} = \sum_{i=1}^{m} n_i = \sum_{j=1}^{n} m_j \)

3) Calculation of Design plane slope

Three methods are discussed herein to calculate the design plane slopes in irrigation direction and the transverse direction.

a) The plane of best fit

This method fulfills a minimum earth works, such that cutt and fill works \( \times \) Infinite planes passing through the centroid give cutt=fill but one plane gives \( \min \text{(cut)} = \min \text{(fill)} \). This is
So-called best plane (optimum plane) having slopes $S_x$ in x-direction and $S_y$ in y-direction.

\[ S_x = \frac{\sum_{i=1}^{n} (\sum_{j=1}^{m} H_{ij} \cdot i) - \sum_{i=1}^{n} \sum_{j=1}^{m} H_{ij} \cdot X_c}{\sum_{i=1}^{n} \sum_{j=1}^{m} N_{ij} \cdot i^2 - \left( \sum_{i=1}^{n} \sum_{j=1}^{m} N_{ij} \right) \cdot X_c^2} \quad (3.4) \]

\[ S_y = \frac{\sum_{i=1}^{n} (\sum_{j=1}^{m} H_{ij} \cdot j) - \sum_{i=1}^{n} \sum_{j=1}^{m} H_{ij} \cdot Y_c}{\sum_{i=1}^{n} \sum_{j=1}^{m} N_{ij} \cdot j^2 - \left( \sum_{i=1}^{n} \sum_{j=1}^{m} N_{ij} \right) \cdot Y_c^2} \quad (3.5) \]

For example, consider the field below:

$X_c = 2.5 \ L_1$

$Y_c = 3 \ L_2$

or $X_c = 125 \ m$

$Y_c = 150 \ m$

$S_x$ and $S_y$ were determined in next table (Page 8).

Natural Levels for Small Field (Network 50 x 50 m)
Sample of calculation for the designed slopes by using plane of best fit method

\[ S_x = \frac{29.5 - 2.5 \times 120}{150 - 20(2.5)^2} = -0.2 \ \text{m} / \text{L}^2 \]

\[ S_y = \frac{356 - 3 \times 120}{220 - 20(3)^2} = -0.1 \]

\[ S_x = -0.2 \times 150 = -0.2 \% \]

\[ S_y = -0.1 \times 150 = -0.15 \% \]
b) The average profile method

1. Calculate average elevations of cells through row, \( \overline{H_i} \) and average elevation of cells through column, \( \overline{H_j} \), and consequently average of all cells, \( \overline{H} \)

\[
\overline{H_j} = \frac{\sum_{i=1}^{m} H_{ij}}{m} \quad \text{--- (3.6)}
\]

\[
\overline{H_i} = \frac{\sum_{j=1}^{n} H_{ij}}{n} \quad \text{--- (3.7)}
\]

\( \overline{H} \) is calculated previously by eq. (3.3).

2. Define the centroid of the area.

3. Draw a sketch for \( \overline{H_i} \) (average columns) with distance of columns from y-axis. Also draw \( \overline{H_j} \) (average of rows) with distance of rows from x-axis.

4. Point out the point \((x_c, \overline{H})\) on first sketch and the point \((y_c, \overline{H})\) on second sketch.

5. A straight line passes through point \((x_c, \overline{H})\) and another straight line passes through point \((y_c, \overline{H})\) should forced to pass through most points of the sketch to give minimum fill and cut, checked by eyes.

