IRRIGATION INFRASTRUCTURE DEVELOPMENT
AND
WATER MANAGEMENT PRACTICES

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INTERNATIONAL ARID LANDS CONSORTIUM
UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID) AND
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FORWARD

This book contains the teaching materials of the practical training course on "Irrigation Infrastructure Development and Water Management Practices". The course was arranged by the University of Illinois at Urbana Champaign, a lead institution of the International Arid Lands Consortium with the assistance from the United States Agency for International Development under the Sustainable Development of Drylands in Asia and Middle East Program. The Department of Water Management, NWFP Agricultural University conducted the course in August 2003. Fifteen Agricultural Engineers and Agricultural Officers from Afghanistan attended this course.

The book is organized in thirteen sections. The first section presents information on "Irrigation and Crop Requirements". The second and third sections describe the "Soil and Water" and "Irrigation Scheduling". and Fifth sections discuss "Flow Measurement in Irrigation Channels" and "Irrigation Application Methods". Sixth and seventh sections are about "Drainage of Agricultural Lands" and "Pumps for Irrigation". Sections and nine present information on "Cereal Crops" and "Pulses". Sections ten and eleven are about "Vegetables "Fruits". Section twelve addresses "Demonstration Plots" and the last thirteenth section presents "Design Irrigation Channel and Hydraulic Structures" in pashto as well as in English language, which are used in irriga infrastructure.

We hope that this book will help Engineers and Agriculturists as Master Trainers in a better way. The competition for water is increasing daily in arid and semi-arid regions and it is imperative we all manage to make the best use of available water.

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Financial support for the production of the book comes from the University of Illinois at Urbana Champaign, United States Agency for International Development (USAID), U.S.A. and their financial support is highly appreciated. The authors is very thankful to Prof. Dr. Syed Iqbal Shah, Vice Chancellor, NWFP Agricultural University, Peshawar for providing all the facilities on the campus for the successful conduction of this course, also participated in the closing ceremony of the course and exchanged ideas with participants. Dr. Abdul Qayyum Khan, Director, University of Illinois Field office has maintained a desire for its publication and provided assistance to the Department of Water Management, his coordination is also highly appreciated.

Prof. Dr. Muhammad Jamal Khan
IRRIGATION CHANNEL AND STRUCTURES DESIGN

- **Watercourse Design**
Watercourse improvement is an utmost necessary of today’s irrigated agriculture of Afghanistan. About 30 to 50% of water is lost in irrigation channels from Karez, river diversion or other irrigation systems before it reaches to the fields. Most of the these watercourses have been constructed by the water users, without proper alignment, cross-section and gradient. This resulted in varying unfavorable velocities leading to silting, scouring, and overtopping of banks, narrow banks and dead storages. Poor haphazard maintenance and inadequate cleaning has lead to the vegetative growth, breaches and overtopping. Rodents’ holes, cutting of banks for turnout, and borrowing of soils from adjoining fields to build checks in the watercourse, resulting in considerable amount of water losses.

I. **Criteria for Water Course Selection**
Watercourse selected for improvement should be those where there will be a high likelihood for success; where farmers’ interests are high. In selecting irrigation channel (watercourse) the following factors should be considered for improvement:
- Farmers must be willing to provide Labours required to improve the water course and to organize and direct the during the planning and construction phase.
- Efforts should be made to select the watercourse having high water losses.
- Priority should be given to the watercourse having percentage of rural poor or small landowners.

II. **Information**
- The objectives of the watercourse improvement should be communicated to the water users through radio, TV, newspaper, poster and personal contact in the villages.
- The farmers should be informed about the benefit of the watercourse improvement
- in term of water saving and reduction in waterlogging and salinity.
- The cost, in term of input required from the farmers.
- Water users association should be formed for proper execution and maintenance of the watercourse improvement programme.

III. **Involvement of Farmers**
Involvement of farmers in phases of improvement (planning, design, construction, monitoring and evaluation) should be ensured.
IV. Planning the Watercourse Improvements project

- Preparation of watercourse improvement plan is one of the essential phase of the project and it involved the following steps:
  - Application from the farmers for the command area for assistance.
  - Conduct farmers meeting to explain the project objectives.
  - Make a soil survey of the watercourse, to find the high water losses portion of the watercourse.
  - Collect from the concerned Department map of the irrigation scheme or it should be prepared.
  - Find the discharge of the watercourse.
  - Use cutthroat flume or other devices for assessment of conveyance losses.
  - Determine the amount of kutch and pikka improvement needed.

V. Final Plan and Design

The construction detailed should be discussed with the farmers and necessary changes should be made. Then the final design should be submitted for sanctioned and approval to the concerned authority.

