QUICK START DESIGN MANUAL
(SPATE DIVERSION WORKS)

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DESIGN MANUAL

CONTENTS

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CONTENTS

SECTION	DESCRIPTION	PAGE
1.0	INTRODUCTION	1 OF 24
2.0	PLANNING ASPECTS/DESIGN CONCEPT	2 OF 24
3.0	STEPS TO BE TAKEN AT THE PRE DESIGN STAGE	2 OF 24
4.0	STEPS TO BE TAKEN AT THE DESIGN STAGE	4 OF 24
5.0	DESIGN OF VARIOUS COMPONENTS	6 OF 24
6.0	TOTAL SAFE DISCHARGING CAPACITY OF THE SPATE DIVERSION WORKS	15 OF 24
7.0	BANK PROTECTIONS	15 OF 24
8.0	DESIGN OF CANAL(S)	16 OF 24

ANNEXES

NO.	TITLE
I	DATA FOR ECONOMICAL DESIGN OF EARTHEN CANALS
II	UPLIFT FORCES AND THICKNESS OF STILLING BASINS
III	DESIGN OF UPSTREAM AND DOWNSTREAM PROTECTIONS FOR DIFFERENT COMPONENTS
IV	BLENCH CURVES
V	ENERGY OF FLOW CURVES
VI	NORMAL DEPTH OF SCOUR V/S UNIT DISCHARGE
VII	NORMAL DEPTH OF SCOUR V/S DISCHARGE

QUICK START DESIGN MANUAL
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1.0 INTRODUCTION

This Quick Start Design Manual, covers the Steps required to do design of Spate Diversion Works and was primarily prepared by the author for refreshing the Yemeni Engineers involved in the field of development of Spate Works. This manual was prepared by the author while he was engaged in Groundwater and Soil Conservation Project that was funded by the World Bank.

To make it adaptable by the Yemeni Engineers, during the course of preparation of this Design Manual, attempt has been to make it as simple as possible but without compromising and/or loosing the technical contents and the resulting outputs.

The guidance and cooperation received from all those, especially Mr. Hamoud Rubaidi, Project Director, Groundwater and Soil Conservation Project and Mr. KS Sharma, Irrigation Engineering Advisor, GSCP in accomplishing the task of preparation of this Quick Start Design Manual is thankfully acknowledged.

Any suggestions to improve this manual are welcome and shall be thankfully acknowledged by the author (Manohar Singh: manohar3311@yahoo.com)

2.0 PLANNING ASPECTS & DESIGN CONCEPT

It is expected that the Planning Aspects and the details of the Design Concept in respect of various components of the Spate Diversion Works are known to the engineers for whom it is intended.

3.0 STEPS TO BE TAKEN AT THE PRE DESIGN STAGE

3.1 STEP – I: RECONNAISSANCE VISIT TO SITE

Make a reconnaissance visit to the proposed site of the Spate Diversion Works to have a feel of the site conditions. During this site visit meet the concerned beneficiaries to know their views about the past and present site conditions and any specific requirements. Some of the relevant available information as listed under the following paragraphs may also be collected during this visit.

3.2 STEP – II: COLLECTION OF SITE INFORMATION

(i) **Location of Site:** Name of Wadi, District, Governorate, Nearest City, Nearest Village, Name of Major Road, Coordinates and Index Map;
(ii) **Weir Axis:** Note down the location of the weir axis in case the beneficiaries are already having some temporary means of diverting the water.
(iii) **Description of Site:** During the reconnaissance visit take notes about the wadi bed conditions, location of canal(s), canal bed conditions, maximum observed water level as may be seen on the wadi banks, type of material in wadi and the canal(s) and any other existing feature;
(iv) **Command Area:** The area(s) under command of the various canal(s) and their location vis-à-vis the location of diversion works;

(v) **Type of Crops:** Type of crops being grown in the command area and percent of area under each of the crops and the corresponding yield of each crop;
(vi) Number of Spates per crop season;
(vii) Duration of each spate; and
(viii) Depth of application of water in the fields.

3.3 STEP – III: COLLECTION OF HYDROLOGICAL INFORMATION

Collect the Hydrological Report containing the Catchment Area, Rainfall Data, Location of Rain Gauges in the Catchment Area and Maximum Floods for the 5, 10, 25 and 50 years flood frequencies as follows:

RETURN PERIOD	DISCHARGE IN CUMECS	USAGE	
5 Years		For Design of less important structures	In cases where in the event of failure of the structure, loss to life and property is minimum
10 Years		For Design of Wadi Bank Protections	
25 or 30 Years		For design of Canal Control Structures	
50 Years		For design of Medium size Spate Diversion Works	In cases where in the event of failure of the structure, loss to life and property is appreciable

3.4 STEP – IV: COLLECTION OF TOPOGRAPHICAL SURVEY MAPS

S. NO.	DESCRIPTION	SCALES	REMARKS
(i)	A plan showing the contour map of the site having a contour interval of 0.25 or 0.50 m for a reach of about 500 m covering the area of interest. This plan in addition to the wadi banks should also show all the existing features & if there is some temporary diversion structure made by the beneficiaries along with the existing Canal(s).	1:500	THESE SCALES ARE ONLY FOR GUIDANCE AND IF NECESSARY THESE SHALL BE MODIFIED TO SUITE A PARTICULAR SITE CONDION
(ii)	Longitudinal profile of the wadi for the above said length.	H = 1:1000 V = 1:100	
(iii)	Cross Sections of wadi at minimum 7 locations: 1 Cross Section at the proposed Weir Axis, 3 Cross Sections in the upstream and 3 Cross Sections in the downstream.	H = 1:100 V = 1:100	
(iv)	Longitudinal profile of the Canal(s) for lengths up to 500 m or more.	H = 1:2000 V = 1:100	
(v)	Cross Sections of the Canal(s) at 50 m each.	H = 1:100 V = 1:100	
(vi)	A map showing the Work Site, Wadi, Canals and Command Area(s).	1:10,000	

3.5 STEP – V: COLLECT DESIGN PARAMETERS RELATED TO SOILS TYPE BASED ON SITE INVESTIGATIONS

Based upon Site Investigations or on the basis of Reconnaissance Visit adopt the Design Parameters related to soil type and wadi bed or Canal bed materials from the Standard Values given in the table below:

ADOPTED VALUES OF VALUES OF LACEY'S SILT FACTOR 'f' AND MANNING'S 'n'		
DESIGN PARAMETERS	**FOR STRUCTURES IN WADI**	**FOR STRUCTURES IN CANAL**
LACEY'S SILT FACTOR "f"	ADOPT FROM THE ABOVE TABLE	ADOPT FROM THE ABOVE TABLE
MANNING'S "n"	ADOPT FROM THE ABOVE TABLE	ADOPT FROM THE ABOVE TABLE

STANDARD VALUES OF LACEY'S SILT FACTOR 'f' AND MANNING'S 'n'				
TYPE OF MATERIAL		**GRAIN SIZE (mm)**	**SILT FACTOR (f)**	**MANNING'S (n)**
SILT	Very Fine	0.052	0.4	0.0179
	Fine	0.120	0.6	0.0198
	Medium	0.158	0.8	0.0210
	Standard	0.323	1.0	0.0225
SAND	Medium	0.505	1.25	0.0230
	Coarse	0.725	1.5	0.0249
	Heavy	1.200	2.0	0.0267
	Gravely	2.5 – 7.0	3 – 4	0.0312
GRAVEL	Medium	7.28	5	0.030
	Heavy	26.10	8 – 10	0.039
BOULDERS	Medium	72.50	15	0.044
	Large	183.80	20	0.050

3.6 STEP – VI: PLAN COMPONENTS OF THE SCHEME

Plan the components as required for the specific site under consideration. Normally a Spate Diversion Work comprises the following components:

- A Permanent Stone Masonry Diversion Weir;
- A Fuse Plug in combination with the Stone Masonry Weir in case of very wide wadis for economizing the cost of the Spate Diversion Works;
- Gated Canal Intake(s) for the canals;
- Gated Silt Sluice(s)for each of the Canal(s) ;
- Wing Walls and Divide Walls;
- Stone Rip Rap Aprons in the upstream and downstream of the weir;
- Rehabilitation of the existing portions of the canal and construction of parts of the canal wherever necessary; and
- Some Wadi Bank Protections on the wadi bank(s) in the upstream of the Spate Diversion Works to protect the agricultural lands or other properties from the HFL;

4.0 STEPS TO BE TAKEN AT THE DESIGN STAGE

4.1 STEP – VII: SELECTION OF WEIR AXIS

In Case of an Existing Temporary Diversion Structure Requiring Rehabilitation: In most cases in Yemen beneficiaries have already built traditional diversion structures on most wadis and had been doing irrigation for decades. This is normally based on their long and tried experience. In such cases it is always desirable to select the same axis of the weir as being used by the beneficiaries.

In Case of Newly Planned Diversion Structure: In order to arrive at a design that is techno-economically most viable, it is normal practice to examine alternative sites for locating the axis of the weir. Accordingly, in such cases more than one alternative should be examined. The merits and demerits of the various alternatives should be discussed in the Design Report.

4.2 STEP – VIII: WADI STAGE-DISCHARGE AND RATING CURVES

Using FLOWMASTER work out the Wadi Stage-Discharge and Rating Curves at a wadi Cross Section where the weir axis is proposed to be located.