6. Determine the slope of straight line from first sketch which equals to \( S_x \) and the slope from straight line of second sketch to give \( S_y \).
The average slope method is the simplest one but with less accuracy. It is built on finding the average of slopes for all rows considering the number of cells in each row. Thus:

\[ S_x = \frac{\sum_{i=1}^{n} N_i \times S_{x_i}}{\sum_{i=1}^{n} N_i} \]  

(3.8)

\[ S_{x_i} = \frac{S_x}{n} \]  

(3.9)

\[ S_{x_i} = \frac{H_{max} - H_{min}}{(m-1) \times L_i} \times 100 \]  

(3.10) elevations of \( H_{max} \) and \( H_{min} \) represent the first and last point in the row.
Sample of calculation for average slope method

\[
S_y = \frac{\sum_{i=1}^{m} N_i \cdot S y_i}{\sum_{i=1}^{m} N_i^2} \quad (3.11)
\]

\[
S_y = \frac{\sum_{i=1}^{m} S y_i}{m} \quad (3.12)
\]

\[
S y_i = \frac{H_i - H_{i-1}}{(m-1) \times L_i} \times 100 \quad (3.13)
\]

Here, \(H_i\) and \(H_{i-1}\) represent the elevations of the first and the last point in the column.
Calculation of Design Levels

With availability of actual levels and the slopes Sx and Sy in x- and y-direction, one can calculate the levels of design plane. Take into account the previous example and considered the method of best fit (optimum method) to clarify the calculation steps.

\[ S_x = 0.2 \text{ m/}L_1 \]
\[ S_y = 0.1 \text{ m/}L_2 \]
\[ H = 6.0 \text{ m} \]

The accuracy used is up to 1 cm.

The equation for the level is:

\[ X_c = 3 \text{ L}_2 = 7 \]
\[ Y_c = 2.5 \text{ L}_1 \]
\[ H = 6 \text{ m} \]

Thus the centroid is not at center of cell. It must be shifted to new location by

\[ 6 + \frac{0.2}{2} = 6.1 \text{ m} \]

All levels should be stated at centers of cells by adding 0.2m/L1 to the left or subtracting 0.2/L1 to the right. If the row no.3 is completed other elevations can achieved easily by considering the 3rd row cell intersection.
Calculation of Earth work (Cut & Fill)

The depths of cutt and fill in the cell of mesh are calculated by comparing the actual levels and the design levels, and if the actual levels > design level the depths therefore are cutt, otherwise are fill. The all depths in the cell then become known (in the centers of these cells).

The cutt depth is assigned by "C" whereas the fill is by "F". From previous example, by considering the design levels & the actual levels, the sum of the depths for cutt and fill is equal = 190 cm

\[
\begin{array}{c|c|c|c|c|c|c}
\hline
& 1 & 2 & 3 & 4 & & \\
\hline
\text{C} & 6.5 & 6.1 & 6.4 & 5.9 & & \\
\text{F} & 6.0 & 6.3 & 6.1 & 5.9 & & \\
\hline
\end{array}
\]

There are many methods available for estimating the quantity of earth works. Two of them were discussed below:

1. Summation method
   * Quick & simple but gives an overestimation.

\[
V_{\text{cutt}} = V_C = \sum C \times (L_1 \times L_2)
\]

\[
V_{\text{fill}} = V_F = \sum F \times (L_1 \times L_2)
\]

\[
V_{\text{cutt}} = V_{\text{fill}} = 190 cm
\]

\[
(3.14)
\]

\[
(3.15)
\]
2. The Four-point method

This method has more accurate and more complicated calculation steps. To accomplish the calculation, a new delineation was adopted for the area by passing horizontal and vertical lines through the centers of cells. Three types of areas were obtained:

a) internal area: with dimension \((L_1 \times L_2)\)

b) lateral area: with dimension \((L_1 \times 0.5L_2)\) or \((0.5L_1 \times L_2)\)

c) corner area: with dimension \((0.5L_1 \times 0.5L_2)\).

The three types above are shown in Figure below.

\[
V_c = \frac{L_1 \times L_2}{400} \left( \frac{H_c}{H_c + H_f} \right) \quad (3.16)
\]

\[
V_f = \frac{L_1 \times L_2}{400} \left( \frac{H_f}{H_c + H_f} \right) \quad (3.17)
\]

\(V_c, V_f\) in \(m^3\), \(H_c, H_f\) in \(cm\), \(L_1, L_2\) in \(m\).