DESIGN CRITERIA OF IRRIGATION CHANNEL
(WATERCOURSE)

The purpose of the irrigation channel is to carry the water from Karez, river diversion, spring or Tubewell to the farmers’ fields. The design objectives include achieving conveyance efficiency (low water losses), preventing silting or erosion and the Full Supply level in the in the watercourse high enough to provide proper working head to all the command area and low to prevent the submergence of outlet.

A. Capacity Requirements

The design capacity of the irrigation channel should be measured with the help of a cutthroat flume or current meter or float method. The capacity of the new irrigation channel will depend upon the command area to be irrigated and type of crops expected to be grown in the area. The water allowance can be assumed 0.5, 0.7 and 1.0 L/S/ha for Northern, central and western Afghanistan respectively.
B. Permissible Velocity
The permissible velocity in a channel depends on its cross-section and longitudinal gradient. The longitudinal gradient adopted shall be such that as to produce a velocity as high as possible without scouring bed and sides of the canal and sacrificing command. High velocity has the following advantages:
1. Reduces cross-sectional area and such has less excavation.
2. Reduced transmission losses
3. Low silt deposition and periodical removal.
4. Retards weed growth.
The maximum permissible velocity for various soils is given in Table 1.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Description of the Soils</th>
<th>Maximum Velocity m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light sand</td>
<td>0.50</td>
</tr>
<tr>
<td>2</td>
<td>Loamy sand</td>
<td>0.75</td>
</tr>
<tr>
<td>3</td>
<td>Clay soft</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>Clay hard</td>
<td>1.25</td>
</tr>
<tr>
<td>5</td>
<td>Soft rock</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>6</td>
<td>Hard rock</td>
<td>2.5-3.5</td>
</tr>
</tbody>
</table>

Minimum non-silting and non-weed velocity is taken as 0.5 m/s.

C. Freeboard
Freeboard is bank height above the maximum designed water surface elevating that should be provided to allow for the most sever operating condition. Minimum free board requirements are as follows:
- Earthen channel 1/3 of the design depth or 15 cm whichever is greater.
- Rectangular lined channel 10 cm
- Trapezoidal channel 7.5 cm

D. Side Slope for Earthen Watercourse
The earthen watercourse should be designed to have stable side slope. The side slope for design flow depth less than one meter is given below:
Table 2. Permissible side slope (Z) in earthen watercourse.

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Excavated Section Permissible Z</th>
<th>Excavated Section Recommended Z</th>
<th>Fill section Permissible section Z</th>
<th>Fill Section recommended Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Loams, silt loam, silty clay and clays</td>
<td>1:1</td>
<td>1:1</td>
<td>1:1</td>
<td>1.5:1</td>
</tr>
<tr>
<td>2. Sandy loam</td>
<td>1:1</td>
<td>1:1</td>
<td>1.5:1</td>
<td>2:1</td>
</tr>
<tr>
<td>3. Loamy sands and sands</td>
<td>1.5:1</td>
<td>2:1</td>
<td>2:1</td>
<td>3:1</td>
</tr>
</tbody>
</table>

E. Full Supply Level

The design water surface elevation should be high enough at field take out points to provide the required flow on to the field surfaces. A minimum working head of at 10-15 cm should be provided at each turnout or nacca for the highest field in its command.

F. Bank Width

The bank width of the watercourse should be equal to the flow depth, but not less than 0.30 m in earthen an lined channels.

G. Watercourse Seepage Losses

The seepage loss rate of earthen watercourses depend upon primarily on the soil texture and density (compaction). Course textured soils (sands) have a higher rate the fine textured soils (clay). The following figure can be used for assessment of seepage losses.
SOIL TEXTURE

A. Fine Textured
   Soil (clays-clay loams)

B. Medium Textured
   Soil (loams + silts)

C. Coarse Textured
   Soil (sandy loams)

NOTE: Seepage loss based on 15 cm/day seepage rate for fine textured soil, 30 cm/day for medium textured soil, and 45 cm/day for coarse textured soil.

FIG SEEPAGE RATES OF DIFFERENT SOIL TEXTURES
Water Course Design

A. Field Survey

1. First conduct a closed circuit bench mark (BM) starting at a benchmark on the outlet assumed to be 10-meter elevation. One Pucca BM should be established such as stones, pump bases, tube well structures etc at each 300m to facilitate further surveying. All surveys should be started and closed on appoint of known elevation. If the error of closure is not within specified limits, the survey must be repeated. The permissible deviation is 0.05 cm per point.