4.3 STEP – IX: DESIGN PARAMETERS FOR THE CANAL INTAKE

- Normal - **USWL** = Same as Crest Level of the Weir (This is the USWL at which the canal intake should be able to pass the design discharge in to the canal, before water starts spilling over the Weir)
- Maximum Pond Level **- USWL** = Same as maximum Pond Level including the flood lift due to weir construction
- **FSD (DSWL)** = Full Supply Depth in the Canal (See Annex - I)
- **Sill Level of Canal Intake** = Wadi Bed Level in front of the Canal Intake + 0.25 to 0.50 m
- **Canal Design Discharge:** Determine the Canal Design Discharge using the following formulae:

$$Q = (2.77 \times A \times W)/(E \times N)$$

Where
Q = Canal Discharge in Cumecs;
A = Net Command Area in Ha;
W = Average Irrigation Application Depth in m;
E = Overall Irrigation Efficiency with improved works; and
N = Average Number of Hours Wadi Flow is available.

DESIGN DISCHARGE IN THE CANAL			
S. NO.	**ITEM**	**VALUES**	**REMARKS**
i	Gross Command Area (GCA)	Ha	
ii	Culturable Command Area (CCA) i.e. Command area net of field bunds & pathways etc.	Ha	90 % of GCA. (Assuming 10 % area to be occupied by field channels, pathways & distribution system etc.)
iii	Command area irrigable at low spates (CIL)	20 %	To be assumed on the basis of discussions with beneficiaries.
iv	Net command area (A)	Ha	About 70 % of the GCA
v	Depth of water application (W)	m	To be adopted on the basis of discussions with beneficiaries.
Vii	Average number of hours wadi flow is normally available in each spate (N)	Hrs	
vii	Overall irrigation efficiency (E)	0.46	Source: Land & Water Conservation Project (LWCP), Preparation Mission Report of 1991.
viii	Discharge (Q) In the Canal at the Intake Point	Cumecs	Formula for determining discharge: Q = 2.77 x A x W / (E x N)

4.4 STEP – X: DESIGN PARAMETERS FOR THE SILT SLUICE

- **Discharge (Q)** = Assume about 50 % of the discharge through Canal Intake
- **USWL** = Same as maximum Pond Level including the flood lift due to weir construction
- **DSWL** = Water level in the wadi at Design Discharge (Q_{50}) of the Weir
- **Sill Level of Silt Sluice** = Same as Wadi Bed Level in front of the Silt Sluice

4.5 STEP – XI: DESIGN PARAMETERS FOR THE OVER FLOW WEIR

- **Discharge (Q)** = Wadi Flow at 30 years or 50 Years Return Period
- **USWL** = Same as maximum Pond Level including the flood lift due to weir construction
- **DSWL** = Water level in the wadi at Design Discharge (Q_{30} or Q_{50}) of the Weir
- **Weir Crest** = Canal Intake Level + Canal FSD + H_L (Assume about 0.15 to 0.20 m)
- **Apron Level in the upstream of the Weir =** Average Wadi Bed Level in front of Weir

4.6 STEP – XII: Upstream & Downstream Water Levels

Determine the downstream water levels in the wadi for the different discharges from the Rating Curve and Wadi Stage-Discharge Curves. Adopt the Upstream Water Levels keeping in view the required FSL in the canal, required weir crest & also the observed HFLs in the wadi and the anticipated flood lift in the upstream due to construction of the overflow weir. The upstream & downstream water levels so determined should be presented in the following table:

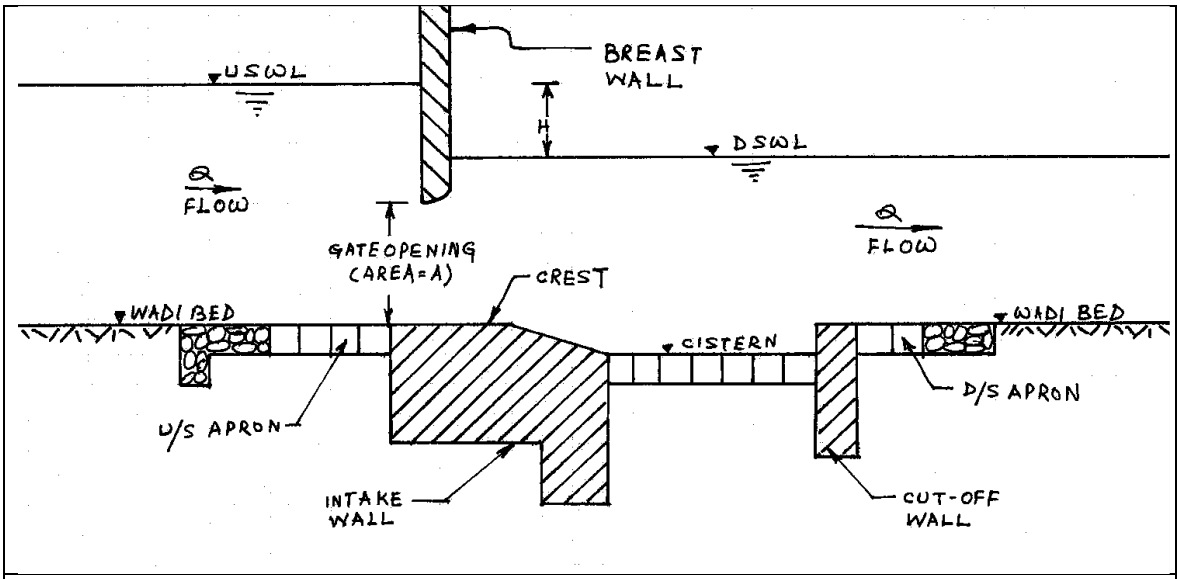
RETURN PERIOD	DISCHARGE (Cumecs)	UPSTREAM HFLs (m)		DOWNSTREAM HFL (m)
5 years				
10 years				
25 or 30 years				
50 years				
REMARKS				

5.0 DESIGN OF VARIOUS COMPONENTS

5.1 STEP – XIII: DESIGN OF SILT SLUICE

5.1.1 Design of Silt Sluice Length of Water Way (Opening)

Since the Silt Sluice(s) are gated & proposed to be provided with breast walls, submerged orifice formulae will be used to design these structures as explained in the conceptual diagram below:



CONCEPTUAL DIAGRAM OF SILT SLUICE

The formula for discharge through submerged orifice is given by

$$Q = C_d \times A \times \sqrt{2gH}$$

In the above formulae we have

Q = Discharge through the silt sluice in Cumecs (m^3/sec)

L = Clear length of water way (m)

C_d = Coefficient of discharge having a value of 0.62

A = Area of opening of the silt sluice / Canal Intake (orifice) in m^2

g = Acceleration due to gravity (9.81 m/sec^2)

H = Effective head over the crest (USWL – DSWL) or (USWL – FSL) in m

5.1.2 Design of Upstream and Downstream Aprons/Protections and Stilling Basin:
Design these appurtenant works as per details given in Annex - III

5.1.3 Design of RCC Breast Wall and Platforms

Design the RCC Breast Walls for the horizontal water pressure from the upstream and dead load. And design the RCC platforms for the Live Load and Dead Load

5.1.4 Design of Radial Gates, Hoisting Arrangements & Hoisting Platform

The design of Vertical Steel Gates & Hoisting Arrangements shall be supplied by the Gate Manufacturer. Or try to use gates having standard size which are readily available in the market.

5.2 STEP – XIV: DESIGN OF GATED CANAL INTAKE

5.2.1 General

As per the criteria for design of spate diversion works, the canal intake should be able to pass the design discharge in to the canal, before water starts spilling over the Weir. The discharge in the canal, when the upstream water level is at HFL would be higher than the full supply discharge of the canal. But this event would be very rare and in such situations to prevent and/or to minimize damage to the canal, the excess flow of water in the canals shall be controlled by operation of the Canal Intake gates.

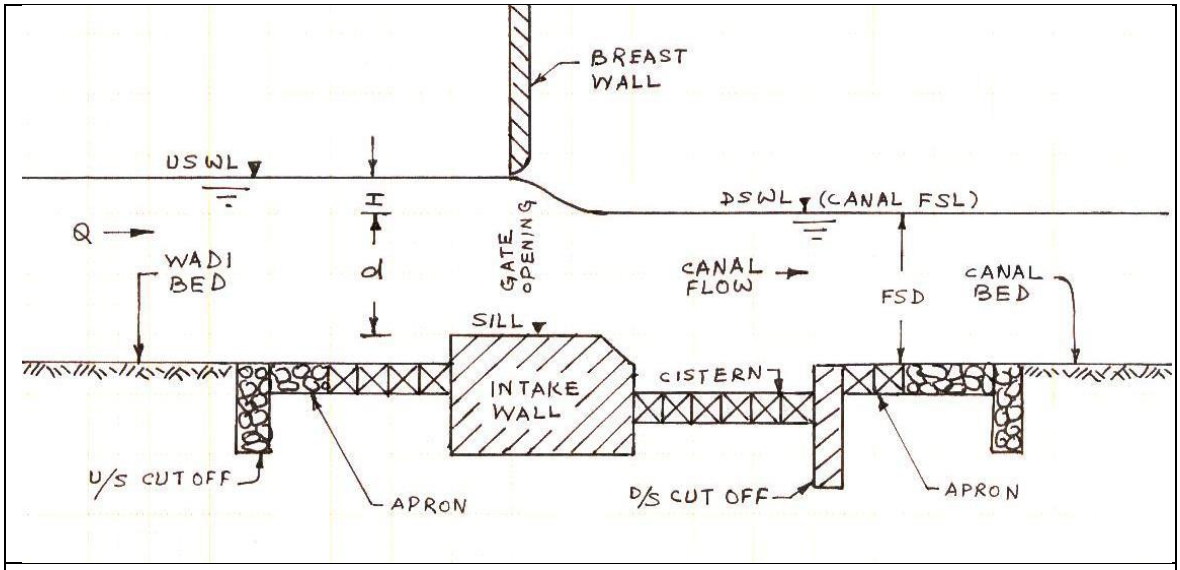
If topography permits a suitable Canal Escape can also be provided either in the upstream or downstream of the Canal Intake. The crest of such an escape shall be kept at the canal FSL. The length of escape shall be designed to account for the surplus discharge likely to enter the canal.

