PHILIPPINE NATIONAL STANDARD

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ICS 65.060.35

Design of Canal Structures – Road Crossing, Drop, Siphon and Elevated Flume

DEPARTMENT OF
AGRICULTURE
PHILIPPINES

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Foreword

The formulation of this national standard was initiated by the Agricultural Machinery Testing and Evaluation Center (AMTEC) under the project entitled "Enhancement of Nutrient and Water Use Efficiency Through Standardization of Engineering Support Systems for Precision Farming" funded by the Philippine Council for Agriculture, Aquaculture and Forestry and Natural Resources Research and Development - Department of Science and Technology (PCAARRD - DOST).

As provided by the Republic Act 10601 also known as the Agricultural and Fisheries Mechanization Law (AFMech Law of 2013), the Bureau of Agriculture and Fisheries Standards (BAFS) is mandated to develop standard specifications and test procedures for agricultural and fisheries machinery and equipment. Consistent with its standards development process, BAFS has endorsed this standard for the approval of the DA Secretary through the Bureau of Agricultural and Fisheries Engineering (BAFE) and to the Bureau of Philippine Standards (BPS) for appropriate numbering and inclusion to the Philippine National Standard (PNS)repository.

This standard has been technically prepared in accordance with BPS Directives Part 3:2003 – RulesfortheStructureandDraftingofInternationalStandards.

The word "shall" is used to indicate mandatory requirements to conform to the standard.

The word "should" is used to indicate that among several possibilities one is recommended as particularly suitable without mentioning or excluding others.

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1 Scope

This standard provides minimum requirements and procedures for hydraulic evaluation andstabledesignofroadcrossing,drop,siphonandelevatedflume.

2 References

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this National Standard:

PNS/BAFS/PAES 218:2017 Open Channels – Design of Main Canals, Laterals and Farm Ditches

3 Symbols and Nomenclature

Parameter	Symbol	Unit
Box Culvert Area	A_b	m^2
Conduit Cross-Sectional Area (based on Orifice Formula)	A_o	m^2
RCP(ReinforcedConcretePipe)Area	A_p	m^2
Canal Area	A	m^2
Canal BottomWidth	b	m
Base Widths	b_1, b_2	m
Orifice coefficient	C	-
Canal Bed Elevation Downstream	$CB_{D/S}$	m
Canal Bed Elevation Upstream	$CB_{U/S}$	m
Water Depth	d	m
Canal TotalDepth	D	m
RCP ActualDiameter	D_p	m
Acceleration due to Gravity	g	m/s^2
Available Head	h_a	m
Box CulvertHeight	h_b	m
Inlet TransitionLoss	h_{Li}	m
Outlet TransitionLoss	h_{Lo}	m
Total Head Loss	h_{LT}	m
Conduit FrictionLoss	h_{Lv}	m
HeadLossduetoVelocityintheConduit	h_{vp}	m
Head Loss due to Velocity Upstream	h_{v1}	m
HeadLossduetoVelocityDownstream	h_{v2}	m
Inlet Coefficient	k_i	
Outlet Coefficient	k_o	

Conduit Length	L	m
Roughness Coefficient	n	-
Canal Discharge	Q	m^3
Canal HydraulicRadius	R	m
Canal Slope	S	-
Canal Side Slope	Ss	-
Conduit Slope	S_f	-
Canal Top Width	T	m
Top Bank Elevation	TB	m
Velocity	V	m/s
Velocity in the Box Culvert	V_b	m/s
Velocity in the RCP	V_p	m/s
Water Surface Elevation Downstream	$WS_{D/S}$	m
Water Surface Elevation Upstream	$WS_{U/S}$	m

4 Definitions

For the purpose of this standard, the following terms shall apply:

4.1
critical depth
depth of water flow where the energy content is at minimum hence, no other backwater forces are involved

4.2
drop
in-line canal structure designed to convey canal water from a higher level to a lower level, duly dissipating the excess energy resulting from the drop in elevation

4.3
elevated flume
waterconveyingconduitortroughwhichissupportedonabutmentsbypiers

4.4
equipment crossing
provision for passing of equipment and small machinery

4.5
invert
inside bottom or sill of t the conduit

4.6
inverted siphon
closed conduit designed to convey canal water in full and under pressure running condition, to convey canal water by gravity under roadways, railways, drainage channels and local depressions

4.7
road crossing
conveys canal water under roads or railroads

5 Road Crossing

A typical plan and half plan view of a road crossing is shown in Figure 1.

5.1 General Criteria

5.1.1 When a road crossing crosses a road or railroad, the intersecting angle must be a right angle as much as possible.

5.1.2 The depth necessary for burying a conduit must be determined, taking into consideration the water level required from hydraulic study, earth cover necessary for the purpose of land use, etc.

5.1.3 The minimum recommended clearance between the road and culvert for railroad and road crossing is 0.90 m while for farm road and thresher crossing is 0.60 m if needed.

5.2 Data Requirement

Profile information of the canal and road crossing such as canal cross-section, velocity of flow, discharge, salient levels on upstream and downstream of the structure shall be provided.

Canal Hydraulic Elements:

- Discharge, Q
- Velocity, V
- Area, A
- Canal Width, b
- Water Depth, d
- Total Depth, D
- Top Width, T
- Hydraulic Radius, R
- Canal Slope, S
- Side Slope (H:V), Ss
- Roughness Coefficient, n
- Top Bank Elevation, TB
- Water Surface Elevation, WS
- Canal Bed Elevation, CB