2. Obtain the Full Supply Level (FSL), crest elevation of the outlets.

3. Conduct a profile survey of bed elevation and average field elevations of the main and all branches of the main irrigation channel.

4. The elevation of the highest fields to be served by each turnout is needed.

5. Prepare a profile map of the main and branch watercourses by plotting the profile, the location and elevation of all the existing water control structures. Locate all the outturns on the profile maps.

Design Procedure

➢ Find the maximum FSL to able to serve the highest field.
➢ Required FSL at Turnout.

Add 0.15 m to the highest field elevation to provide the working head needed to move water from the watercourse to the field. If the highest field is located downstream add a minimum of 0.01 m for each 100 m of distance.

➢ Water Surface Profile

Water surface profile should be plotted on the map.

➢ Select the size and shape of the watercourse and check the hydraulics.

Manning’s equation is generally used for flow characteristics.

➢ The design velocity should be less than erosive velocity.

➢ Sedimentation may occurs if the velocity is too low.

➢ It may not be practical to change the flow depth if it varies few cm.

➢ Bottom width or flow depth can be adjusted to compensate for a change in slope.
Water Control Structures
The location of turnouts should be shown on the map. Check structures are used in the watercourse to provide working head needed at turnouts. The spacing between the check structures can be estimated by the following equation.

\[ L = \frac{FB}{(2^* S)} \]

L is the distance upstream in meter a check structure can serve.

\[ FB = \text{Freeboard (m)} \]

\[ S = \text{bed slope in m/m} \]

Example

\[ FB = 0.15 \text{ m} \]

\[ S = 0.0004 \text{ m/m} \]

\[ L = \frac{0.15 \text{ m}}{(2^* 0.0004 \text{ m/m})} = 187.5 \text{ m}, \text{ therefore the check structures can serve turnouts as far as 188 m upstream.} \]

Design of Canal on Non-alluvial Soils

Non-alluvial soils are hard soils e.g. loam, clay, moorum, boulder, etc. They are stable for the purpose of canal design and there is no silt problem. The only criterion in the channel design of these channels is the adoption of non-scouring velocity close the critical velocity of the soils. Table 2. gives the values of critical velocities

Table 3. Critical velocities for different soils.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Description of the Soils</th>
<th>Critical Velocity m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Earth</td>
<td>0.3-0.6</td>
</tr>
<tr>
<td>2</td>
<td>Ordinary moorum</td>
<td>0.6-0.9</td>
</tr>
<tr>
<td>3</td>
<td>Hard moorum</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>Boulders</td>
<td>1.5-1.8</td>
</tr>
<tr>
<td>5</td>
<td>Soft rocks</td>
<td>1.8-2.4</td>
</tr>
<tr>
<td>6</td>
<td>Hard rock</td>
<td>&gt; 3.0</td>
</tr>
</tbody>
</table>
**WATERCOURSE HYDRAULICS**

**Watercourse or channel cross-section Nomenclature:**

- **b**: Bottom width
- **d**: Flow depth
- **B**: Width at water surface = b + (2Z * d)
- **D**: Total depth of watercourse = d + FB
- **FB**: Free board
- **BW**: Bank width
- **Z**: Side slope, the slope of the sides expressed as the ratio of horizontal to vertical, shown as Z:1, (such as 1:1, 1.5:1, 2:1, etc.)
- **FSL**: Full supply level (design water surface)
- **TW**: Top width of the ditch = b + (2Z * D)
- **PW**: Pad width = B + 2* BW + 4(FB + Z)

**Hydraulic formulas:**
The basic hydraulic formula for channel capacity is:

\[ Q = A \cdot V. \]

Robert Manning (1969) presented a formula for uniform flow in empirical coefficient based on roughness of the channel to determine velocity.

Manning's Formula is: \[ V = \left[ R^{2/3} \cdot S^{1/2} \right] / n \]

by combining the two previous formulas, channel capacity or quantity of flow can be determined by:

\[ Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n} \]

**NOTE:** See Appendix for tables to find two thirds powers, three halves and square roots of decimal numbers.

- **Q**: Quantity of flow in cubic meters per second
- **V**: Mean velocity in meters per second
- **A**: Flow area in square meters
- **P**: Wetted perimeter in meters
- **R**: Hydraulic radius in meters = A / P
Table of Roughness Coefficient "n" for Small Channels