The sill level of the Canal Intake shall be provided at a level which is higher than the wadi bed level by about 0.25 to 0.50 m, so that entry of silt in to the canal is prevented or minimized.

5.2.2 Clear Width of the Intake when the Sill is Submerged and the Upstream Water Level is Between the Sill and the Bottom of Breast Wall

When the USWL level is same as the crest level of the weir/bottom level of the breast wall, it should be possible to pass the design discharge of the Canal, so that the required discharge in the canal is available before the water starts overflowing the weir back in to the wadi.

The conceptual diagram showing the formation of profile of flow is given below:



CONCEPTUAL DIAGRAM OF CANAL INTAKE

Drowned Weir Formula neglecting the head due to velocity of approach, shall be used for determining the length of water way and/or for discharge calculations. This formula is given below :

$$Q = 2/3 \times C_1 \times L \times \sqrt{2g} \times H^{3/2} + C_2 \times d \times L \times \sqrt{2gH}$$

In the above formulae we have

Q = Discharge in Cumecs (m^3/sec)

L = Clear length of water way (m)

C_1 = Numerical coefficient (Assumed value = 0.577)

C_2 = Numerical coefficient (Assumed value = 0.80)

g = Acceleration due to gravity (9.81 m/sec^2)

H = Difference of upstream & downstream water levels (m)

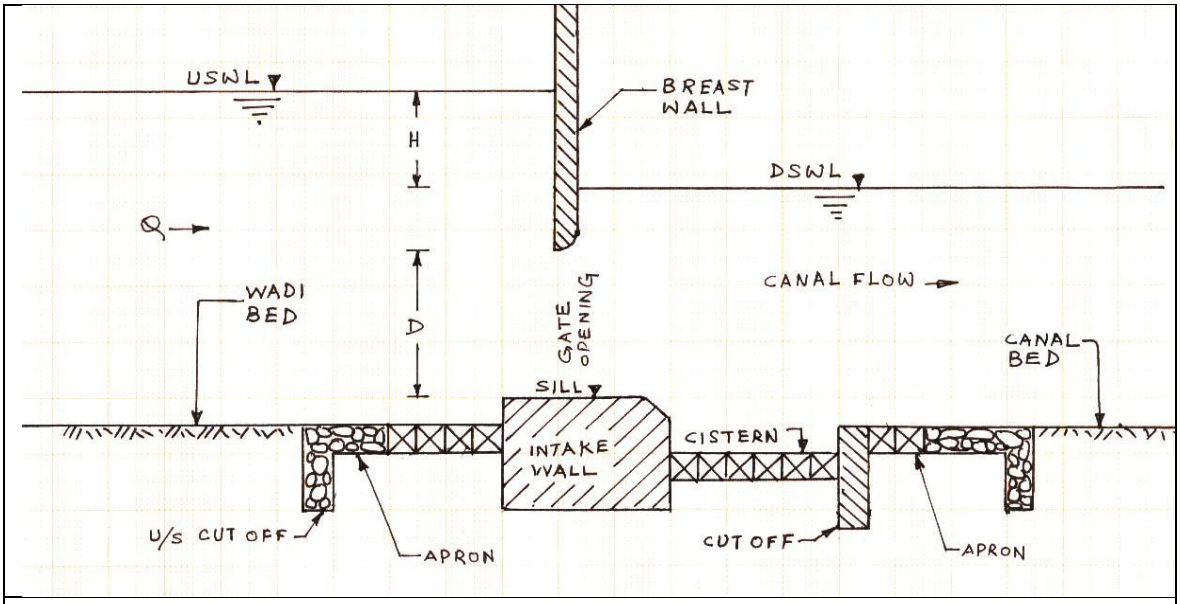
d = Depth of downstream water level above the crest (m)

After determining the length of the Canal Intake provide the number of bays in such a manner that the width of the Steel Vertical Gate is not more than 2 m from the consideration of the operation and maintenance of the Gates.

5.2.3 Discharge Over the Canal Intake when the Upstream Pool Level is above the Bottom Level of the Breast Wall

Discharging capacity of the canal intake at the upstream pond level shall, however, be more than that worked out in the previous Paragraph. The water level (FSL) in the canal shall also rise in that event. Since the canal intake shall be gated & provided with breast wall, the discharging capacity shall be worked out using the drowned orifice formulae.

The conceptual diagram showing the formation of profile of flow through submerged orifice is given below:



CONCEPTUAL DIAGRAM OF CANAL INTAKE

The formula for discharge through submerged orifice is given by

$$Q = C_d \times A \times \sqrt{2gH}$$

In the above formulae we have

Q = Discharge through the Canal Intake in Cumecs (m^3/sec)

L = Clear length of Canal Intake (m)

C_d = Coefficient of discharge having a value of 0.62

A = Area of opening of the Canal Intake (orifice) in m^2

g = Acceleration due to gravity (9.81 m/sec^2)

H = Effective head over the crest (USWL – DSWL) or (USWL – FSL) in m

Since the required design discharge and also the FSD in the canal would be available, as soon as the pond level reaches the weir crest level and as most of the times wadi is expected to have low discharges, the excess discharge in the canal on account of rise in water level beyond the crest level shall be controlled by means of operation of Canal Intake gates to prevent damage to the canal. In certain cases where Canal Escape can be provided, the crest level shall be kept at the Canal FSL.

5.2.4 Design of Upstream and Downstream Aprons/Protections and Stilling Basin:

Design these appurtenant works as per details given in Annex - III

5.2.5 Design of RCC Breast Wall and Platforms

Design the RCC Breast Walls for the horizontal water pressure from the upstream and dead load. And design the RCC platforms for the Live Load and Dead Load

5.2.6 Design of Radial Gates, Hoisting Arrangements & Hoisting Platform

The design of Vertical Steel Gates & Hoisting Arrangements shall be supplied by the Gate Manufacturer. Or try to use gates having standard size which are readily available in the market.

5.2.7 Design of Ungated Canal Intake

In situations, where due to economical reasons it is not possible to provide gates, the Canal Intake can be designed as ungated. Breast Wall shall also not be required in such cases.

The clear width of the Canal Intake shall be designed in the same manner as given in paragraph 5.2.2 of this Manual.

But to prevent damage to the canal under higher floods, it would be essential to provide a Canal Escape either in the upstream or the downstream of the Canal Intake depending upon the Topography. The crest of such an escape shall be kept at the canal FSL. The length of escape shall be designed to account for the surplus discharge likely to enter the canal.

The sill level of the Canal Intake shall be provided at a level which is higher than the wadi bed level by about 0.25 to 0.50 m, so that entry of silt in to the canal is prevented or minimized.

5.3 STEP – XV: DESIGN OF MASONRY OVERFLOW WEIR

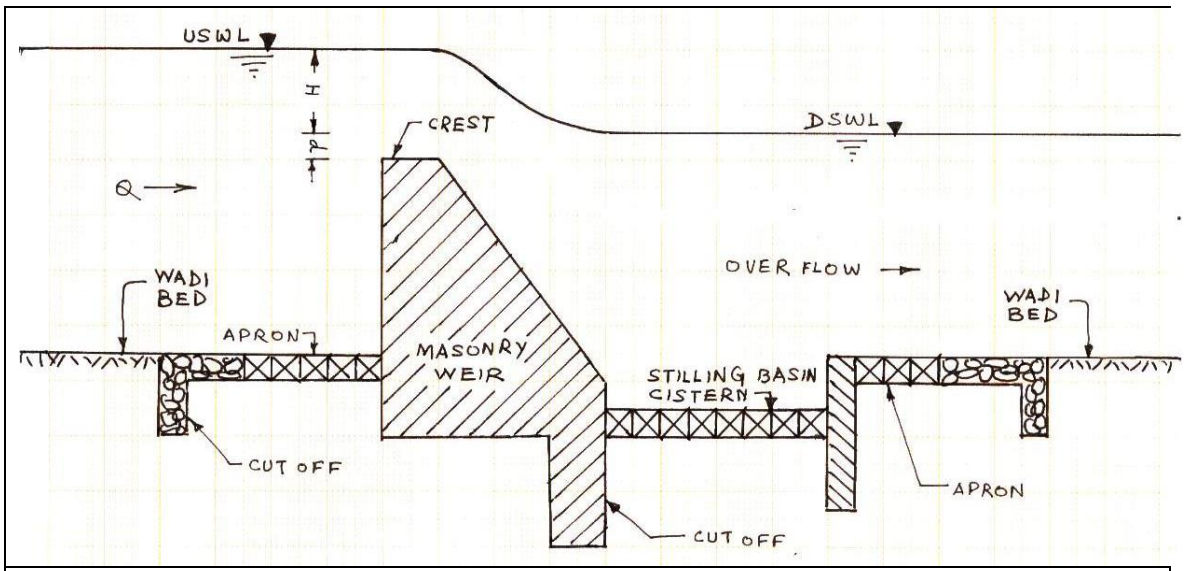
5.3.1 Length of the Weir When the Weir Crest is Submerged

In this condition the downstream water level (DSWL) is above the weir crest and the Drowned Weir Formula neglecting the head due to velocity of approach, shall be used for determining the length of water way and/or for discharge calculations. This formula is given below along with the conceptual sketch:

$$Q = 2/3 \times C_1 \times L \times \sqrt{2g} \times H^{3/2} + C_2 \times d \times L \times \sqrt{2gH}$$