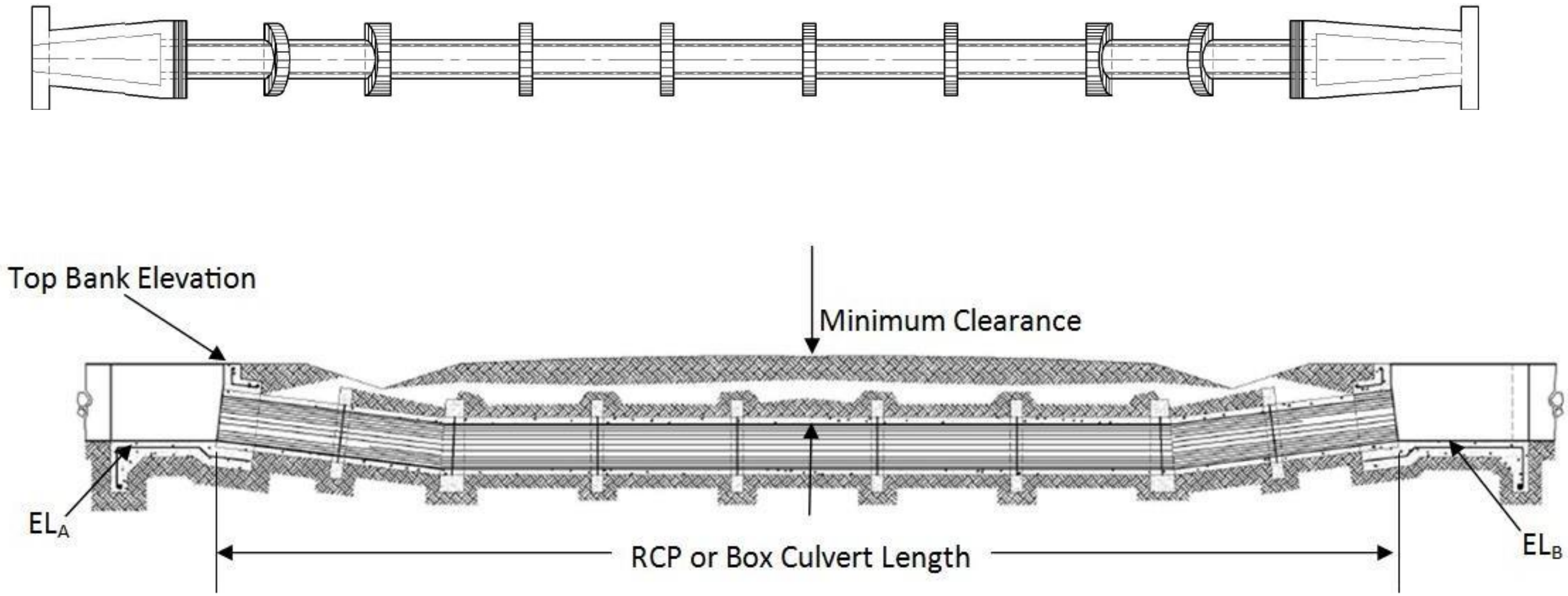

Figure 1. Plan View of a Road Crossing

5.3 Design Procedure

5.3.1 Determine the conduit size – The conduit may be a reinforced concrete pipe (RCP) or box culvert.

5.3.1.1 Determine the area of the conduit assumed full flowing using the orifice formula in section 5.4.1.

5.3.1.2 Select a trial size of the conduit from Table 1.

5.3.1.3 Compute for the area of the selected trial size (A_p or A_b) using the formula in section 5.4.2.

5.3.1.4 If A_o is less than or equal to A_p or A_b, then the computed A_p or A_b is acceptable thus, use the trial size.

↓

5.3.2 Determine the available head – Use the formula in section 5.4.3

↓

5.3.3 Determine the conduit velocity– Use the formula in section 5.4.4. The maximum allowable velocity is shown in Table 2.

↓

5.3.4 Determine the invert elevation– Use the formula in section 5.4.6 and 5.4.5 to account for the head loss due to velocity.

↓

5.3.3 Determine the total head loss– Use the formula in section 5.4.10 which will account for the inlet transition loss, conduit friction loss, and outlet transition loss. The total head loss shall be less than or equal to the available head. Otherwise, a different size of conduit shall be checked for.

5.4 Design Equations

5.4.1 Orifice Formula

$$A_o = \frac{Q}{C\sqrt{2gh_a}}$$

where:

A_o is the conduit cross-sectional area (m^2) Q is the canal discharge (m^3/s)
C is the orifice coefficient, 0.60 – 0.75
g is the acceleration due to gravity, 9.805 m/s^2 h_a is the available head (m)

5.4.2 Area of the Conduit

For RCP,

$$A_p = \frac{\pi D_p{}^2}{4}$$

For boxculvert,

$$A_b = \frac{(b_1 + b_2)}{2} h_b$$

where:

A_p is the RCP area (m^2) A_b is the boxculvert (m^2)
D_p is the RCP actual diameter, m (Refer to Table 1) b_1, b_2 is the base widths (m)
h_b is the boxculvert height (m)

Table 1. Nominal and Actual Diameter of RCP

Nominal Diameter, cm (in)	Actual Diameter, cm
75 (30)	76
60 (24)	61
45 (18)	46

5.4.3 Available Head

$$h_a = WS_{U/S} - WS_{D/S}$$

where:

$WS_{U/S}$ is the water surface elevation upstream, m $WS_{D/S}$ is the water surface elevation downstream, m

5.4.4 Conduit Velocity

For RCP,

$$V_p = \frac{Q}{A_p}$$

For boxculvert,

$$V_b = \frac{Q}{A_b}$$

where:

V_p is the velocity in the RCP (m/s)
V_b is the velocity in the box culvert (m/s) Q
is the canal discharge (m^3/s)

Table 2. Maximum Allowable Velocity in Conduits

Conduit	Velocity, m/s
RCP with earth transition	1.00
RCP with concrete transition	1.50
Box Culvert	1.20

5.4.5 Head loss Due to Velocity

$$h_{vp} = \frac{{V_p}^2}{2g}$$

$$h_{vb} = \frac{{V_b}^2}{2g}$$

where:

h_{vp} is the head loss due to velocity in the pipe (m)
h_{vb} is the head loss due to velocity in the box culvert (m) g is the acceleration due to gravity, 9.805 m/s^2

5.4.6 Invert Elevation

$$El_A = WS_{U/S} - (D_p + 1.5h_{vp})$$
$$El_A = WS_{U/S} - (D_p + 1.5h_{vb})$$
$$El_B = EL_A - S_f L$$

where:

El_A is the invert elevation at A (m) EL_B
is the invert elevation at B (m)
$WS_{U/S}$ is the upstream water surface level (m)
S_f is the conduit slope (Minimum slope = 0.005 for straight line profile)
L is the conduit length (m)

5.4.7 Inlet transition loss

$$h_{Li} = k_i \left(\frac{V_1^2}{2g} - \frac{V_p^2}{2g}\right)$$

$$h_{Li} = k_i \left(\frac{V_1^2}{2g} - \frac{V_b^2}{2g}\right)$$

where:

k_i istheinletcoefficient(Pleasereferto Table3) V_1 is
the initial velocity (m/s)
V_p is the velocity in the pipe (m/s)
V_b is the velocity in the box culvert (m/s)
g is the acceleration due to gravity, 9.805 m/s^2

Table 3. Inlet and Outlet Coefficients of Open Canal Transition to Closed Conduit

Type of Transition	Inlet Coefficient	Outlet Coefficient
Streamlined warp to rectangular opening	0.10	0.20
Straight warp to rectangular opening	0.20	0.30
Brokenback to rectangular opening	0.30	0.50
Straight warp with bottom corner fillets to RCP opening	0.30	0.40
Brokenback to RCP opening	0.40	0.70
Earth canal to RCP opening	0.50	1.00

5.4.8 Conduit friction loss

$$h_{Lv} = \left[\frac{V_p n}{\left(\frac{A_p}{P_p}\right)^{2/3}}\right]^2 \times L \text{ or } h_{Lv} = \left[\frac{V_b n}{\left(\frac{A_b}{b}\right)^{2/3}}\right]^2 \times L$$

or

$$h_{Lv} = S_f \times L$$

where:

V_p is the velocity in the pipe (m/s) A_p
is the area of the pipe (m)
P_p is the perimeter of the pipe (m) L is
the conduit length, = (m)
S_f is the conduit slope (Minimum conduit slope = 0.005 for straight line profile)

5.4.9 Outlet transition loss

$$h_{Lo} = k_o(h_{v2} - h_{vp})$$

where:

k_o is the outlet coefficient (Refer to Table 4)
h_{v2} is the canal head loss due to velocity downstream, m $h_{vp}=h_{vb}$ is the head loss due to velocity in the pipe or box culvert, m

5.4.10 Total Head Loss

$$h_{LT} = 1.10\ (h_{Li} + h_{Lv} + h_{Lo})$$

where:

h_{LT} is the total head loss (m)
h_{Li} is the inlet transition loss (m) h_{Lv} is the conduit friction loss (m) h_{Lo} is the outlet transition loss (m)

6 Drop

6.1 General Criteria

6.1.1 Drop structures shall be provided for the stability of the canal when there is substantial change in canal elevation.

6.1.2 The location and type of drop structures shall be determined through comparative design with regard to the stability and cost.

6.1.3 The lining materials and flow velocities for scouring and erosion shall be considered in type selection.

6.1.4 If the elevation difference is more than 5 m, an inclined drop or chute shall be used.

6.2 Data Requirement

6.2.1 Contour plan of the area.

6.2.2 Profile sheet showing locations and types of all canal structures nearby to study the possibility of combining the drop with any of them.