<table>
<thead>
<tr>
<th>Description</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>lined Earthen Channels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. new-straight and uniform</td>
<td>.020</td>
<td>.025</td>
<td>.025</td>
</tr>
<tr>
<td>2. aged and vegetated with:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Short grass</td>
<td>.030</td>
<td>.040</td>
<td>.035</td>
</tr>
<tr>
<td>b. Long grass</td>
<td>.050</td>
<td>.080</td>
<td></td>
</tr>
<tr>
<td>lined Channels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. concrete</td>
<td>.012</td>
<td>.018</td>
<td>.014</td>
</tr>
<tr>
<td>2. brick plastered</td>
<td>.012</td>
<td>.018</td>
<td>.013</td>
</tr>
<tr>
<td>3. brick unplastered</td>
<td>.016</td>
<td>.020</td>
<td>.018</td>
</tr>
</tbody>
</table>

Problem 1.
Design an irrigation channel to carry a discharge of 14.16 cumecs with a velocity of 0.775 m/s, assume side slope 1:1; bed slope 1 in 5000 and Manning's n = 0.0225

Solution:
From equation \( Q = A \times V \)
\[ A = \frac{Q}{V} = \frac{14.16}{0.775} = 18.27 \text{ m}^2 \]
\[ A = (B + D) \times D = 18.27 \text{ m}^2 \]
Wetted perimeter
\[ P = B + 2D \]

Hydraulic Radius: \( R = \frac{18.27}{(B + 2D)} \)
Using manning equation another value of \( R \) is found out

\[ V = \frac{1}{n R^{1.25} S^{1/6}} \]
\[ 0.775 = \frac{1}{0.0225 R^{1.25} \times (1/5000)^{0.5}} \]
\[ R = 1.37 \text{ m} \]

From equation [2] and [3]
\[ 1.37 = \frac{18.27}{(B + 2D)} \]
\[ B = \frac{18.27}{1.37} - 2 \]
\[ 2D = 13.336 - 2.8328D \]
Substituting the value of B in equation [1]

\[ 18.27 = (13.336 - 2.828D)D + D^2 \]

\[ D^2 - 13.336D + 18.27 = 0 \]

It is a quadratic equation in D, solving for D
D = 5.476 and 1.828

Taking D = 5.476
B = 13.336 - 2.828 x 5.476 = -2.15 m which is not possible

Taking D = 1.828 m
B = 13.336 - 2.828 x 1.828 = 8.17 m
A = (8.17 + 1.828) 1.828 = 18.3 m², hence it is correct.

**UNLINED CANAL DESIGN**

Balancing Depth
Balancing depth is that depth of a canal section, such that the quantity of excavation from the bed is equal to earth filling required for making banks. A canal running in balancing depth is very economical in construction.

h = Height of the bank above the canal bed level (d + F.B)
d = canal full supply level
b = design bed with
y = balancing depth
z = bed cutting slope
n = bank filling slope
t = bank with at top
Area of cutting = (b + 3) y
Area of filling = 2 [t + n(h-y)](h-y)

For the balancing depth
Area of cutting = Area of filling
Usual value of Z and n are 1 and 1.5 corresponding to cutting slope of 1:1 and filling slope 1.5:1. Putting these values
(b+y)y = 2(h-y)[t + 1.5(h-y)]
On simplification, we get
\[ y^2 - y(b/2 + 5h + t) + h(t + 3/2 h) = 0 \]
Problem 2. A canal has a bed width of 10 m, F.S. depth of 1.5 m, bank width 2 m, cutting slope 1:1, and filling slope 1.5:1 and free board 0.5 m. Calculate balancing depth.

Solution:

\[ H = 2.0 \text{ m (d + F.B)} \]
\[ B = 10 \text{ m} \]
\[ t = 2 \text{ m} \]

Using the equation 1
\[ y^2 - y (10/2 + 3x2 + 2) + 2(2 + 3/2 \times 2) = 0 \]
\[ y^2 - 13y + 10 = 0 \]
\[ y = 13 \pm \sqrt{(13^2 - 4 \times 10)}/2 \]
\[ y = 13 \pm 11.35/2 = 0.82 \text{ m} \]

Check

Cutting = \((b + y)\) y = \((10 + 0.82)\) 0.82 = 9 m².

Filling = \(2[2 + 1.5(2.0 - 0.82)](2.0 - 0.82)\) = 9 m².

Minimum working head

Working head at field = 7.5 cm

Working head at outlet = 15 cm

Working head from:

1. Major distributory to a minor = 30 cm
2. Branch to major distributory = 50 cm
3. Main branch to branch = 50 cm
4. Main canal to main branch = 60 cm

An off take is of a channel is placed upstream of a contour point in the parent channel as far as possible.