\(H_c\) and \(H_f\) is calculated according to above types of areas.

a) for internal area

\[H_c = C_1 + C_2, \quad H_f = F_1 + F_2\]

b) for lateral area (likewise area adjacent to \(C_1, C_2\))

\[H_c = C_1, \quad H_f = F_2\]

c) for corner area

\[H_c = C_1, \quad H_f = 0\]

The total earth works is equal to sum of earth work of all areas.
Earthwork Balance

1 m$^3$ of cut volume from natural soil $\Rightarrow$ 0.8 m$^3$ fill volume $\Rightarrow$ \( \frac{C}{F} = \frac{1}{0.8} \Rightarrow \frac{C}{F} = 1.25 \)

Shrinkage factor (SF):
\[
SF = (\frac{C}{F} - 1) \times 100 = 25\%
\]

C/F ratio ranged from 1.15 to 1.6 depending on the grading of the earth surface.

* Water content for soil:
  - Dry season $\Rightarrow$ use C/F 1.15
  - Wet season $\Rightarrow$ use C/F (high) 1.5

* Type of equipment used:
  - Heavy equipment $\Rightarrow$ low C/F

\[
\Sigma C_b = \Sigma C + nc \times \Delta H \quad (3.18) \\
\Sigma F_b = \Sigma F - nf \times \Delta H \\
\text{(C/F)} = \frac{\Sigma C + nc + \frac{\Delta H}{(C/F)}}{\Sigma F - nf + nc} \quad \text{-- (3.20)}
\]
**Examples**  
**For Land Grading**

**Ex1:** Design the land grading of the field, shown in Figure below, using the plane of best fit to determine the design slopes, summation method for earthwork calculations. Consider a ratio of cut to fill (C/F) ranged from 1.2 to 1.45. The intervals of mesh points is 50x50 m. The design should reveal the following:

- **a)** Final design level at center of mesh unit (cells).
- **b)** Volumes of cut and fill after performing the earthwork balance.
- **c)** Plot the contour line of no cut & no fill (divide line of cut and fill regions).
- **d)** If the cost of $1m^3$ of cut, transport, and grading soil to use as fill is 9000 JD, estimate the land grading cost for 1 hectare.

**Solution:**

**a)** The field is a square shape, therefore the centroid is located at intersection point of both diagonals. $Xc = 2L_1$, $Yc = 2L_2$, $Sx$ and $Sy$ can be calculated from following tables:

From eq.(3.6) and (3.7):

$$Sx = \frac{871.8 - 2(434.7)}{42 - 9 \times 2^2} = 0.4/L_1 \text{ meter}$$

$$Sy = \frac{867.6 - 2(434.7)}{42 - 9 \times 2^2} = -0.3/L_2 \text{ meter}$$

From eq.(3.3)

$$\overline{H} = \frac{434.7}{9} = 48.3 \text{ m}$$

Let the design plane of above slopes pass through the centroid of the field with a level of $\overline{H}$ at this point to get the design levels. Thenafter, calculate the cut and fill at each cell to obtain the total depths of cut and fill over whole field.

$$\sum C = 20 + 10 + 60 = 90 \text{ cm}$$

$$\sum F = 20 + 20 + 30 + 20 = 90 \text{ cm}$$

By considering earthwork balance:

- $n_c = 5$ (including non-cut points and non-fill points)
- $n_f = 4$

From eq.(3.20) with $C/F = 1.2$:

$\Delta H = 1.83 \text{ cm}$ approximate the result close to 1 cm, thus;

$\Delta H = 2 \text{ cm}$, now check $C/F$ with this value of $\Delta H$, however the new value of $C/F$ is within a given range ($C/F=1.22$).
b) From eqs. (3.18 & 3.19):
\[\sum C_b = 90 + 5 \times 2 = 1 \text{ m}\]
\[\sum F_b = 90 - 4 \times 2 = 0.82 \text{ m}\]