6.2.3 Canal cross-section, velocity of flow, discharge, salient levels on upstream and downstream of the structure

6.2.4 Details of lining proposed/provided on the upstream and downstream of the structure

6.2.5 Proposed height of drop as shown in the profile sheet

6.2.6 Foundation material from the point of view of exit gradient characteristics and for uplift computations

6.2.7 Subsoil water level and its seasonal fluctuations

6.2.8 Detailed functional requirements of drops, when combined with any other type of structure

6.3 Types of Drop

- Vertical Drop
- Rectangular Inclined Drop
- Baffled Apron Drop

6.3.1 Vertical Drop

A longitudinal section of a vertical drop and the symbols used in the design procedure are shown in Figure 2.

6.3.1.1 Range of Drop and Discharge - may be conveniently used for drops up to 1 m but can be designed for drops up to 2.5 meter and final selection shall be on cost considerations by comparing with other alternatives. The discharge can be safely designed up to 8 m^3.

6.3.1.2 Energy Dissipation - turbulent diffusion. A basin serves as a water cushion protects the floor against impact of falling water.

6.3.1.3 Design Procedure

6.3.1.3.1 Determine the critical depth – Use the formula in section 6.3.1.4.1 to compute for the headloss due to upstream canal velocity, height of drop and critical depth.

↓

6.3.1.3.2 Compute for the basin length – Use the formula in section 6.3.1.4.3 while the formula for critical velocity is shown in section 6.3.1.4.2.

↓

6.3.1.3.3 Determine the basin elevation – Use the formula in section 6.3.1.4.4.

↓

6.3.1.3.4 Check for the discharge– Use the formula in section 6.3.1.4.5. If the determined value for the discharge is significantly different from the canal discharge, adjust the width.

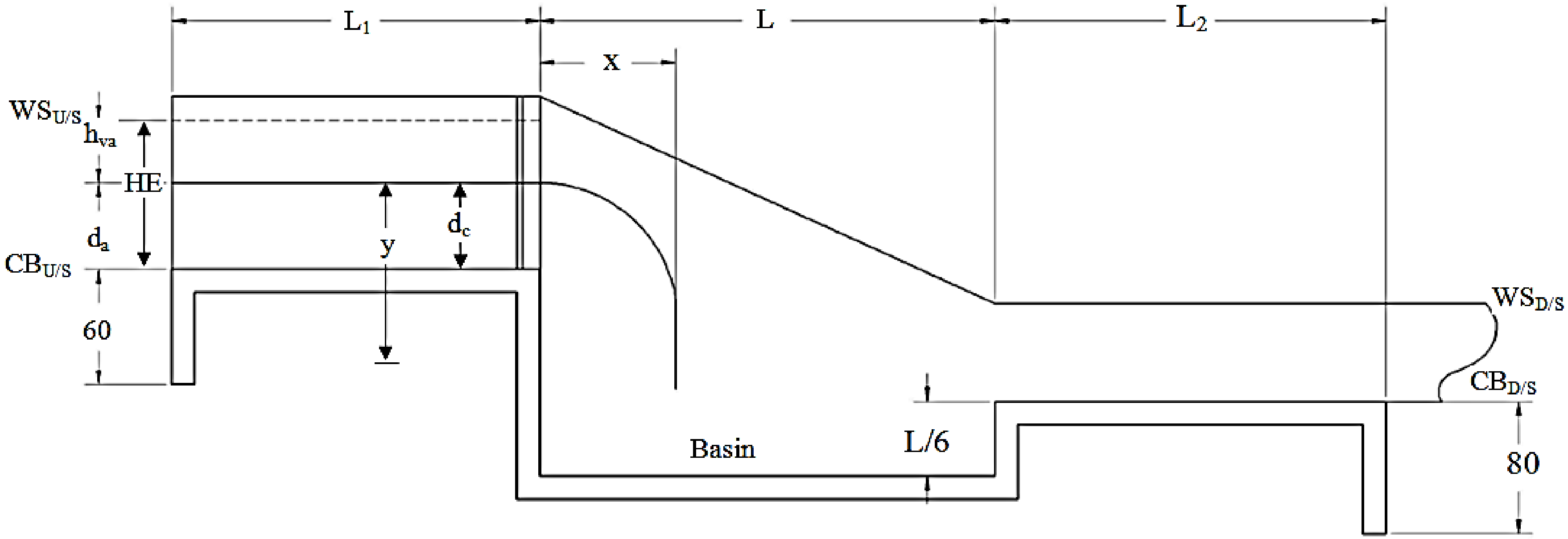

Figure 2. Longitudinal Section of a Vertical Drop

6.3.1.4 Design Equations

6.3.1.4.1 Critical Depth

$$h_{va} = \frac{V_a^2}{2g}$$

$$HE = d_a + h_{va}$$

$$d_c = \frac{2}{3}HE$$

where:

h_{va} is the head loss due to upstream canal velocity (m)
V_a is the upstrem velocity (m/s)
g is the gravitational acceleration (m/s^2)
HE is the height of drop (m)
d_a is the water depth upstream (m)
d_c is the critical depth (m)

6.3.1.4.2 Critical Velocity

$$V_c = \frac{Q}{bd_c}$$

where:

V_c is the critical velocity (m)
Q is the canal discharge (m^3/s)
b is the canal width (m)
d_c is the critical depth (m)

6.3.1.4.3 Basin Length

$$y = CB_{U/S} - CB_{D/S} + d_c$$

$$t = \sqrt{\frac{2y}{9.8}}$$

$$x = V_c \times t$$

$$L = 2x + 0.30$$

where:

$CB_{U/S}$ is the elevation of the canal bed upstream (m)
$CB_{D/S}$ is the elevation of the canal bed downstream (m)
d_c is the critical depth (m)
L is the basin length

6.3.1.4.4 Basin Elevation

$$El_B = CB_{D/S} - \frac{L}{6}$$

where:

EL$_B$ is the basin elevation (m)
CB$_{D/S}$ is the elevation of the canal bed downstream (m) L is the basin length

6.3.1.4.5 Discharge

$$Q = 1.705 bHE^{3/2}$$

where:

b is the canal width (m) HE
is the height of drop (m)

6.3.2 Rectangular Inclined Drop

A longitudinal section of a rectangular inclined drop and the symblos used in the design procedure are shown in Figure 3.

6.3.2.1 Range of Drop and Discharge - convenient for all discharges and for drops up to 5 m

6.3.2.2 Energy Dissipation - affected by formation of hydraulic jump in the stilling pool at the end of rectangular inclined through and is more effective when tail water has no wide fluctuations

6.3.2.3 Components

6.3.2.3.1 Upstream Transition - produce gradual change of water prism and velocity from canal to the structure

6.3.2.3.2 Inlet – controls the upstream water level and prevents erosion of the canal bed on the upstream

6.3.2.3.3 Inclined Channel chute - accelerates the water to flow at supercritical velocity so that hydraulic jump is formed in the stilling pool & excess energy is dissipated

6.3.2.3.4 Stilling Pool – provided at the lower end of the inclined channel to create hydraulic conditions conductive to formation of a hydraulic jump under full and partial flows nd accomplish dissipation of excess energy

6.3.2.3.5 Outlet – controls the water level in the stilling pool

6.3.2.3.6 Downstream transition - provides smooth change of velocity from the outlet to canal section to reduce turbulence and erosion.