> **Lining Material**

An ideal canal lining should be impervious, strong, durable, and adaptable to the shape of the canal prism, inexpensive and easy to construct. Concrete, earth and asphalt have been used in many forms as lining material. Soil sealants have also been used with some success as an inexpensive method of control of seepage from existing canals but could not be used as a permanent canal lining. One of the classifications of the various types of lining may be as under.

A- Rigid and Semi-rigid linings
1. Portland Cement concrete
2. Asphalt Lining
3. Brick Masonry
B- Earth lining
1 Compact Earth (Thin) Lining
2 Compact Earth (Thick) Lining
3 Bentonite Lining

C- Membrane Linings
1 Buried Asphalt Membrane
2 Plastic Film

D- Soil Sealants
1 Chemical Sealants

DESIGN OF AQUEDUCT
SLAB DESIGN

\[
\begin{align*}
F_y &= 40,000 \text{ P.S.I} \\
F_e &= 3,000 \text{ P.S.I} \\
\text{Clear Span} &= 2.5 \text{ feet} \\
\text{Effective span} &= \frac{2.5' + 2(75 \times 0.75)}{100} = 3.63\text{ft} \\
\text{Loads} \\
a) \text{Slab} &= 0.5 \times 1.50 = 75 \text{ P.S.F} \\
b) \text{Water} &= 2 \times 62.4 = 124 \text{ P.S.F} \\
c) \text{Silt} &= 0.5 \times 110 = 55 \text{ P.S.F} \ \\
\text{Total dead load} &= 254.8 \text{ PSF} \\
\text{Live Load} \\
\text{Impact} &= \frac{25 \times 150}{100} = 150 \text{ PSF} \\
\text{Total Live load} &= 37.5 \text{ PSF} \\
\text{Factored load} &= \frac{150 + 37.5}{4} = 43.75 \text{ PSF} \\
&= 675.47 \text{ PSF} \\
\mu &= \frac{WuL^2}{12} \quad \text{(Fixed end moment)} \\
&= \frac{675.47 \times (3.63)^2}{12} \\
&= 741.72 \text{ Lbs-ft} \\
&\text{using 4 bars and 3/4" clear cover.}
\end{align*}
\]
\[ d = 6 - \frac{3}{4} - \frac{1}{2} (1/2) = 5 \text{ inches} \]

\[ \phi = 0.90 \]

\[ \frac{\mu_{ud}}{\phi bd^2} = \frac{Ru = 741.72 \times 12}{0.90 \times 12 \times 5} = Ru \]

\[ Ru = 164.83 \text{ PSI} \]

\[ e = \frac{1}{m} \left( 1 - \frac{1}{1 - 2 \frac{m}{fy}} \right) \]

\[ e = \frac{1}{15.68} \left( 1 - \frac{1}{1 - 2 \frac{15.68 \times 164.83}{40000}} \right) \]

\[ e = \frac{1}{15.68} \left( 1 - 0.9332 \right) \]

\[ e = 0.00426 \text{ which is less than } e_{\min}. \text{ Therefore using } e_{\min} = 0.005 \]

\[ Ast = e \cdot bd \]

\[ Ast = 0.005 \times 12 \times 5 = 0.3 \text{ inch} \]

Using 4 bars

\[ \text{No. of Bars} = \frac{1.3}{0.196} = 1.53 \text{ bars} \]

\[ \text{Spacing} = \frac{12}{1.53} = 7.5'' \text{ C/C} \]

\[ \text{Distribution steel} = 0.002 \cdot bd = 0.002 \times 12 \times 6 = 0.144 \text{ in} \]

Using 3 bars

\[ \text{No. of Bars/ft} = 0.144 = 1.31 \text{ bars} \]
Spacing = \frac{12}{1.31} = 9.16'' C/C say 9'' C/C

DESIGN OF BEAM

Clear span = 30 ft
Effective span = \frac{30 + \frac{75 \times 1.5 \times 2}{100}}{1.5} = 32.25\text{ feet}

Load:
B. a) Dead Load
   i) Slab = 1.25 \times 0.5 \times 150 = 93.75 Lbs/ft
   ii) Silt load = 1.25 \times 0.5 \times 110 = 68.75 Lbs/ft
   iii) Assume beam load = 2 \times 1 \times 150 = 300 Lbs/ft
   iv) Total dead load = 462.5 Lbs/ft

C. b) Live Load
   i) Live load = 100 Lbs/ft
   ii) Live load due to water = 1.5 \times 1.5 \times 62.4 = 140.4 Lbs/ft
   iii) Impact load = 25\% \text{ of live load} = 140.4 Lbs/ft
   iv) Total live load = 300 Lbs/ft