In the above formulae we have

Q = Discharge in Cumecs (m^3/sec)
L = Clear length of water way (m)
C_1 = Numerical coefficient (Assumed value = 0.577)
C_2 = Numerical coefficient (Assumed value = 0.80)
g = acceleration due to gravity (9.81 m/sec^2)
H = Difference of upstream & downstream water levels (m)
d = Depth of downstream water level above the crest (m)



CONCEPTUAL DIAGRAM OF MASONRY OVERFLOW WEIR

5.3.2 Length of the Weir When the Crest is not Fully Submerged

In this condition the downstream water level (DSWL) is below the weir crest level and Free Fall Formulae shall be used. When the DSWL is below the crest level, we have d = 0 in the formulae under drowned condition given in the above paragraph.

$$\therefore Q = 2/3 \times C_1 \times L \times \sqrt{2g} \times H^{3/2}$$

In the aforesaid formulae we have

Q = Discharge in Cumecs (m^3/sec)
L = Clear length of water way (m)
C_1 = Numerical coefficient (Assumed value = 0.577)
g = acceleration due to gravity (9.81 m/sec^2)
H = Difference of upstream water level and the weir crest (m)

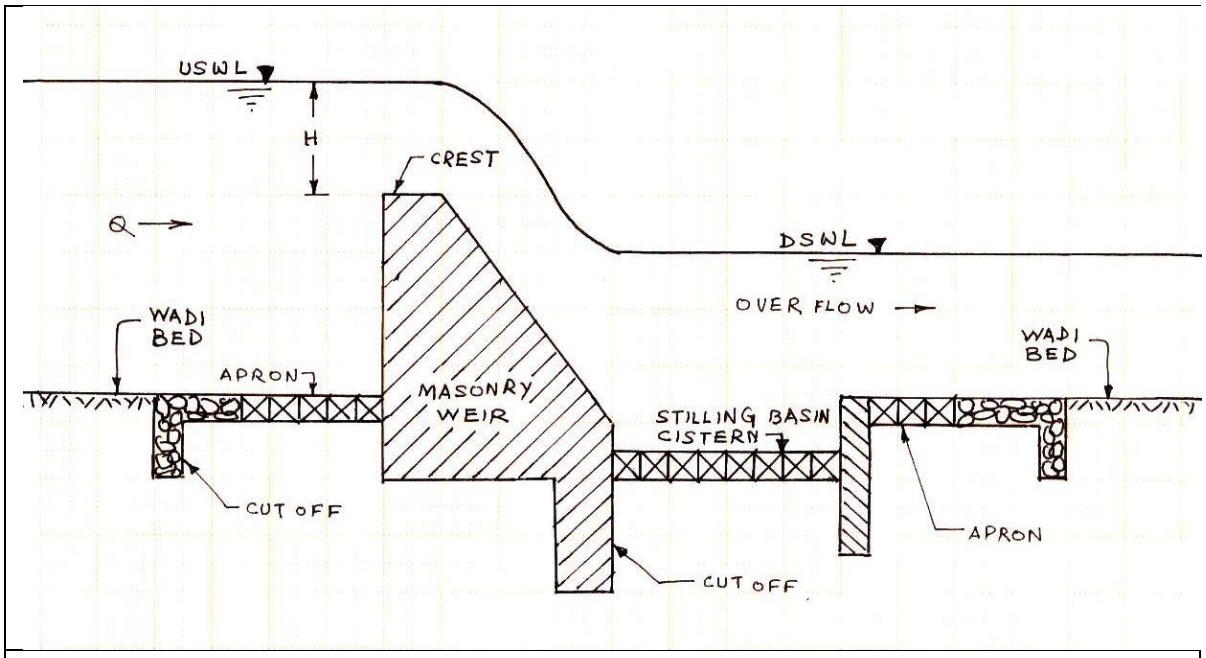
Substituting the values of C_1 & g in the above formulae, we get

$$Q = 1.7 \times L \times H^{3/2}$$

or

$$Q = C_d \times L \times H^{3/2} \quad (C_d : \text{Discharge Coefficient} = 1.7)$$

The conceptual diagram showing various parameters is presented below:



CONCEPTUAL DIAGRAM OF MASONRY OVERFLOW WEIR

5.3.3 Design of Upstream and Downstream Aprons/Protections and Stilling Basin:

Design these appurtenant works as per details given in Annex - III

5.3.4 Energy Dissipation & Stilling Basin

In accordance with what has been stated in (Annex – I) the upstream & downstream protection works and/or aprons are proposed to be made from gabions. Below these gabions filter fabric of suitable specifications shall be provided. Further to above and in order to prevent any clogging of the synthetic filter fabric, 20 cm thick graded sand-gravel mixture between the formation level and the filter cloth under the gabion cistern shall also be provided.

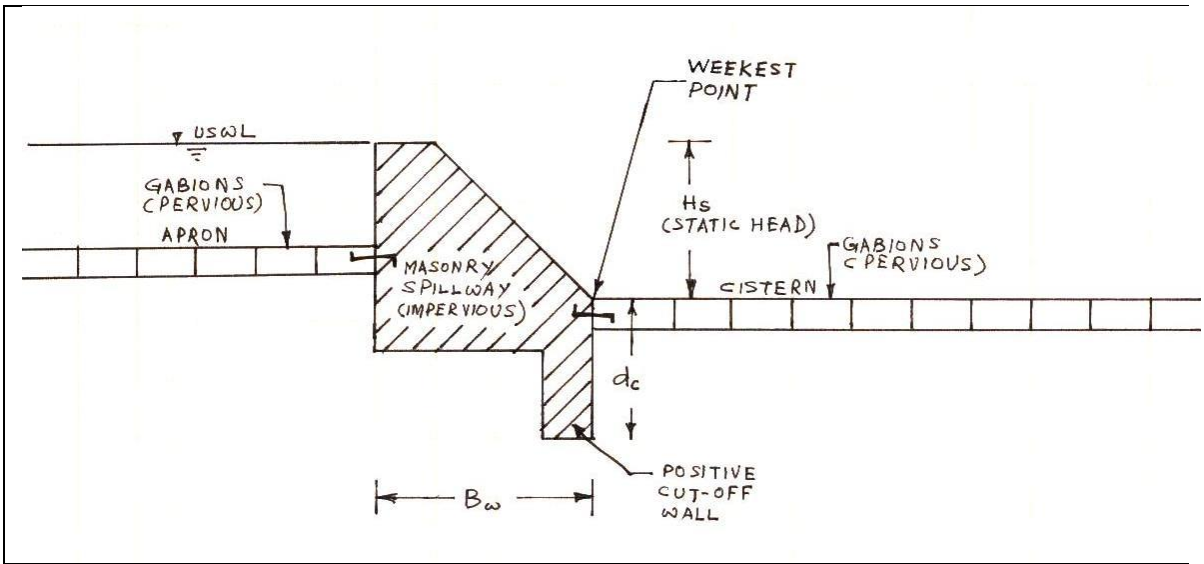
5.3.5 Exit Gradient

The junction of the toe (downstream face) of the masonry weir with the cistern that is made of the gabion boxes is normally a vulnerable location from the view point of piping from below. It would therefore, be ensured that the Exit Gradient at this location is within safe limits (0.20) prescribed for alluvium soils to prevent occurrence of any type of piping.

For a standard form consisting of floor of length 'B_W', with a vertical cut-off depth 'd_C', the exit gradient (G_E) at its downstream end is given by the following equation:

G_E = $\{H_S/d_C\} \times \{1/\pi\sqrt{\lambda}\}$
H_S = Maximum static head = USWL – Cistern Level
B_W = Base width of Weir in m
d_C = Depth of the cut-off wall at the toe of the weir
α = B_W/d_C
$1/\pi\sqrt{\lambda}$ = A parameter to be read from Khosla's Exit Gradient Curves for a particular value of α
Or calculate $\lambda = (1 + \sqrt{1+\alpha^2})/2$

The diagram below shows the conceptual details of the weir section for calculating the exit Gradient:



CONCEPTUAL DIAGRAM FOR EXIT GRADIENT

Normally a safe limit of 0.20 is prescribed for the alluvium type of soils to prevent occurrence of any type of piping and therefore, it should be ensured that the exit gradient at this location is within this limit.