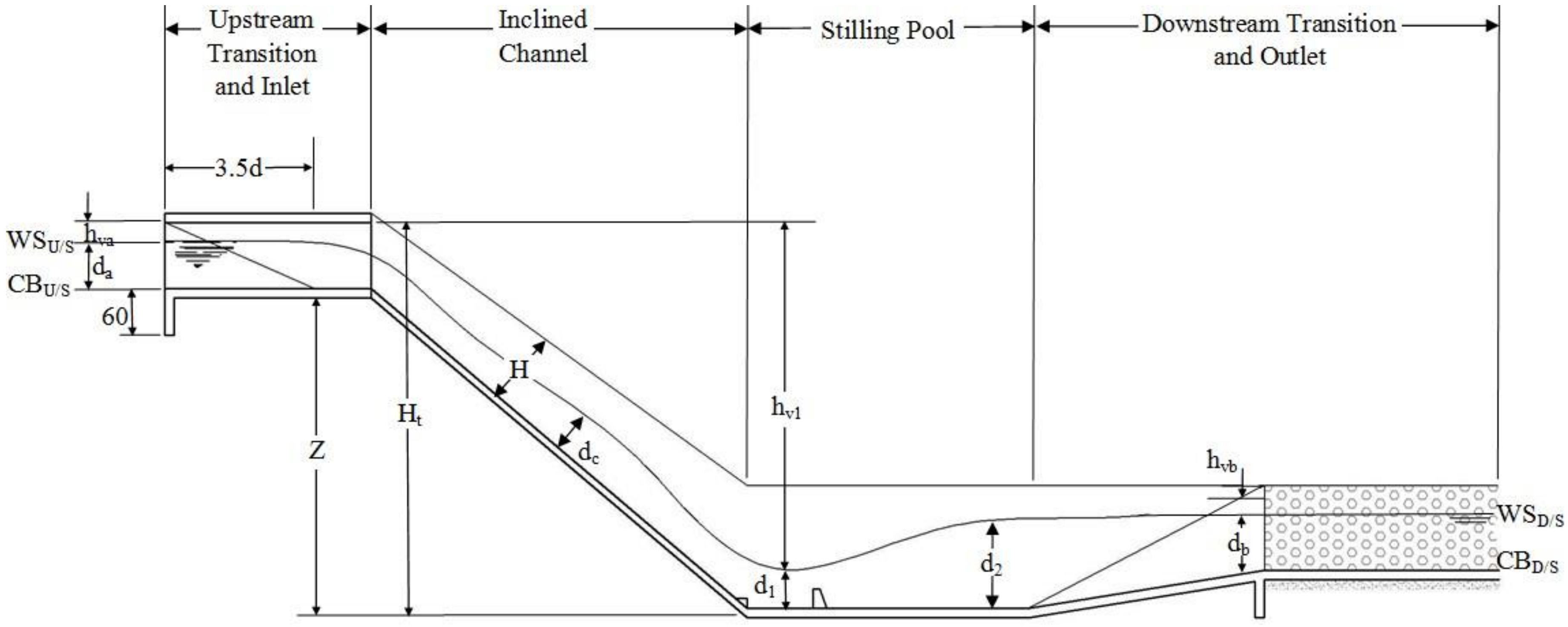

Figure 3. Longitudinal Section of a Rectangular Inclined Drop

6.3.2.4 Design Procedure

6.3.2.4.1 Determine the basin width – Use the formula in section 6.3.2.5.1 and subsequently compute for the critical depth.

↓

6.3.2.4.2 Determine d_1 (refer to Figure 3)
6.3.2.4.2.1 Assume a pool elevation and compute for the upstream energy elevation using the formula in section 6.3.2.5.3.
6.4.2.4.2.2 Compute for the upstream velocity head (section 6.3.2.5.2)
6.4.2.4.2.3 Assume a value for d_1 ($<d_c$) and compute for v_1 and h_{v1}. Verify resulting value using the result of Bernoulli's Equation (section 6.3.2.5.5)
6.4.2.4.2.4 If the computed value for $h_{v1} + d_1$ satisfies Bernoulli's Equation, then use the assumed d_1. Otherwise, assume another d_1.

↓

6.3.2.4.3 Determine d_2 (refer to Figure 3) – Use the formula in section 6.3.2.5.6

↓

6.3.2.4.4 Check for the required pool elevation – Use the formula in section 6.3.2.5.3. The computed required pool elevation shall be approximately equal to the assumed pool value in section 6.3.2.4.2.1.

↓

6.3.2.4.5 Determine the length of pool – Calculate the Froude number shown in section 6.3.2.4. Based on the Froude number, compute for the length of pool.

↓

6.3.2.4.6 Determine the size of chutes and floor blocks – Use the formula in 6.3.2.5.9. The minimum values of chute blocks and floor blocks including block

6.3.2.5 Design Equations

6.3.2.5.1 Basin Width

$$b = \frac{18.48\sqrt{Q}}{Q + 9.92}$$

$$q = \frac{Q}{b}$$

$$d_c = \sqrt[3]{\frac{q^2}{g}}$$

where:

b	is the basin width (m)
Q	is the canal discharge (m^3/s)
q	is the canal discharge per unit width (m^2/s)
d_c	is the critical depth (m)

6.3.2.5.2 Upstream Energy Elevation

$$Z = CB_{U/S} - assumed\ pool\ elevation$$

where:

Z	is the upstream energy elevation (m)
$CB_{U/S}$	is the elevation of the canal bed upstream (m)

6.3.2.5.3 Upstream Velocity Head

$$h_{va} = \frac{V_a^2}{2g}$$

where:

h_{va}	is the headloss due to upstream canal velocity(m)
V_a	is the upstream velocity (m/s)
g	is the gravitational acceleration (m/s^2)

6.3.2.5.4 V_1 and h_{v1}

$$v_1 = \frac{q}{d_1}$$

$$h_{v1} = \frac{v_1^2}{2g}$$

where:

v_1	is the velocity at d_1 (m)
q	is the canal discharge per unit width (m^2/s)
d_1	is the depth at pt. 1, m (see Figure 3)
h_{v1}	is the velocity headloss at d_1, (m/s)
g	is the gravitational acceleration, (m/s^2)

6.3.2.5.5 Bernoulli's Equation

$$Z + d_a + h_{va} = d_1 + h_{v1}$$

6.3.2.5.6 d_2, v_2 and h_{v2}

$$d_2 = \frac{-d_1}{2} + \sqrt{\left[\left(\frac{2 \times v_1^2 \times d_1}{g}\right) + \frac{d_1^2}{4}\right]}$$

$$v_2 = \frac{q}{d}$$

2

$$h_{v2} = \frac{v_2^{\,2}}{2g}$$

6.3.2.5.7 Required Pool Elevation

$$h_{vb} = \frac{v_b^{\,2}}{2g}$$

$$Energy\ Elevation_{D/S} = WS_{D/S} + h_{vb}$$

$$Required\ Pool\ Elevation = Energy\ Elevation_{D/S} - (d_2 + h_{v2})$$

6.3.2.5.8 Length of Pool

$$F = \frac{V}{\sqrt{gd_1}}$$

If	F	≤ 4.5		;	$L_p = 3.5d_1$
	4.5	<F<	9	;	$L_p = 4d_1$
	F	≥ 9		;	$L_p = 5d_2$

where:

F isthe Froude number L_p
is the length of pool (m)