Factor load = \frac{Wu = 1.7 \times 300 + 1.4 \times 462.5 = 1203}{8} \text{ Lbs/ft}

Mu = \frac{1203 \times (32.25)}{8} = 156399.39

Mn = Mu = \frac{173777 \text{ Lab/ft}}{0.9}

Use = b = 12''
   d = 24''

Mn = \frac{173777 \times 12}{12 \times (24) \times (24)} = 302
\[ e = \frac{1}{m} \left( 1 - \frac{1}{f_y} \frac{2}{m} \frac{R_u}{1000} \right) \]

\[ e = \frac{1}{15.68} \left( 1 - \frac{1}{40000} \frac{2}{302} \right) = 0.0081 \]

\[ \text{Ast} = 0.0081 \times 12 \times 24 = 2.3328 \text{ in}^2 \]

\[ \text{Use} = \text{use 4 bars} \]

\[ \text{No. of Bars} = \frac{2.3328}{0.196} = 11.9 \text{ bars} \quad \text{say 12 bars} \]

**DESIGN OF AQUEDUCT BEAM-2**

Clear span \( = 20 \text{ ft} \)

Effective span \( = 20 + 2 \times (0.75) = 21.5 \text{ feet} \)

Use

\[
\begin{align*}
F_c &= 3000 \text{ psi} \\
F_y &= 40000 \text{ psi}
\end{align*}
\]

**Loads.**

\[
\begin{align*}
\text{D. Dead Load} & \\
\text{i. Self beam load} &= 1 \times 10 \times \frac{20 \times 150}{12} = 20.83 \text{ Lbs/ft} \\
\text{ii. Slab load} &= 1 \times 1 \times 0.5 \times 150 = 125 \text{ Lbs/ft} \\
\text{iii. Silt load} &= 1 \times 1 \times 0.5 \times 110 = 55 \text{ Lbs/ft} \\
\text{Total dead load} &= 200.8 \text{ Lbs/ft}
\end{align*}
\]

\[
\begin{align*}
\text{i. Water load} &= 1 \times 1.8 \times 62.4 = 112.3 \text{ Lbs/ft} \\
\text{ii. Live load} &= 100 \text{ lbs/ft} \\
\text{iii. Impact load} &= 30\% \text{ of live load} = 63.696 \text{ Lbs/ft} \\
\text{Total live load} &= 275.99 \text{ Lbs/ft}
\end{align*}
\]

Factor load \( = 1.7 \times 275.99 + 1.4 \times 200.8 = 750 \text{ Lbs/ft} \)

\[ \mu = \frac{750 \times (21.5)^2}{2} = 43343 \text{ Lbs/ft} \]
\[
\begin{align*}
M_n &= \frac{M_u}{\phi} = \frac{M_u}{0.9} = \frac{M_n \times 12 \text{ bd}^2}{b d^2} \\
M_n &= 48159 \text{ Lbs/ft} \\
R_u &= 144.47 \text{ Psi} \\
\text{Take } b &= 10 \text{ inches and } d = 20 \text{ inches} \\
\text{As } R_u \text{ less than 200 Psi} \\
\text{Hence using } e \min i.e \ 0.005
\end{align*}
\]

**Problem 3.**
A canal is crossing a stream under siphonic condition. Design a siphon with the following data:

**Stream**
- Discharge \( Q \) = 400 cfs
- Highest Flood Level = 475.58 (at the point of crossing)
- Bed Width, \( B \) = 100 ft.

**Canal**
- \( Q \) = 100 cfs.
- \( V \) = 2.5 ft/sec
- \( n \) = 0.0225 (unlined)
- F.S.L = 478.70
- Bed level = 474.70
- B.W. = 10 ft.
- Full Supply Depth = 4 ft.
- Free Board = 1.5 ft.
- Hydraulic Slope = 1:4000

**Solution**
To determine which type of cross drainage structure would be suitable at this place, consider the following:
1. Canal discharge = 100 cfs
2. Stream discharge = 400 cfs
3. Stream discharge is greater than the canal discharge.
4 Highest Flood Level (H.F.L.) of the stream at the point of crossing in 475.58 whereas the bed level of canal is 474.70. Difference = 0.88 ft.

5 The difference is too small as free board for an aqueduct.

In view of the above, the canal will cross the stream through a siphon.
Length of siphon = Bed Width of Stream + 10% + Side Slopes
= 100 + 10% + 2 x 45
= 200 ft.
Discharge of siphon = 100 + 10%
= 110 cfs

Assume velocity in the barrels = 4 ft./sec (For self-cleaning purposes)

Design of concrete square barrels

A = \( \frac{Q}{V} \)
= \( \frac{110}{4} \) = 27.5 ft²

Let side of barrel = a
Area of barrel = a x a
\( a^2 \) = 11.0
a = 5.25 ft.
Barrel will be pre-cast, concrete sections.