The safe value of Exit Gradient for various types of soils are as as follows:

s. no.	Type of soil	Safe value of Exit Gradient
1	Fine Sand	0.15 – 0.16
2	Coarse (Alluvium) Sand	0.16 – 0.20
3	Gravel	0.20 – 0.25
4	Gravel with Boulders	0.25 – 0.30

5.3.6 Design of Section of Masonry Weir

Top Width of the Weir: Top width of the weir on the consideration of elementary profile (stress criterion) of the weir is given by the following formula:

$T_w = d/\sqrt{\partial}$ in m

Where T_w = Top width of weir in m
d = USWL – Weir Crest Level
∂ = Unit weight of masonry in T/m^3

Top width of the weir on the consideration of safety of the weir against sliding is given by the following formula:

$T_w = d/\mu\,\partial$

Where T_w = Top width of weir in m
d = USWL – Weir Crest Level
∂ = Unit weight of masonry in T/m^3
And μ = Coefficient of friction

The maximum of the two values of T_w obtained from the above said two considerations should be adopted subject to a minimum of 1.0 m

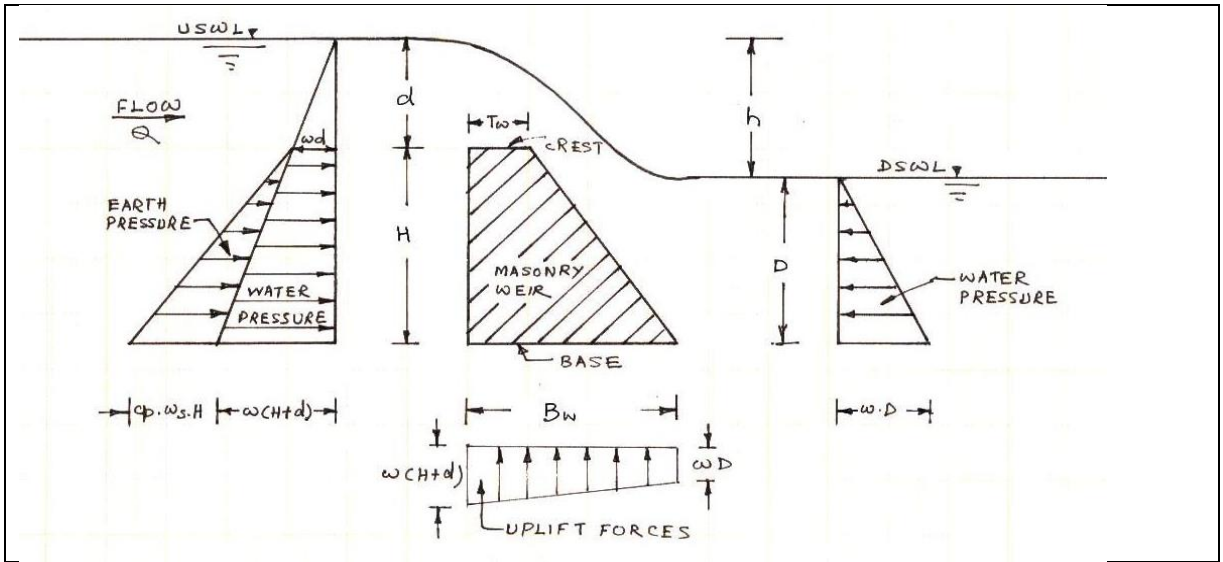
Bottom Level of the Weir: Bottom level of the weir shall be decided from the following two considerations:

(i) Scour and (ii) Bottom level of the Stilling Basin Floor

Adopt the bottom level of the weir at a level which is lower of the two levels obtained from the above considerations. And accordingly, the stability of the weir wall should be also be checked at this level.

Stability Analysis of the Weir Section: Check the stability of the weir for the following loading conditions:

- Self-Load of the Masonry Weir;
- Upstream Water Pressure when the Water Level is at HFL;
- Downstream Water Pressure when the Water Level is at DSWL;
- Uplift Forces at the Bottom of the weir;
- Weight of the Water Column on the top and Downstream Slope of the Weir; and
- Earth Pressure on the upstream face of the weir as it would be silted after few spates.



CONCEPTUAL DIAGRAM FOR STABILITY ANALYSES OF MASONRY OVERFLOW WEIR

5.3.7 RCC Coping on the Weir Top

To prevent any damage that might be caused due to continuously flowing water to the top surface of the weir that is made of stone masonry, RCC (1:2:4) Coping 300 mm thick suitably anchored to the top should be provided.

5.4 STEP – XVI: DESIGN OF DIVIDE WALLS/WING WALLS

5.4.1 General

In order to divide the varied nature of flow between Overflow Weir portion and the Silt Sluice, suitable Divide Walls shall be provided between Canal Intake, Silt Sluice and the Overflow Weir. Similarly, suitable Wing Walls with Weep Holes shall be provided at the left and right banks of the wadi.

The Wing Wall shall be designed as Retaining Walls as these have to retain earth on one side. The wing walls shall be provided with suitable drainage arrangements to drain off the water and thus reduce hydrostatic pressure at the back of the wall. Commonly used drainage system is to provide weep holes, wherever necessary to release the excess pressure from the soil behind the wing walls.

The worst loading combination shall be when there is no water in the wadi and wet soil on the back of the Wing Walls. Accordingly the Wing Walls shall be designed as Gravity Structure to resist the following forces:

- Self-Load of the Wing Walls;
- Weight of the backfill on the back of the Wing Walls; and
- Horizontal Pressure from the backfill considering it as Saturated Soil;

5.4.2 Scour Depth/Bottom Level of the Wing Walls

The bottom level of the Wing Walls shall be determined from the consideration of maximum scour as follows:

The standard depth of scour in a wadi is given by the following formula:

$$R = 0.475\ (Q/f)^{1/3}$$

Where R = Standard depth of scour (m) below wadi HFL;
Q = Maximum Design Discharge (Cumecs);
f = Silt factor.

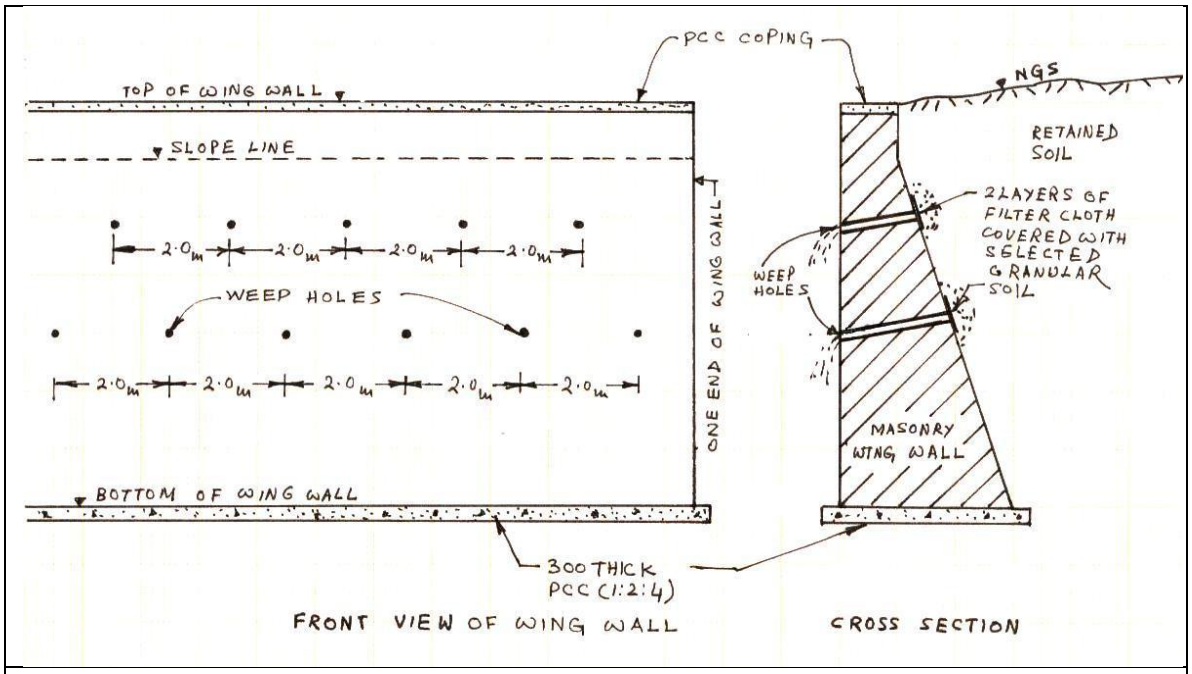
The recommended depth of scour is usually taken as follows:

5.4.3 Design Parameters

• Foundation level	=	m
• Top level of wing wall	=	m
• D/S Slope Level	=	m
• U/S Slope (H/V)	=	
• D/S Slope (H/V)	=	
• Top width of wing wall	=	m
• Angle of internal friction (Φ)	=	Degrees
• Unit weight of Masonry	=	Ton/m^3
• Unit weight of wet earth	=	Ton/m^3
• Bearing Capacity of soil	=	Ton/m^2
• Maximum allowable compressive stress in masonry	=	Ton/m^2
• Coefficient of friction (μ)	=	

5.4.4 Weep Holes

As mentioned before the wing walls shall be designed as Retaining Walls as these have to retain earth on one side. The wing walls shall be provided with suitable drainage arrangements to drain off the water and thus reduce hydrostatic pressure at the back of the wall. Commonly used drainage system is to provide weep holes, as shown in the diagram below.



CONCEPTUAL DIAGRAM FOR WEEP HOLES IN WING WALL

The weep holes shall consist of PVC pipes of 75 mm diameter and shall be spaced about 2.0 m center to center both horizontally (staggered) and vertically. The lower most line of the weep holes shall be placed at a height of 300 mm from the bed of the wadi at that location. The weep holes shall be prevented from clogging and loss of soil from the backfill by two layers of filter cloth. These filter clothes on the end of the weep hole pipe shall be covered by selected granular soil.

6.0 Step – XVII: TOTAL SAFE DISCHARGING CAPACITY OF THE SPATE DIVERSION WORKS

The total safe discharging capacity of the Spate Diversion Works as a whole shall be determined as follows :

$$Q_{TA} = Q_O + Q_S + Q_C + Q_E$$
$$Q_{TB} = Q_O + Q_E$$

here Q_{TA} = Total safe discharging capacity of the Spate Diversion Works as a whole, in the event when Silt Sluice and Canal Intake Gates are opened and the Canal Escape also is functional; and

and Q_{TB} = Total safe discharging capacity of the Spate Diversion Works as a whole, In the event when Silt Sluice gate and Canal Intake Gate is closed but Canal Escape is functional.

The total safe discharging capacity of the Spate Diversion Works as a whole shall not be less than the maximum design discharge.