6.3.2.5.9 Sizes of Chutes and Floor Blocks

6.3.2.5.9.1 Height of chute blocks, h_1

$$h_1 = d_1$$

6.3.2.5.9.2 Height of floor blocks

For d_2 = 0 to 2.44 m, $h_2 = \frac{1}{4} d_1$

For d_2 = 2.45 to 7.30 m, $\frac{1}{8} d_2 < h_2 < \frac{1}{4} d_2$

For d_2 > 7.30 m, $h_2 = \frac{1}{8} d_2$

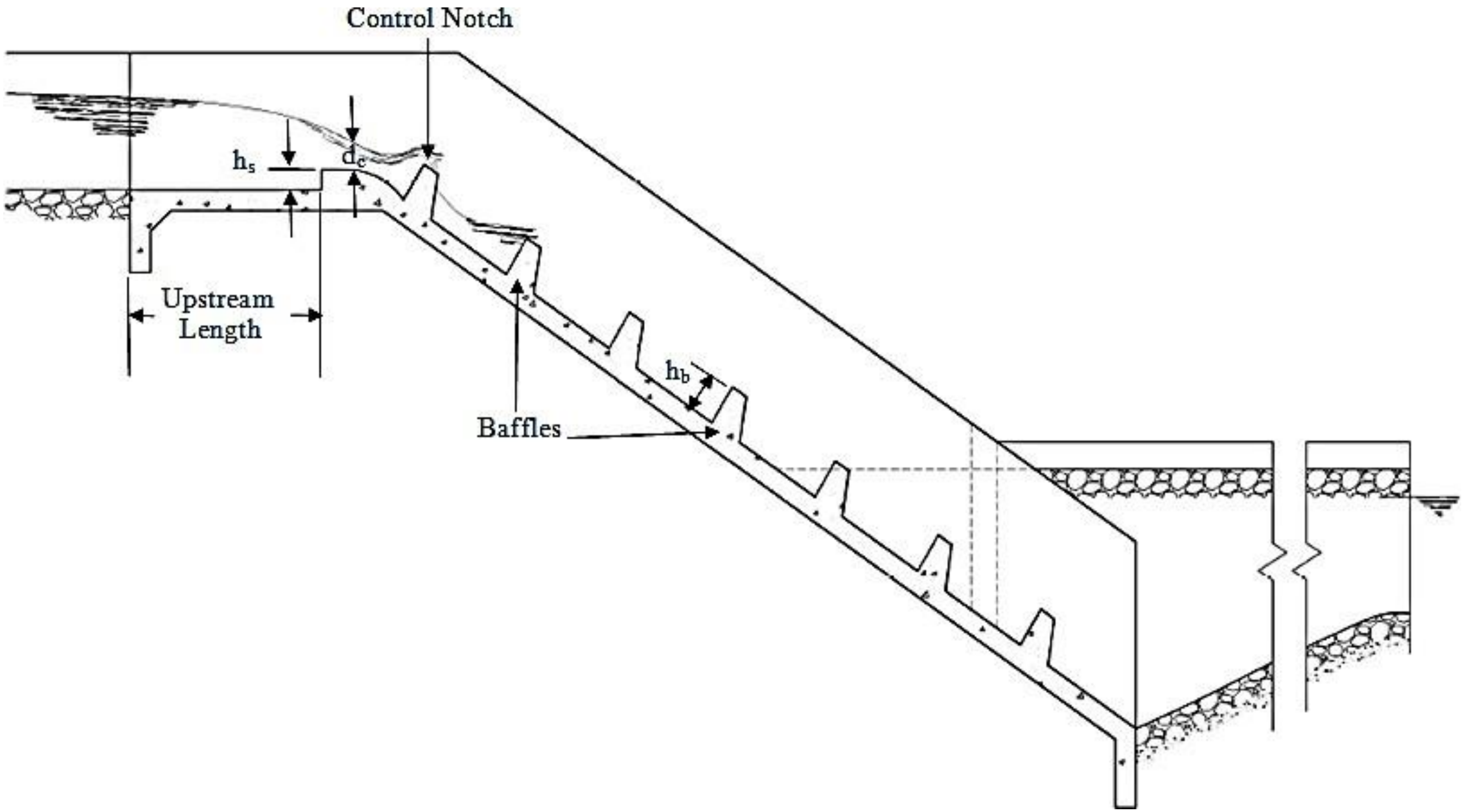

Figure 4. Longitudinal Section of a Baffled Apron Drop

6.3.3 Baffled Apron Drop

A longitudinal section of a baffled drop and the symbols used in the design procedure are shown in Figure 4.

6.3.3.1 Range of Drop and Discharge – Table 5 shows the ranges of discharges per meter width based on hydraulic laboratory and field tests.

Table 5. Recommended Discharge Per Meter Width of Chute

Canal Discharging Capacity, Q (m^3)	Discharge per meter width of chute, q (m^3/m)
Up to 1	0.45 to 0.95
1 to 3	0.95 to 1.40
3 to 5	1.40 to 1.85
5 to 13	1.85 to 2.80
13 to 28	2.80 to 4.65
28 and above	4.65 to 5.60

SOURCE: NIA, Design Manual on Irrigation Facilities, 1990.

6.3.3.2 Energy Dissipation - occurs as the water flows over the concrete baffle blocks which are located along the floor of the chute

6.3.3.3 Components

6.3.3.3.1 Control Notch/ Inlet Sill – prevents racing of water on the upstream, ensures generation of critical velocity at that point and provides controlled water surface on the upstream

6.3.3.3.2 Cutoff Walls/ Wingwalls – decrease percolation at the upstream and downstream, and to retain the backfill along the slope

6.3.3.4 Design Procedure

Table 6 shows the recommended structural dimensions for a baffled apron drop, which may be consulted if desired.

↓

6.3.3.4.1 Determine the chute width – Use the formula in section 6.3.3.5.1 where the discharge per unit width of chute is given in Table 5 based on canal discharging capacity.

↓

6.3.3.4.2 Determine baffle block dimensions – Use the formula in section 6.3.3.5.3 to compute for the height. The width and spacing shall lie between 1 to 1.5 times the height of the baffle block

↓

6.3.3.4.3 Determine partial block width - Partial block width shall be between 1/3 to 2/3 of the height of the baffle block

↓

6.3.3.4.4 Determine the upstream length - The minimum upstream length is normally kept as twice the depth of water at the inlet cutoff.

↓

6.3.3.4.5 Determine the height of the sidewalls - Height of the sidewalls normal to the chute is normally kept as 3 times the height of baffle blocks.

*add equation for height of the sidewalls

6.3.3.5 Design Equations

6.3.3.5.1 Chute Width

$$B = \frac{Q}{q}$$

where:

B is the chute width (m)
Q is the canal discharge (m^3/s)
q is the discharge per meter width of chute (m^3/m)

6.3.3.5.2 Critical Depth

$$d_c = \sqrt[3]{\frac{q^2}{g}}$$

where:

q is the canal discharge per unit width (m^2/s) d_c
is the critical depth (m)

6.3.3.5.3 Height of the Baffle Block

$$hb = 0.9\ d_c$$

where:

hb is the height of baffle block (m) d_c is
the critical depth (m)

*height of the sidewalls

Table 6. Recommended Dimensions for Baffled Apron Drops

Channel Capacity (m^3)	Intensity (m^3/m)	Minimum Upstream Length from Bend (m)	Minimum Width of Chute Section (m)	Height of side wall normal to chute (m)	Radius of Curve (m)	Baffle Height Normal to Slope (m)	Baffle and Spacing Width (m)	Length of Wing Wall Near Bottom (m)
Up to 5	0.45 to 1.85	3.00	1.80	1.50	1.80	0.50	0.50 to 0.70	-
5 to 13	1.85 to 2.80	3.50	3.00	2.10	2.50	0.60	0.90	2.30
13 to 28	2.80 to 4.65	5.00	5.00	3.00	3.60	0.90	1.40	2.90
Above 28	4.65 to 5.60	6.00	6.00	3.00	3.60	0.90	1.40	2.90

SOURCE: NIA, Design Manual on Irrigation Facilities, 1990.