Scour
Depth of scour, R = \( 0.9(q^{2/3})^{1/3} \)
Assume, \( f \)
= 1.0
\( q = 0.9 \left( \frac{4}{1.0} \right)^{1/3} \)
\( q = \frac{Q}{B} = \frac{400}{100} = 4 \)

\( R = 2.27 \) ft.

Max Scour Depth = 2 R
2 R = 2 x 2.27 = 4.54 ft.

Barrel will be laid in the following shape at a level at least 4.54 ft. below the bed level.

Head Loss = Inlet loss + Friction loss through the barrel + Loss at bends + Loss at exit.
Loss at Inlet, $h_i$

\[ h_i = 0.5 \frac{V^2}{2g} \]
\[ V = 4 \text{ ft./sec} \]
\[ h_i = 0.5 \left( \frac{4}{2} \times 32.2 \right) = 0.12 \text{ ft.} \]

Friction loss, $hf$

The loss of head due to friction can be measured by the slope of the energy line or the water surface in the barrel. This is calculated by Manning's formula. Total head loss due to friction would be equal to:

\[ hf = S \times \text{Length of the barrel} \]
\[ n = 0.014 \]

Area of barrel, \[ A = 27.5 \text{ ft}^2 \]

Wetted Perimeter, \[ P = 4 \times 5.25 = 21 \text{ ft} \]

Hydraulic Mean Depth, \[ R = \frac{A}{P} = \frac{27.5}{21} = 1.31 \]

Velocity, \[ V = \frac{1.486}{n} \times R^{2/3} \times S^{1/2} \]
\[ 4 = \frac{1.486}{0.014} \times 1.31^{2/3} \times S^{1/2} \]
\[ S = 0.03 \]

Loss due to friction, \[ hf = S \times \text{Length of the barrel} = 0.03 \times 200 = 6 \text{ ft.} \]

Loss of head at bends, $h_b$

\[ h_b = 2(V^2 / 2g) \]

where $f = \sin^2 \delta / 2 + 2 \sin^4 \delta / 2$
\[ \delta = 11.3'' \]
\[ \delta / 2 = 5.65'' \]
\[ f = (\sin 5.65')^2 + 2 (\sin 5.65')^4 \]
\[ f = 0.009992 \]
\[ h_b = 2 \times 4^{2/2g} \times f = 0.005 \text{ ft} \]

Loss of head at Exit, $h_e$

\[ h_e = 0.5/2g (V^2 - V_1^2) \]

Where $V = \text{Vel. In barrel}$
\[ V_1 = \text{Vel. In canal} \]
\[ h_e = 0.5/2g (4-2.5) = 0.012 \text{ ft.} \]

Total Head Loss

\[ = h_i + h_f + h_b + h_e \]
\[ = 0.12 + 0.005 + 1.012 = 6.14 \text{ ft.} \]
F.S.L. of canal on the downstream of the siphon

\[ \begin{align*}
\text{F.S.L.} & = \text{Head Loss} \\
& = 478.70 - 6.14 \\
& = 472.56
\end{align*} \]

**Retaining Wall**

**DESIGN OF RETAINING WALL**

**OF SHIKOLAI IRRIGATION CHANNEL.**

\[ \begin{align*}
H &= 7 \text{ feet} \\
\text{Top width} &= 1.5 \text{ feet} \\
\text{Bottom width} &= 3.75 \text{ feet} \\
\text{Soil.} &= 120 \text{ P.C.F} \\
\text{Stone} &= 150 \text{ P.C.F} \\
\phi &= 30^\circ \\
W1 &= 1575 \text{ Lbs} \\
W2 &= 1.18125 \text{ Lbs} \\
W &= W1 + W2 = 2756.25 \\
X1 &= 3 \text{ feet} \\
X2 &= 1.5 \text{ feet} \\
P &= \left(\frac{H^2}{2}\right) \times \left[1 - \sin(\phi)\right] \\
&= \left(\frac{7^2}{2}\right) \times \left[1 - \sin(30^\circ)\right] \\
&= \frac{980}{2} \\
&= 980 \text{ Lbs} \\
M &= P(H/3) = 2286.67 \\
Mr &= W1 \times X1 + W2 \times X2 = (1575 \times 3) + 1.18125 \times 1.5 = 6496.87 \text{ Lbs/ft} \\
\text{F.O.S AGAINST OVERTURNING} \\
\frac{Mr}{Mo} = \frac{6496.87/2286.67}{2.84} = 2.84 \\
\text{which is greater than 2 hence safe} \\
\text{F.O.S AGAINST SLIDING} \\
\frac{(UW)}{P} = \frac{(0.55 \times 2756.25)/2286.67}{1.55} = 1.55 \\
\text{which is greater than 1.5 hence O.K.}
DESIGN OF RETAINING WALL