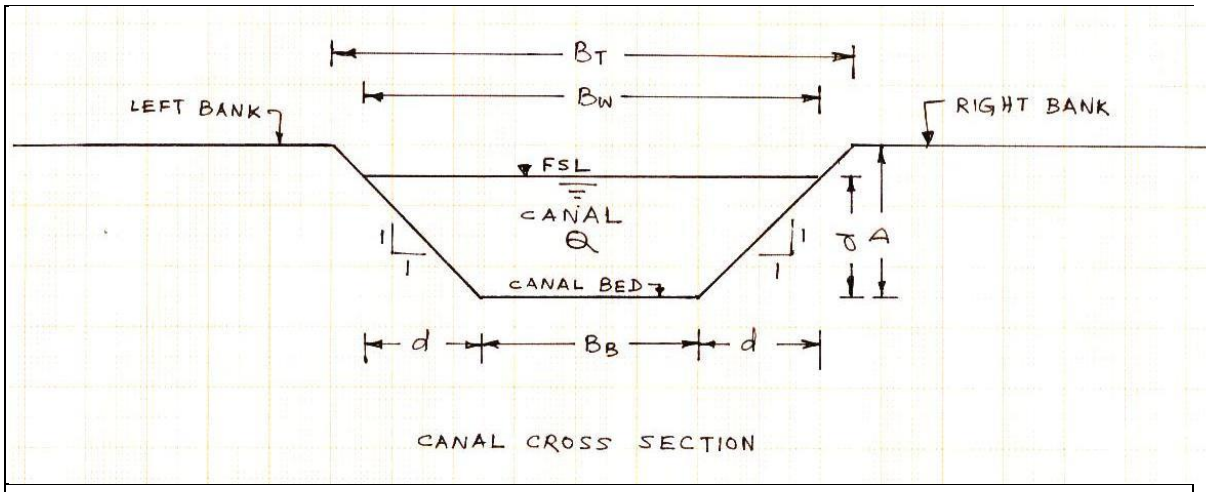
7.0 STEP – XVIII: DESIGN OF BANK PROTECTIONS

As mentioned before, wherever necessary wadi banks and adjoining lands in the vicinity of the Spate Diversion Works shall be suitably protected up to the maximum upstream pond level that is likely to occur. The Wadi Bank Protections therefore, shall be provided and designed accordingly.

8.0 STEP – XIX: DESIGN OF CANAL(S)

Design Parameters: The canal shall have the following design parameters,

- Q (Discharge) in m^3/s = Known
- d (Depth of water - FSD) in m = Known
- B_B (Internal Base Width) in m = To be Determined
- H:V (Side Slopes) = Adopt as 1:1 or depending on site conditions
- A (Area of flow) m^2 = $[(B_B + B_W)/2] \times d$
- P (Wetted Parameter) in m = $B_B + 2\{\sqrt{2}\, d^2\}$
- R (Hydraulic Mean Radius) in m = A/P
- S (Canal Bed Slope) = Adopt from Annex - I
- N (Manning's 'n') = Adopt from Table given on page 3 of 23



CONCEPTUAL DIAGRAM OF CANAL CROSS SECTION

Manning's Formula for design of canal section

We have velocity of flow (V) in the canal = $(1/N) \times R^{2/3} \times S^{1/2}$

And Discharge (Q) in the canal = $A \times V$

Thus from the above Base Width of the canal can be determined.

Alternately FLOWMASTER Software can also be used to design the canal sec using same Design Parameters.

ANNEXES

ANNEX – I

DATA FOR ECONOMICAL DESIGN OF EARTHEN CANALS BASED ON KENNEDY'S THEORY (VALUE OF SILT ROUGOSITY COEFFICIENT = 0.0225)				
CANAL DISCHARGE (cumecs)	BED WIDTH (m)	WATER DEPTH (FSD) (m)	BED SLOPE (1 in -------)	MEAN VELOCITY (m/sec)
0.06	0.61	0.30	2500	0.24
0.11	0.82	0.37	2500	0.30
0.17	1.07	0.43	2860	0.31
0.23	1.22	0.46	2860	0.33
0.28	1.45	0.49	3330	0.34
0.34	1.60	0.53	3330	0.36
0.40.	1.68	0.55	3330	0.37
0.45	1.83	0.58	3640	0.38
0.51	1.91	0.59	3640	0.39
0.57	2.01	0.61	3640	0.40
0.85	2.44	0.68	3640	0.44
1.13	2.82	0.78	4000	0.46
1.27	2.97	0.81	4000	0.47
1.42	3.13	0.84	4000	0.47
1.70	3.35	0.88	4000	0.51
1.98	3.66	0.91	4000	0.53
2.26	3.96	0.97	4000	0.54
2.55	4.11	1.02	4000	0.54
2.83	4.42	1.04	4440	0.55
3.54	4.88	1.11	4440	0.58
4.25	5.18	1.12	4440	0.61
4.95	5.64	1.23	4440	0.63
5.66	5.94	1.31	4440	0.66
7.08	6.70	1.43	4440	0.71
8.50	7.31	1.46	4440	0.71
9.91	8.08	1.57	5000	0.71
11.30	8.69	1.61	5000	0.74
12.70	9.30	1.68	5000	0.76
14.20	9.75	1.72	5000	0.77
17.00	10.70	1.83	5000	0.79
19.80	11.90	1.86	5000	0.82
22.60	12.80	1.92	5000	0.86
25.50	14.00	1.95	5000	0.87
28.30	15.30	1.98	5000	0.91
30.00	13.90	2.30	5000	0.93
60.00	26.90	2.30	5000	1.03
142.00	56.50	2.50	6670	0.97
283.00	105.00	2.59	6670	1.03
283.00	110.00	2.68	8000	0.96

UPLIFT FORCES AND THICKNESS OF STILLING BASINS

Most of the Spate Diversion Works in Yemen are located in wadis having permeable foundations. In the Request for Proposal (RFP No. GSCP/CS/QCBS/1/2004 of November 2004) for the Consultancy Services for Survey, Design and Preparation of Bidding Documents for Small and Medium Spate Diversion Works under Groundwater & Soil Conservation Project, it has been proposed that these have to be low cost flexible structures made with gabion or similar materials. Accordingly, to make the structures more cost effective the upstream & downstream protection works and/or aprons are proposed to be made from gabions baskets filled with suitable size stones, which have about 25 – 30 % voids and thus permeable. Below these gabions synthetic filter fabric of suitable specifications shall be proposed.

Further to above and in order to prevent any clogging of the synthetic filter fabric, 20 cm thick graded sand-gravel mixture between the formation level and the filter cloth under the gabion cistern shall also be provided.

Therefore, it is expected that the bulk of uplift forces will get dissipated and the residual uplift pressures, if any are likely to be of very low order and shall be effectively taken care of by the self weight of the gabions. Accordingly, while designing various components uplift forces shall be considered only below the (impervious) masonry walls/aprons & shall be ignored while designing the floors of stilling basins, upstream & downstream aprons made of gabion works so that these are techno-economically viable.

DESIGN OF UPSTREAM AND DOWNSTREAM APRONS/PROTECTIONS FOR DIFFERENT COMPONENTS

SCOUR DEPTH

We have Regime Scour depth as below:

$$R = 1.35\,(q^2/f)^{1/3}$$ or use ANNEX - VI

Where

R = Regime Scour Depth below the HFL in m;

q = Unit Discharge over the Weir/Sill in Cumecs/m; and

f = Lacey's Silt Factor

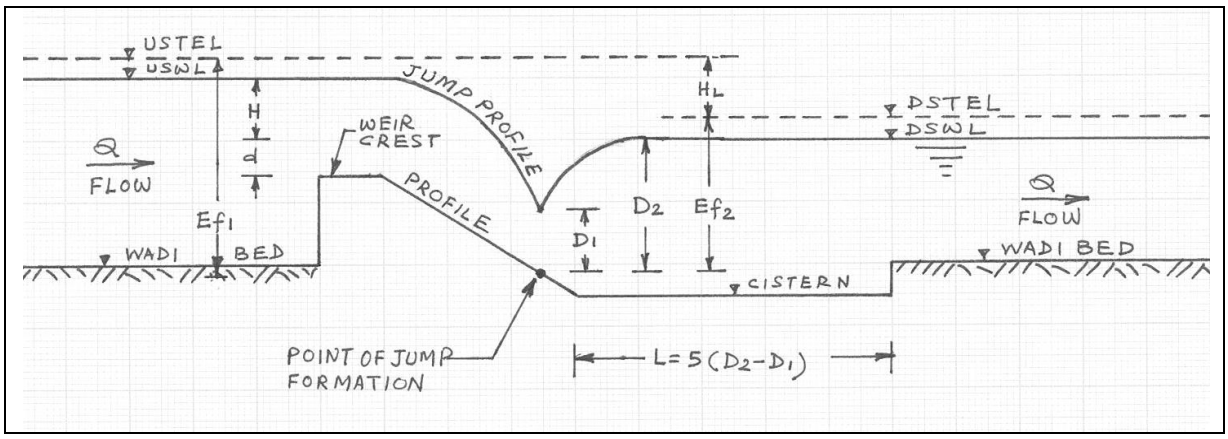
Therefore, Recommended Scour Depth for the upstream cut-off = 1.25 x R

And Recommended Scour Depth for the downstream cut-off = 1.50 x R

The upstream cut off wall should, therefore, be taken up to a minimum reduced level of USWL - Recommended scour depth in the upstream & downstream cut off wall up to the level of DSWL - Recommended scour depth in the downstream.