7 Inverted Siphon

A cross-section of an inverted siphon is shown in Figure 5.

7.1 Components

7.1.1 Inlet and Outlet Transition – provided at the inlet and outlet of a siphon to reduce head loss and to prevent canal erosion in the unlined canals by causing a gradual velocity change between the canal and the conduit

7.1.2 Conduit – designed for internal pressure and external backfill pressures

7.1.3 Blowoff Structure and Manhole – provided at or near the low point of a relatively long and important siphons across a natural drainage, to permit draining the conduit for inspection and maintenance

7.1.3.1 A manhole is often included with a blowoff on long siphons, 1 m diameter and more, to provide an intermediate access point for inspection and maintenance

7.1.3.2 Blowoff may be used in conjunction with wasteways to drain out canal water.

7.1.3.3 Short siphons can be dewatered by pumping from either ends

7.1.4 Combination with Wasteway – to divert the canal flow to a natural drain

7.1.5 Freeboard – safety margin to prevent overtopping of canal banks

7.1.6 Erosion Protection – provided adjacent to the siphons in earth canals

7.1.7 Trash Racks – provided at the inlet of the siphons to prevent entry of floating trash into the siphon and to ensure safety of people and animals.

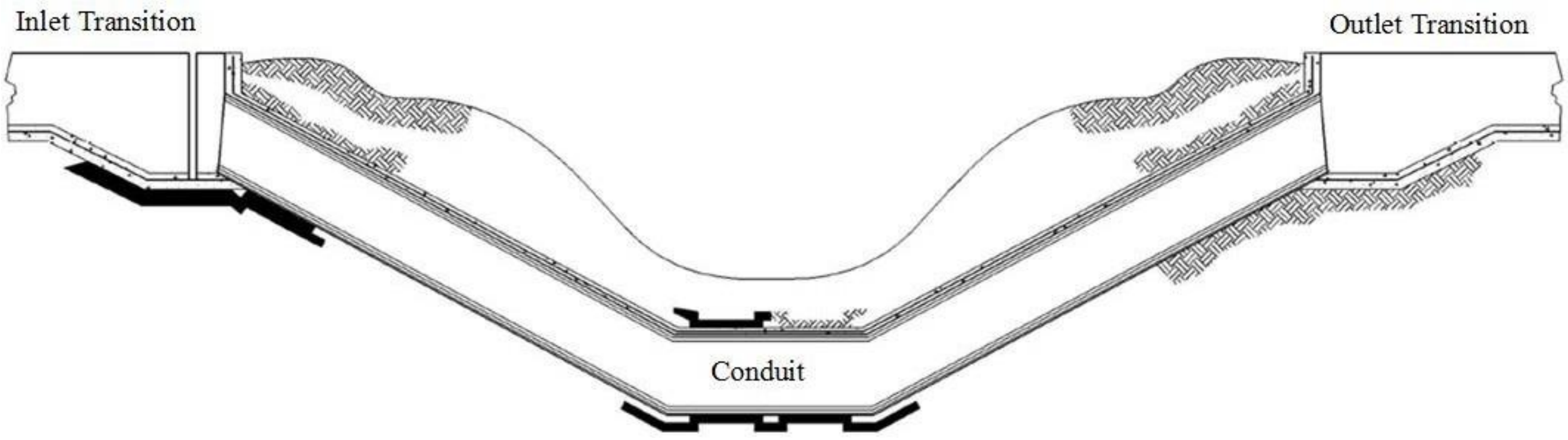

Figure 5. Cross-section of a proposed inverted siphon at a river showing the outline of the conduit

7.2 Data Requirement

7.2.1 Contour plan around the site

7.2.2 Cross-section of the river or creek indicating the maximum flood elevation, minimum water surface elevation, type of riverbed or bank materials and the type of debris carried by the floodwater as shown in Figure 6.

7.2.3 Profile of riverbed 50 m to 100 m upstream and downstream

7.2.4 Canal Hydraulic Elements:

- Discharge, Q
- Velocity, V
- Area, A
- Canal Width, b
- Water Depth, d
- Total Depth, D
- Top Width, T
- Hydraulic Radius, R
- Canal Slope, S
- Side Slope (H:V), Ss
- Roughness Coefficient, n
- Top Bank Elevation, TB
- Water Surface Elevation, WS
- Canal Bed Elevation, CB

7.3 Design Considerations

7.3.1 The inverted siphon shall be designed to be as short as possible.

7.3.2 When an inverted siphon crosses such important facilities as road, river and railway, the intersecting angle shall be as near as possible a right angle.

7.3.3 Minimum cover over the conduit shall be 1 m for river, railway or highway crossing and 0.6 m for village roads and for roadside ditches.

7.3.4 For cross-drainage works, minimum cover shall be 1 m and even more if retrogression is anticipated.

7.3.5 Minimum cover of 0.2 m for crossing below a lined canal and 0.6 m below an unlined canal shall be provided.

7.3.6 The slope of the conduit should neither be steeper than 1:2 nor flatter than 1/200.

7.3.7 To prevent sediment settling at the bottom of the conduit, a minimum velocity of flow shall be kept as 1.5 m/s to 2 m/s if head loss permits.

7.3.8 Vertical transitions in the bed profile of the siphon shall not be steeper than 1:4 at entry and 1: 6 at exit.

7.3.9 A tangential curve shall be provided at the entry, exit and at the bottom of siphon at change of slopes.

7.3.10 For small structures, broken back transitions are recommended. But for large discharges, it is preferable to provide curved transition, which reduces turbulence.

7.4 Design Procedure

7.4.1 Locate and layout the profile of the structure – All requirements of cover, slopes, bend angles and expected submergence of inlet and outlet as specified in section 7.3 shall be satisfied

↓

7.4.2 Compute for the available head – Use the formula shown in section 7.5.1

↓

7.4.3 Approximate a conduit size – Use the formula in section 7.5.2
7.4.3.1 Assume a velocity of 1.5 m/s to 2.0 m/s through the conduit.
7.4.3.2 Determine the area of the conduit. Based on the result, choose an appropriate standard size of the conduit and compute for the actual velocity in the conduit. *refer to equation 8.4.2

↓

7.4.4 Compute for the total head loss – Use the formula in section 7.5.8 which accounts for the inlet and outlet transition loss, bend loss, friction loss loss and trashrack loss. The total head loss shall be less than or equal to the available head, h_a. Otherwise, a different size of conduit shall be checked for.

↓

7.4.5 Determine the conduit invert elevations – Use the formula in sections 7.5.9 and 7.5.10. For inlet transition, the difference in invert of transition shall not exceed ¾ of the conduit height For outlet transition, the maximum difference in invert levels is ½ of the conduit height while the required seal should be less than 1/6 ff the conduit height.