\[ H = 12 \text{ ft} \]
\[ \text{Top width} = 2 \text{ ft} \]
\[ \text{Bottom width} = 6.75 \text{ ft} \]
\[ \varphi = 30^\circ \]
\[ W_1 = 3600 \text{ Pounds} \]
\[ W_2 = 4275.5 \text{ Pounds} \]
\[ W = W_1 + W_2 = 7875.5 \text{ Pounds} \]
\[ X_1 = 5.75 \text{ ft} \]
\[ X_2 = 3.17 \text{ ft} \]
\[ Pa = \frac{1}{2} \left(1 - \sin \varphi\right) r H^2 \]
\[ \left(1 + \sin \varphi\right) \]
\[ Pa = \frac{1}{2} \left(1\right) x 120 x (12)^2 \]
\[ = \frac{1}{6} \times 120 \times 144 \sqrt{3} = 2880 \]
\[ Mo = Pa \times H/3 = 2880 \times 12/3 = 11520 \]
\[ Mr = W_1 \left(\frac{1}{3}\right) + W_2 \left(\frac{1}{2}\right) = 34251.25 \]
\[ \text{F.O.S against over turning} = \frac{Mr}{Mo} = 2.97^2 \]
\[ \text{F.O.S against Sliding} = \frac{UW}{P} = \frac{0.55 \times 7875.5}{2880} = 1.55 \]

Which is greater than 1.5 Hence O.K.
DESIGN OF SUPER PASSAGE

Assume 2.5 ft x 3.5 ft: Clear section and 6" thick RCC Slab.

Fy = 40 K.S.I
Fe = 3 K.S.I

Clear width = 3.5 feet
Effective width = 5.75 feet

E. Loads

a) D.L. = \frac{6}{12} \times 150 = 75 \text{ P.S.F.}

b) L.L. = 25\% \text{ of L.L.} = 200 \text{ P.S.F}

Impact. Total L.L. = 1.4 (D.L.) + 1.7 (L.L.)
Factored Load = 1.4 (75) + 1.7 (200) = 530 \text{ P.S.F}

\[ W_1^2 = \frac{2190.39 \text{ Lbs/ft}}{8} \times 5.75 \times 5.75 = \]

\[ 8 \] Using 4 bars and \( \frac{1}{4} \) " Clear cover

\[ d = 5" \]
\[ \phi = 0.90 \]
\[ M_{12} = 2190.39 \times 12 = 97.35 \text{ K.S.I} \]
\[ \phi_{bd} = 0.9 \times 12 \times 5 \times 5 \]

As 97.35/200
Hence minimum steel is used

i.e. Ast = \phi \text{ min bd}
= 0.005 \times 12 \times 5 = 0.3 \text{ in}^2

No. of Bars = 0.3
= 1.53

Spacing = 12
= 7.84" C/C
Say 7.5" C/C

\[ D^o \text{ Steel} = 0.902 \text{ Ag} = 0.012 \times \text{ b x h} \]

ASD = 0.002 \times 12 \times 5
Using 3 bars

No of Bars = 0.144
= 1.31

Spacing = \frac{12}{1.31} = 9.16" C/C
say 9" C/C
REFERENCES


15. Department of Agronomy, University of Agriculture, Faisalabad (Pakistan).


23. International Rice Research Institute, Field Problems of Tropical Rice.


33. Ochse 1.1, Soule M.1, Dijkman M.1, Weihlbourg, C, Tropical and Sub-Tropical Agriculture, 1960, MacMillan Co.

34. Ou. S.H. Rice Diseases, Commonwealth Mycological Institute, England.

35. Pakistan Central Cotton Committee, "Cotton Production Plan 1996-97".


37. PARC/CLIMMYT, NARC, AERU (P ARC), Increasing wheat productivity, 1986. Islamabad- AARI, Faisalabad.


40. Bhatti, M. Binaras and others. Cultivation of Fodder Crops in Pakistan (Urdu), PARC, Islamabad.


45. PARC, Rice Production in Pakistan, 1993.
51. Foundation of Pakistan, Islamabad.
52. Shahid & Others, 1993. Water Use and Crop Production in Pakistan, PARC, Islamabad,