HYDRAULIC JUMP FORMATION

A typical diagram explaining the Hydraulic Jump phenomenon along with terms used therein is given below:



In the above diagram we have

USTEL	:	Upstream Total Energy Line;
DSTEL	:	Downstream Total Energy Line;
USWL	:	Upstream Water Level;
DSWL	:	Downstream Water Level;
H_L	:	Head Loss (Difference between USTEL & DSTEL);
H	:	Head Loss between USWL and DSWL;
Ef_1	:	Energy of flow before jump formation;
Ef_2	:	Energy of flow after jump formation;
D_1	:	Depth of water before jump formation;
D_2	:	Depth of water after jump formation; and
d	:	Difference between DSWL and crest of the weir.

LENGTH OF STILLING BASIN/ENERGY DISSIPATION

The length of Stilling Basin/Energy Dissipation shall be determined using the Blench Curves presented in Annex–IV

Neglecting the velocity head, we have

H_L (Head Loss) = USWL – DSWL

Using the values of H_L & q the value of Ef_2 can be determined from the Blench Curves

Then $Ef_1 = Ef_2 + H_L$

Length of Stilling Basin is given by the formulae

$L_S = 5 (D_2 - D_1)$

Where L_S is length of Stilling Basin and D_1 & D_2 have already been defined earlier. The values of D_1 & D_2 shall be worked out from the Energy of Flow Curves (Annex – V) for the corresponding values of Ef_1 & Ef_2.

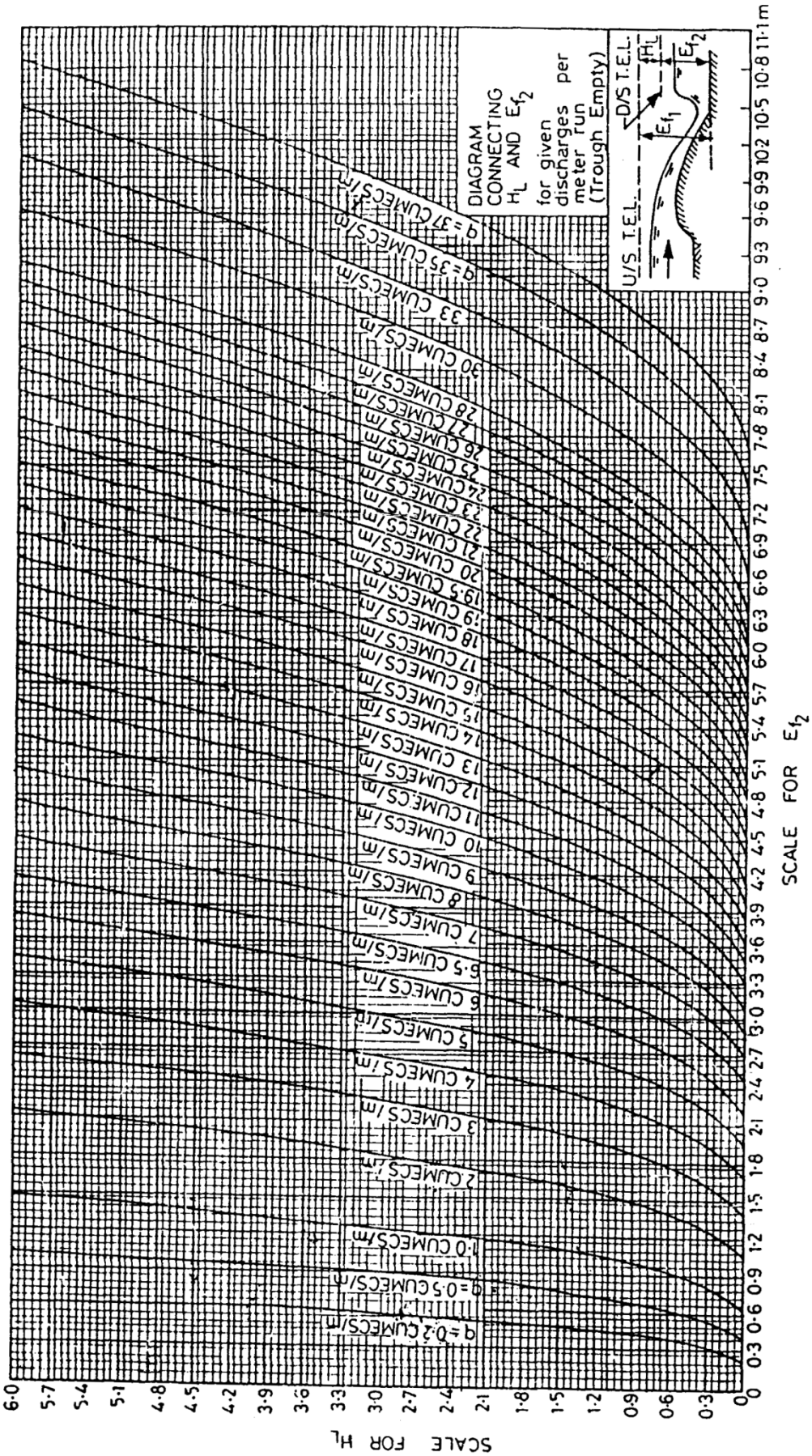
LEVEL OF CISTERN OF STILLING BASIN

Level of Stilling Basin cistern is given by the formulae :

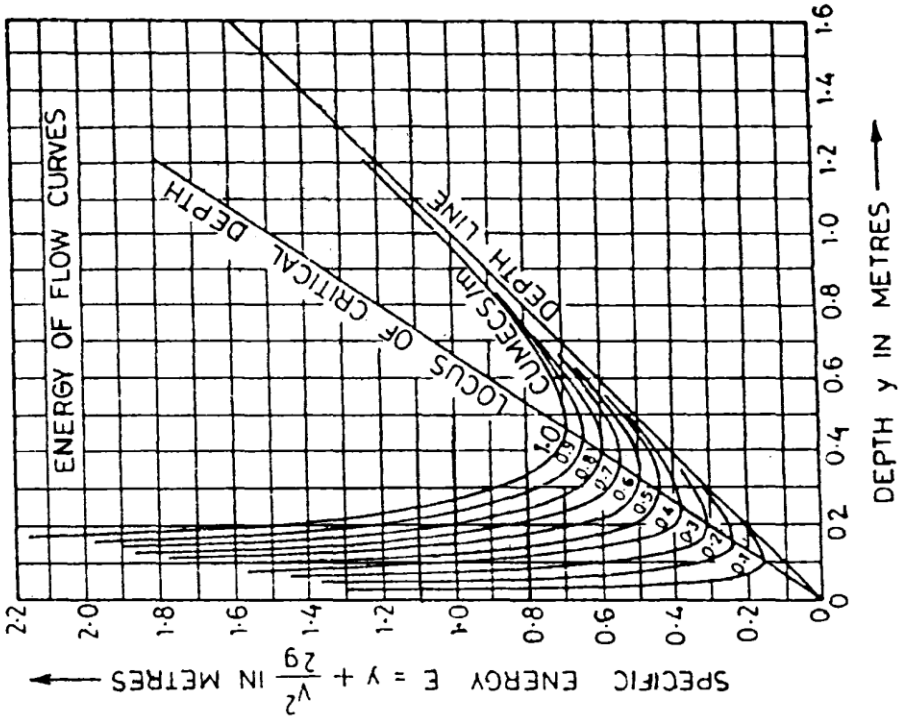
L_C = DSWL - Ef_2 (Neglecting the Velocity Head)

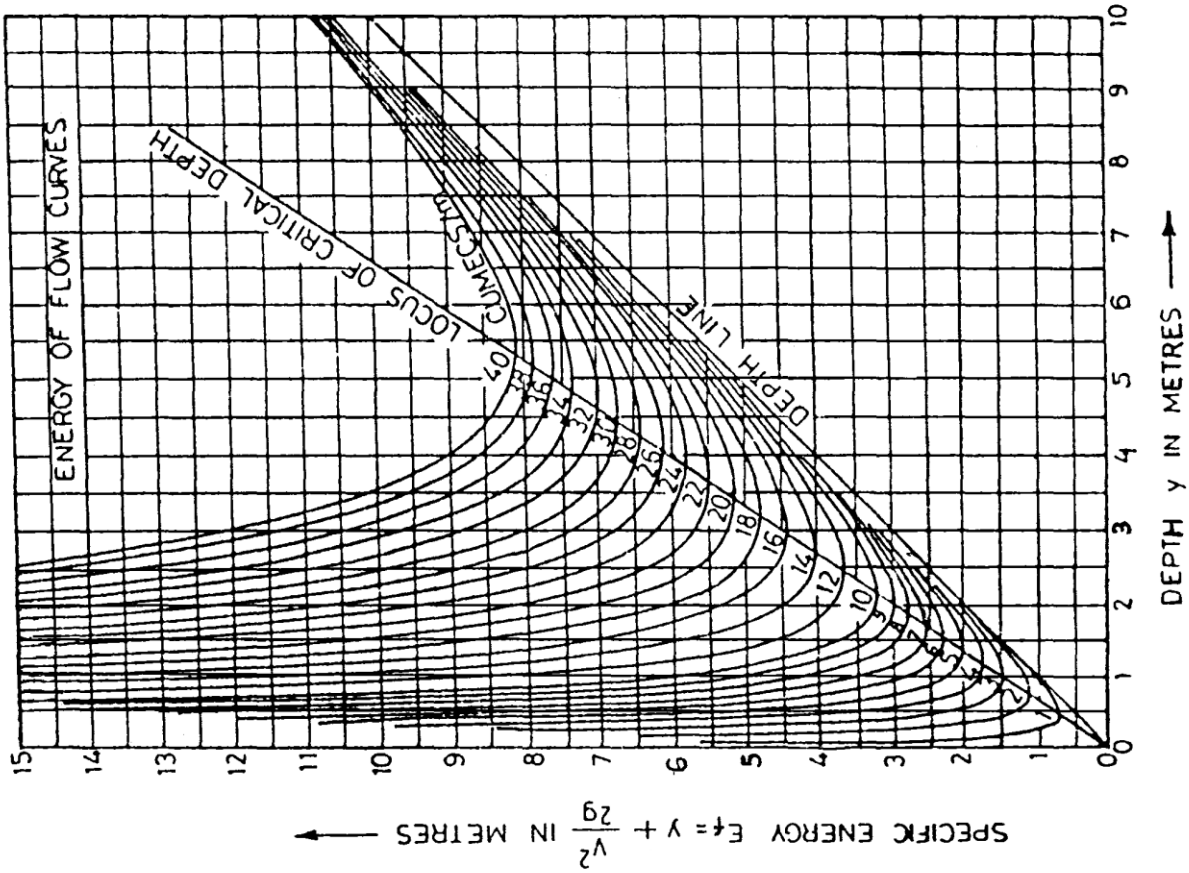
In the above formulae L_C is the level of Stilling Basin Cistern, whereas DSWL & Ef_2 have already been defined earlier.