7.5 Design Equations

7.5.1 Available Head

$$h_a = WS_{U/S} - WS_{D/S}$$

where:

h_a is the available head (m)
$WS_{U/S}$ is the water surface elevation upstream (m) $WS_{D/S}$ is the water surface elevation downstream (m)

7.5.2 Size of the Conduit

$$A_p = \frac{Q}{V_a}$$

where:

A_p is the conduit area (m^2)
Q is the canal discharge (m^3/s)
V_a is the assumed velocity in the conduit (m/s)

7.5.3 Velocity Head Loss

In the conduit:

$$h_{vp} = \frac{V_p^2}{2g}$$

Due to velocity upstream/downstream the canal:

$$h_{v1} = \frac{V_1^2}{2g} \text{ and } h_{v2} = \frac{V_2^2}{2g}$$

where:

h_{vp} is the head loss due to velocity in the conduit (m)
h_{v1}, h_{v2} is the head loss due to velocity upstream and downstream the canal (m)
V_p is the actual velocity in the conduit (m/s)
g is the acceleration due to gravity, 9.805 m/s^2

7.5.4 Transition Loss

Inlet: $h_{Li} = k_i(h_{v1} - h_{vp})$
Outlet: $h_{Lo} = k_o(h_{v2} - h_{vp})$
where:

k_i is the inlet coefficient (Please refer to Table 3) k_o is the outlet coefficient (Refer to Table 4)
h_{vp} is the head loss due to velocity in the conduit, m
h_{v1}, h_{v2} is the head loss due to velocity upstream and downstream the canal, m

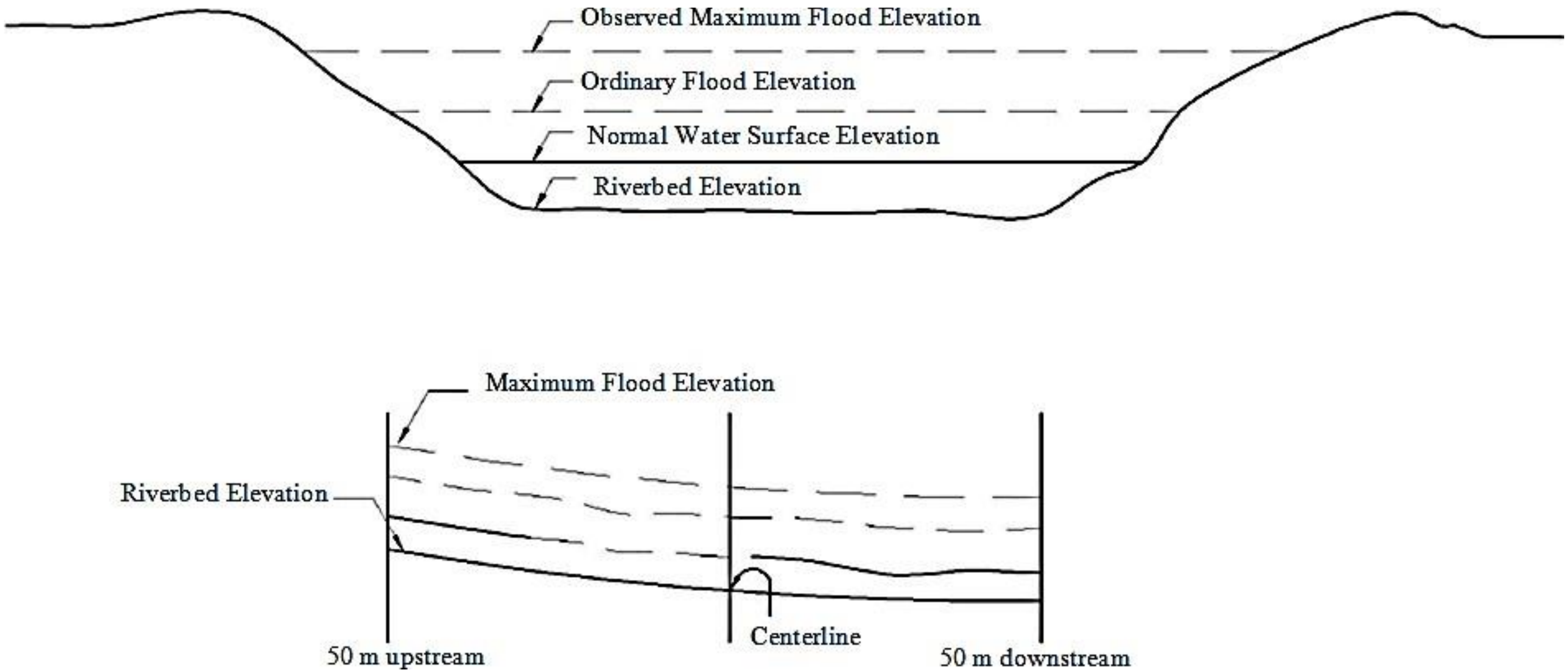

Figure 6. Cross-section and profile of a river

7.5.5 Conduit friction loss

$$h_{Lv} = \left[\frac{V_p n}{\left(\frac{A_p}{P_p}\right)^{2/3}}\right]^2 \times L$$

or

$$h_{Lv} = S_f \times L$$

where:

- V_p is the velocity in the conduit (m/s)
- A_p is the area of the conduit (m)
- P_p is the perimeter of the conduit (m)
- L is the conduit length (m)
- S_f is the conduit slope (Minimum slope = 0.005 for straight line profile)

7.5.6 Bend loss

$$h_b = \left(0.124 + 3.104\left(\frac{S}{2R}\right)^{1/2}\right) \times h_{vp} \times \frac{\theta}{180} \times number\ of\ bends$$

where:

- S is the conduit width (m)
- R is the radius along the center line (m)
- h_{vp} is the head loss due to velocity in the conduit (m)
- θ is the deflection angle

7.5.7 Trashrack Loss * check formula form literature

$$h_{tr} = 0.361\left(\frac{T \times V}{D}\right)(\sin A)(\sec)^{15/8}$$

where:

- h_{tr} is the head loss due to trashrack
- T is the thickness of trashrack bars (cm)
- V is the velocity below the trashrack (m/s)
- D is the center to center spacing of bars (cm)
- A is the inclination angle of herack with the horizontal
- B is the angle of approach or horizontal inclination
- k_{tr} is the trashrack loss coefficient
- h_{v1} is the upstream velocity

7.5.8 Total Head Loss

$$h_{LT} = 1.10\,(h_{Li} + h_{Lv} + h_b + h_{tr} + h_{Lo})$$

where:

h_{LT} is the total head loss (m)
h_{Li} is the inlet transition loss (m) h_{Lv} is the conduit friction loss (m) h_b is the bend loss (m)
h_{tr} is the headloss due to trashrack (m) h_{Lo} is the outlet transition loss (m)

7.5.9 Conduit Invert Elevation at Starting POint

$$Inlet\ Water\ Seal = 1.5\Delta h_v$$

$$Height\ of\ Opening = \frac{conduit\ height}{\cos\theta}$$

$$\text{Conduit Invert Elevation at Starting Point} = WS_{\underline{U}/S} - \left(\begin{matrix}\text{Inlet Water Seal or}\\ \textbf{8}\text{ cm whichever is higher}\end{matrix}\right) - \text{Height of Opening}$$

where:

$WS_{U/S}$ is the upstream water surface level (m)
Δh_v is the change in velocity head (m)

8.1.1 Invert Elevation at Outlet

$$Outlet\ Water\ Seal = 0.7\Delta h_v$$

$$Height\ of\ Opening = \frac{conduit\ height}{\cos\theta}$$

$$\text{Conduit Invert Elevation at Starting Point} = WS_{\underline{D}/S} - \left(\begin{matrix}\text{Outlet Water Seal or}\\ \text{8 cm whichever is higher}\end{matrix}\right) - \text{Height of Opening}$$

where:

$WS_{D/S}$ is the downstream water surface level (m)
Δh_v is the change in velocity head (m)

8 Elevated Flume

A longitudinal view of an elevated flume is shown in Figure 7.