From eqs. (3.14 & 3.15):
\[\forall c = 1.00 \ (50 \times 50) = 2500 \text{ m}^3\]
\[\forall f = 0.83 \ (50 \times 50) = 2050 \text{ m}^3\]

c) The contour line between cut & fill regions is plotted after the values of cut and fill are fixed at intersection of a new mesh generated by delineation passing through centers of old cells as shown below:

\[\text{Diagram showing contour lines}\]

d) Total area of the field = 150x150 = 22500 m^2 = 2.25 hec

Volume of cut = 2500 m^3

Cost = \[\frac{2500 \text{ m}^3 \times 9000 \text{ ID/m}^3}{2.25 \text{ hec}}\] = 10,000,000 ID / hec
Ex2: Design the land grading of the small field, shown in Figure, using the average slope method and considering C/F=1.5. Determine the final design levels at each point and estimate the earthwork. The intervals are 20x20m.

Solution:

From eq. (3.9):
\[ Sx = \frac{12 - 11.9}{1} \times 20 \times 100 = 0.5\% \\
Sx_2 = \frac{(12.0 - 12.1)/[(2-1)\times20]}{x100} = -0.5\% \\
From eq. (3.9): \quad Sx = 1.5 + (-0.5)/2 = 0.5\% = 10m / 20m \\
From eq. (3.13):
\[ Sy = \frac{(12.1 - 11.9)/[(2-1)\times20]}{x100} = 1.0\% \\
Sy_2 = \frac{(12.0 - 12.2)/[(2-1)\times20]}{x100} = -1.0\% \\
From eq. (3.12): \quad Sy = 1.0 + (-1.0)/2 = 0 \\
From eq. (3.3): \quad H = \frac{11.9 + 12.2 + 12.1 + 12.0}{4} = 12.05 m \\
Let the design plane of calculated slopes pass through the centroid of the field with a level of \( H \) at this point to get the design levels. Thenafter, calculate the cut and fill at each cell to obtain the total depths of cut and fill over whole field as shown in figure.
\[
\sum C = 10 + 10 = 20 cm \\
\sum F = 10 + 10 = 20 cm
\]

By considering earthwork balance:
\[ n_c = 2 \]
\[ n_f = 2 \]
From eq. (3.20) with C/F=1.5: \( \Delta H = 2 cm \)
Now lower all levels at centers of cells by 2cm, the final levels are shown in figure.

From eqs. (3.18 & 3.19):
\[
\sum C_b = 20 + 2 \times 2 = 0.24 m \\
\sum F_b = 20 - 2 \times 2 = 0.16 m
\]

From eqs. (3.14 & 3.15):
\[ V_c = 0.24 (20 \times 20) = 96 m^3 \]
\[ V_f = 0.16 (20 \times 20) = 64 m^3 \]
Ex3: The values shown in table represent the natural ground levels at center of mesh unit of the land grading. If the design slopes are given as $S_x=0.4\%$ and $S_y=0\%$, while the intervals are $25\times 25 \text{m}$, find the:

a) by using the summation method, the volumes of earthwork at $(C/F)$ ratio $=1.0$

b) $\Delta H$ required to lower the design plane in order to get $C/F=1.5$

Solution:

Since the field is unsymmetrical shape, therefore the centroid must determined by using eqs.(3.1&3.2) as follow:

$$X_c = \frac{(1\times 1+2\times 2+2\times 3)}{(1+2+2)} = 2.2 \text{ L}_1 = 55 \text{ m}$$

$$Y_c = \frac{(2\times 1+3\times 2)}{(2+3)} = 1.6 \text{ L}_2 = 40 \text{ m}$$

From eq.(3.3)

$$\bar{H} = \frac{7.1 + 7 + 6.9 + 6.8 + 7.30}{5} = 7.02 \text{ m}$$

Let the design plane of above slopes pass through the centroid of the field with a level of $\bar{H}$ at this point to get the design levels, as shown in figure.