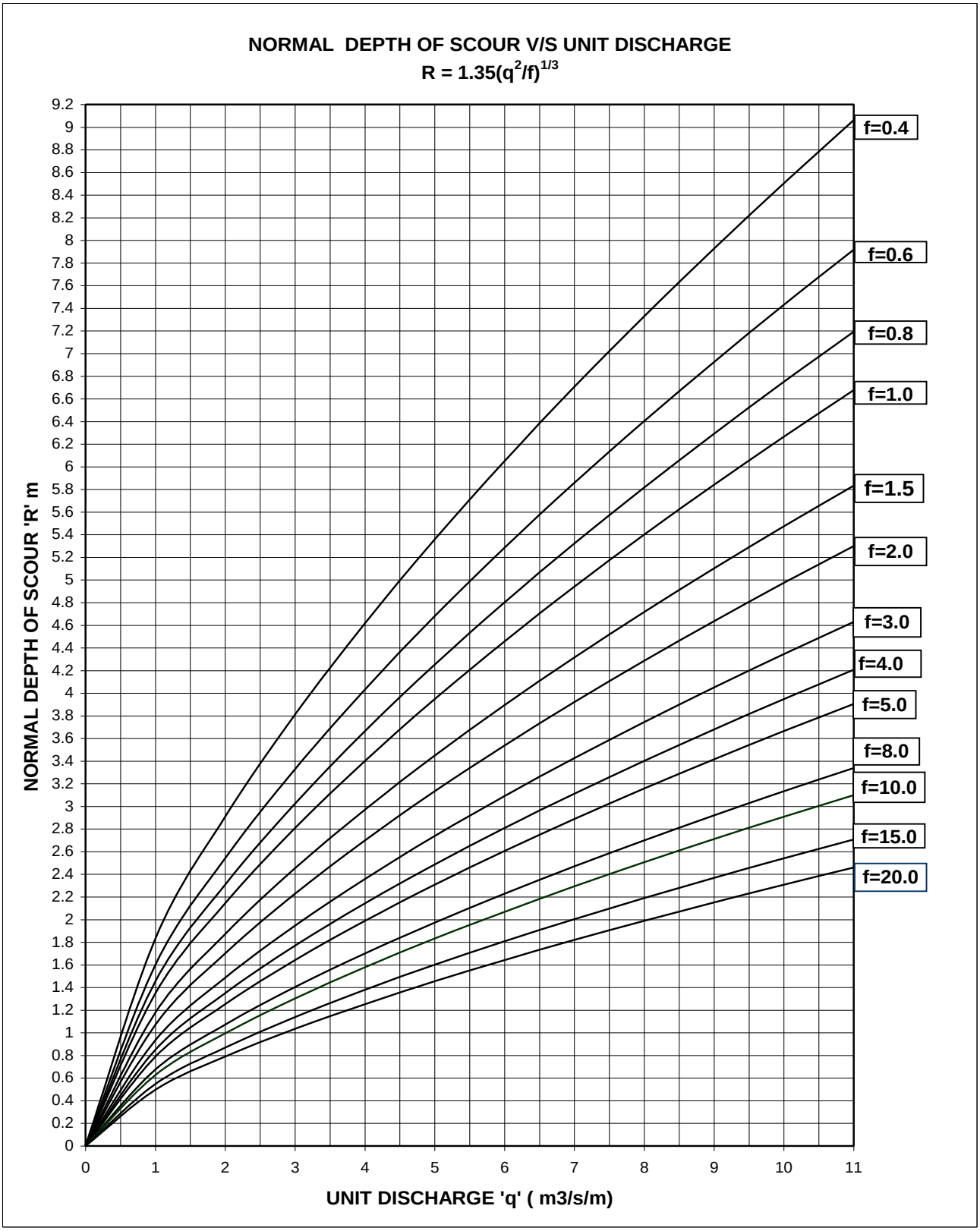
BLENCH CURVES

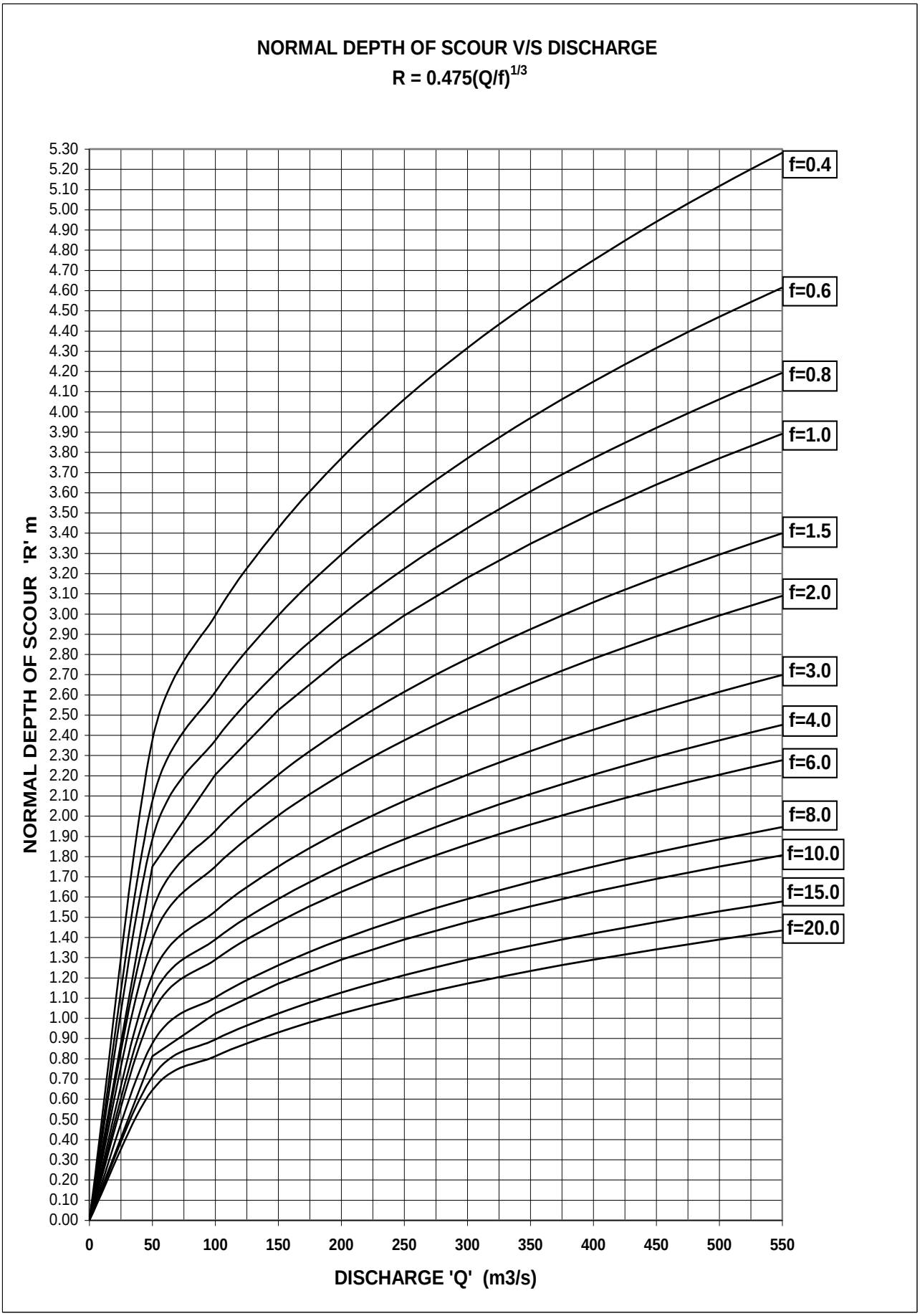


ENERGY OF FLOW CURVES






NORMAL DEPTH OF SCOUR V/S UNIT DISCHARGE
R = 1.35(q2/f)1/3
NORMAL DEPTH OF SCOUR 'R' m
UNIT DISCHARGE 'q' (m3/s/m)
f=0.4
f=0.6
f=0.8
f=1.0
f=1.5
f=2.0
f=3.0
f=4.0
f=5.0
f=8.0
f=10.0
f=15.0
f=20.0


NORMAL DEPTH OF SCOUR V/S DISCHARGE
R = 0.475(Q/f)^1/3
NORMAL DEPTH OF SCOUR 'R' m
DISCHARGE 'Q' (m3/s)
f=0.4
f=0.6
f=0.8
f=1.0
f=1.5
f=2.0
f=3.0
f=4.0
f=6.0
f=8.0
f=10.0
f=15.0
f=20.0