8.1 Data Requirement

Profile information of the elevated flume such as velocity of flow, discharge, salient levels on upstream and downstream of the structure and type of inlet and outlet transition shall be required.

Canal Hydraulic Elements:

- Discharge, Q
- Velocity, V
- Area, A
- Canal Width, b
- Water Depth, d
- Total Depth, D
- Top Width, t
- Hydraulic Radius, R
- Canal Slope, S
- Side Slope, Ss
- Roughness Coefficient, n

Elevations:

- Top Bank, TB
- Water Surface, WS
- Canal Bed, CB

8.2 Design Criteria

8.2.1 An elevated flume is suitable if canal bed level is high enough at the crossing point to provide enough freeboard over design flood level of drainage or there is enough vehicular clearance for rail and road traffic.

8.2.2 The acceptable bed-depth ratio of the flume section shall range from 1 to 3 where be-depth ratio of 2 is the most hydraulically efficient.

8.2.3 The initial velocity in the flume section shall range from 1.2 m/s to 1.5 m/s.

8.2.4 The slope of the flume section shall be less than the critical slope to prevent undesirable water surface undulations.

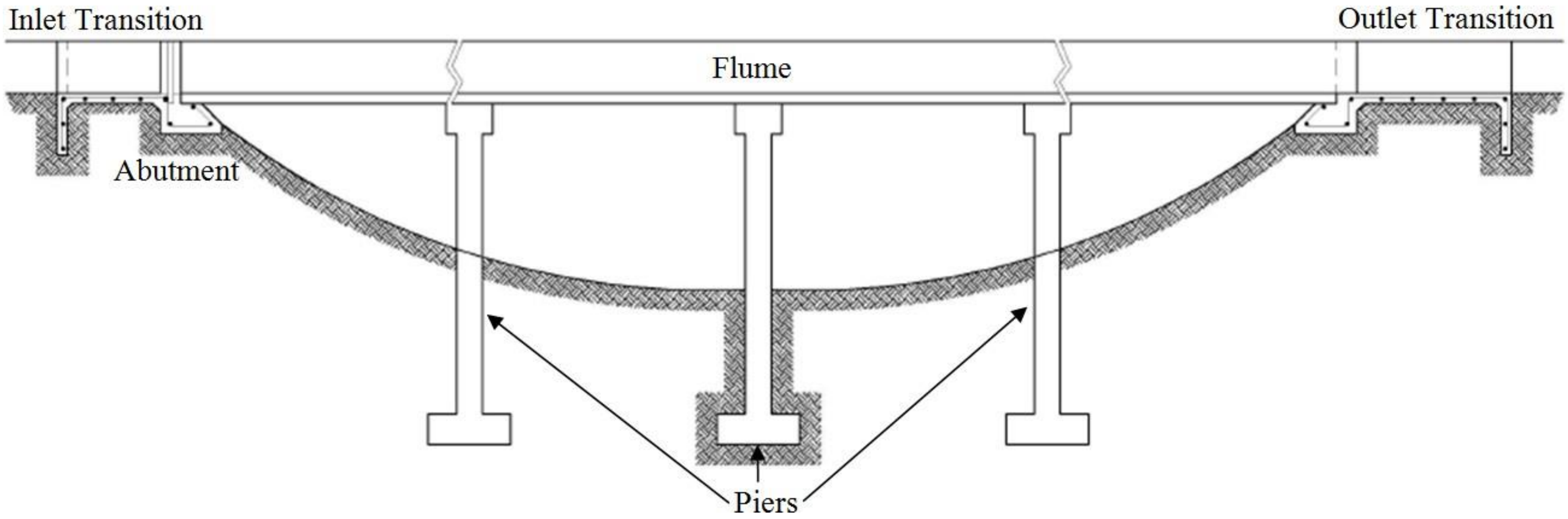

Figure 7. Longitudinal View of an Elevated Flume

8.3 Design Procedure

The following design procedure does not cover the design of elevated flume substructures such as abutments, piers and walls.

8.3.1 Determine the flume size

8.3.1.1 Determine the trial area of the flume using the formula in section 8.4.1 by assuming a velocity in the flume of 1.2 m/s to 1.5 m/s.

8.3.1.2 Using the computed trial area, determine the width and the depth of the rectangular flume within an acceptable ratio of b/d = 1 to 3.

8.3.1.3 Using the chosen depth and width, compute for the actual velocity in the flume (as shown in section 8.4.2)

↓

8.3.2 Compute for the friction slope and critical slope – Use the formula in section 8.4.3 for the friction slope and 8.4.4 for the critical slope. The computed critical slope shall be greater than the critical slope where n=80% of design n. Otherwise, select a different flume size and repeat the previous steps.

↓

8.3.3 Determine the invert elevation– Use the formula in 8.4.5 and 8.4.6.

↓

8.3.4 Determine the length of upstream and downstream transitions – Use the formula in 8.4.8

8.4 Design Equations

8.4.1 Trial Area

$$A_{trial} = \frac{Q}{V_a}$$

where:

A_{trial} is the trial flume area (m^2)
Q is the canal discharge (m^3/s)
V_a is the assumed conduit velocity (m/s)

8.4.2 Actual velocity

$$V_f = \frac{Q}{A_f}$$

where:

A_f isthecomputedflumearea,(m^2) Q isthecanaldischarge(m^3/s)
V_f is the actual velocity in the flume (m/s)

8.4.3 Friction Slope

$$S_f = \frac{V_f n}{\left(A_f / P_f\right)^{2/3}}$$

where:

S_f is the friction slope
V_f istheactualvelocityintheflume(m/s) n is thedesignroughnesscoefficient
A_f isthecomputedflumearea(m^2) P_f istheperimeteroftheflume(m)

8.4.4 Critical Slope

$$q = \frac{Q}{b}$$

$$d_c = \sqrt[3]{\frac{q^2}{2g}}$$

$$A_c = b \times d_c$$

$$P_c = b + 2d_c$$

$$V_c = \frac{Q}{A_c}$$

$$S_c = \frac{V_c n_c}{\left(A_c / P_c \right)^{2/3}}$$

where:

Q is the canal discharge (m^3/s)
b is the canal width (m)
q is the discharge per meter width (m^2/s)
d_c is the critical depth (m)
V_c is the velocity in the flume based on critical depth (m/s)
n_c is the 80% of design roughness coefficient
A_c is the flume area based on critical depth (m^2)
P_c is the perimeter of the flume based on critical depth (m)
S_c is the critical slope

8.4.5 Invert Elevation at Inlet

$$\text{Flume invert elevation at } A = WS_{U/S} - 1.3\Delta h_v - d_{flume}$$

where:

$WS_{U/S}$ is the upstream water surface level (m)
Δh_v is the change in velocity head (m)
d_{flume} is the height of flume (m)

8.4.6 Ivert Elevation at Outlet

$$\text{Flume invert elevation at } B = \text{Flume invert elevation at } A - (S_f \times L)$$

where:

S_f is the friction slope
L is the length of flume from inlet to outlet (m)

8.4.8 Length of upstream and downstream transitions

$$L_1 = \frac{b_a/2 - b_f/2 + 1.5 d_a}{\tan 27.5}$$

$$L_2 = \frac{b_b/2 - b_f/2 + 1.5 d_b}{\tan 22.5}$$

where:

L_1,L_2 is the length of upstream and downstream transitions, respectively (m)
b_a isthewidthofflumeatthestartofconvergingsection(m) b_b is thewidthofflumeattheendofdivergingsection(m)
d_a isthedepthofwateratflumeinlet(m) d_b isthe depthofwateratflumeoutlet(m)

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