Thenafter, calculate the cut and fill at each cell to obtain the total depths of cut and fill over whole field.

$$\sum C = 10 + 20 = 30 \text{ m}$$

$$\sum F = 10 + 20 = 30 \text{ cm}$$

By considering earthwork balance:

$n_c = 3$ (including non-cut points and non-fill points)

$n_f = 2$

From eqs.(3.14 &3.15):

a) $V_c = 0.3 \ (25 \times 25) = 187 \text{ m}^3$

b) From eq.(3.20) with $C/F=1.5$: $\Delta H = 0.025 \text{ m} = 2.5 \text{ cm}$
Ex4: The small area shown in figure was a part of a land grading design for large project whose interval in x-direction $L_1=30\text{m}$ and in y-direction $L_2=20\text{m}$. The natural ground levels at points $d,e,b,$ and $s$ are 48.4, 48.0, 48.6, 48.0, respectively, while design levels are 48.1, 48.0, 48.3, 48.4. Calculate the volume of earthwork.

Solution:

From the balance of natural ground levels and the design levels at points $d,e,b,$ and $s$, the depths of cut and fill for the area $kabg$ shown in figure are calculated by using Eqs.(3.16&3.17) for subareas 1,2,3, and 4. The results are shown in the table below:

<table>
<thead>
<tr>
<th>Area No.</th>
<th>$H_c$(cm)</th>
<th>$H_f$(cm)</th>
<th>$V_c$(m$^3$)</th>
<th>$V_f$(m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>0</td>
<td>45</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>0</td>
<td>45</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>40</td>
<td>19.39</td>
<td>34.39</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>40</td>
<td>54.39</td>
<td>24.39</td>
</tr>
</tbody>
</table>

$\text{Sum}=163 \text{m}^3$ for Cut; $\text{Sum}=58 \text{m}^3$ for Fill.

Ex5: A survey for small field was carried out in order to implement a land grading of intervals $L_1 \times L_2=20 \times 25\text{m}$. Thus, the mesh consists of 6 rows and 10 columns. The averaged natural ground levels are given below:

<table>
<thead>
<tr>
<th>No. of row or column</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row (x-axis)</td>
<td>67.0</td>
<td>67.2</td>
<td>67.3</td>
<td>67.3</td>
<td>67.5</td>
<td>67.6</td>
<td>67.6</td>
<td>67.6</td>
<td>67.6</td>
<td>67.6</td>
</tr>
<tr>
<td>Column(y-axis)</td>
<td>67.7</td>
<td>67.7</td>
<td>67.4</td>
<td>67.3</td>
<td>67.3</td>
<td>67.2</td>
<td>67.2</td>
<td>67.1</td>
<td>67.0</td>
<td>67.1</td>
</tr>
</tbody>
</table>

Use average profile method to determine the design slopes in x- and y-direction. Show in a lot the profile of average levels in x- and y-direction associated with slopes as percent with sign.

Solution:

$\bar{H}=$ Mean of average levels $= \frac{67.0+67.2+67.3+67.3+67.5+67.6}{6} = 67.3 \text{ m}$

$X_c=100 \text{m}, \ Y_c=75 \text{m}$
Along y-distance

The first point was selected by sight is \((12.5, 67.05)\), whereas the second point is \((y_c, H)\). Thus, the slope \(S_y\) can be calculated as:

\[
S_y = \frac{67.3 - 67.05}{75 - 12.5} \times 100 = 0.4\%
\]

Along x-distance

The first point was selected by sight is \((10.67.63)\), whereas the second point is \((x_c, H)\). Thus, the slope \(S_x\) can be calculated as:

\[
S_x = \frac{67.3 - 67.63}{100 - 10} \times 100 = -0.36\%
\]