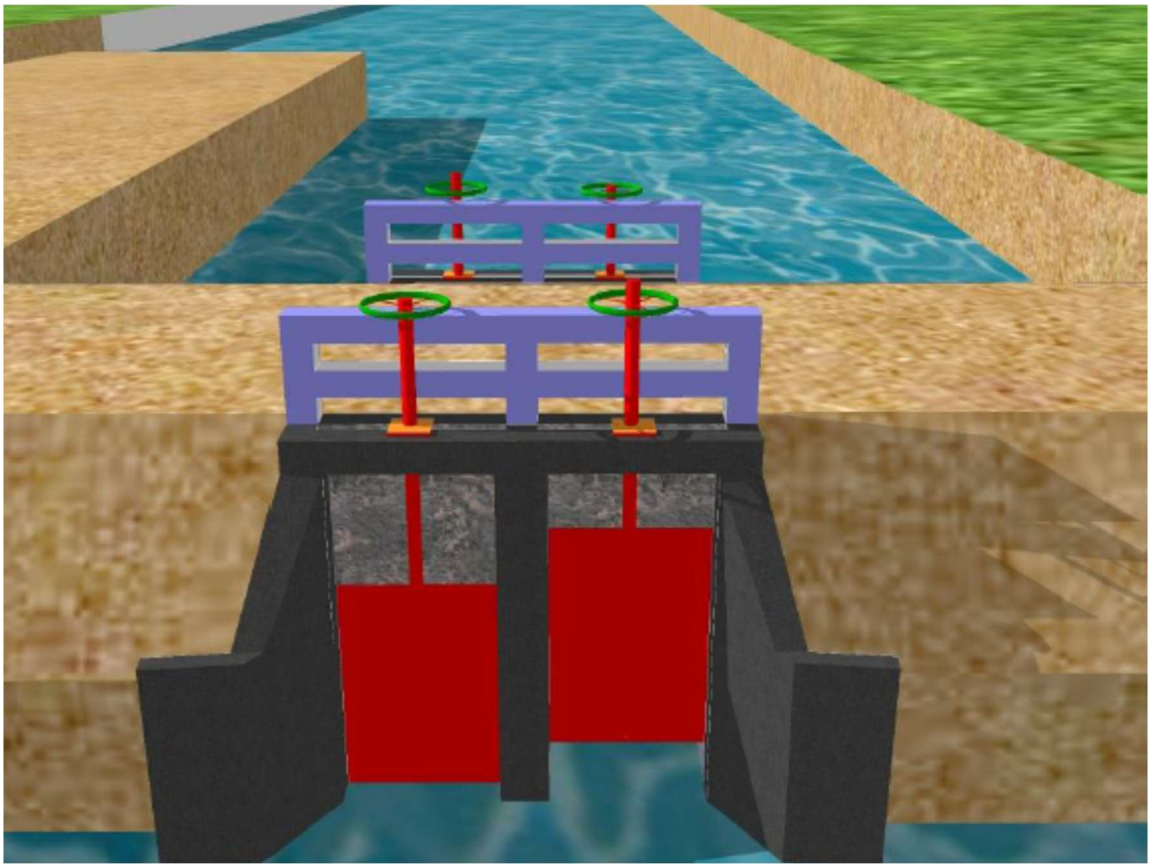
WATER RETENTION STRUCTURE
Polder 29 Gajendrapur Uttar
Design Report



V2 dd. 26 March 2020

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Bibliography

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[2] USBR, Design of small canal structures, United States Department of the Interior: Bureau of Reclamation, 1978.

[3] USDA-SCS, TR no. 25 Design of open channels, Washington: United States Department of Agriculture - Soil Conservation Service, 1977.

[4] FHWA, Hydraulic design of highway culverts -second edition, Hydraulic Design Series no. 5, FHWA-NHI-01-020, Federal Highway Administration USA, 2001, revised in 2005.

[5] USACE, 1110-2-2100 Stability Analysis of Concrete Structures, Washington: United States Army Corps of Engineers, 2005.

[6] USACE, EM 1110-1-1905 Bearing Capacity of Soils, Washington: United States Army Corps of Engineers, 1992.

[7] USACE, EM 1110-2-1902 Slope stability, Washington: United States Army Corps of Engineers, 2003.

1. Introduction

1.1. Background

In the village and WMG of Gajendrapur Utter and surrounding WMGs, WMG-members aim to retain water at the end of the monsoon season to irrigate land at the end of the monsoon season and during the Rabi (dry) season. The main problem in the area is that high-land and low-land plots have too little water at the end of the Karif II (wet) season as well as during the Rabi (dry) season (see annex 3). In some other parts of the polder, this problem is now solved by using ground water with shallow tube wells .

With the implementation of a retention structure in the Dholvanga Khal, surface water becomes available to use for irrigation.

1.2. Study area

Based on a Digital Elevation Model, the drainage area comprises 500 hectares of the Telikhali sluice catchment (+- 2400 hectares). Based on imagery (see annex 1), it is likely that the drainage area is smaller than 500 hectares. The drainage area likely comprises only about 60% per cent of these 500 hectares, amounting to about 300 hectares.

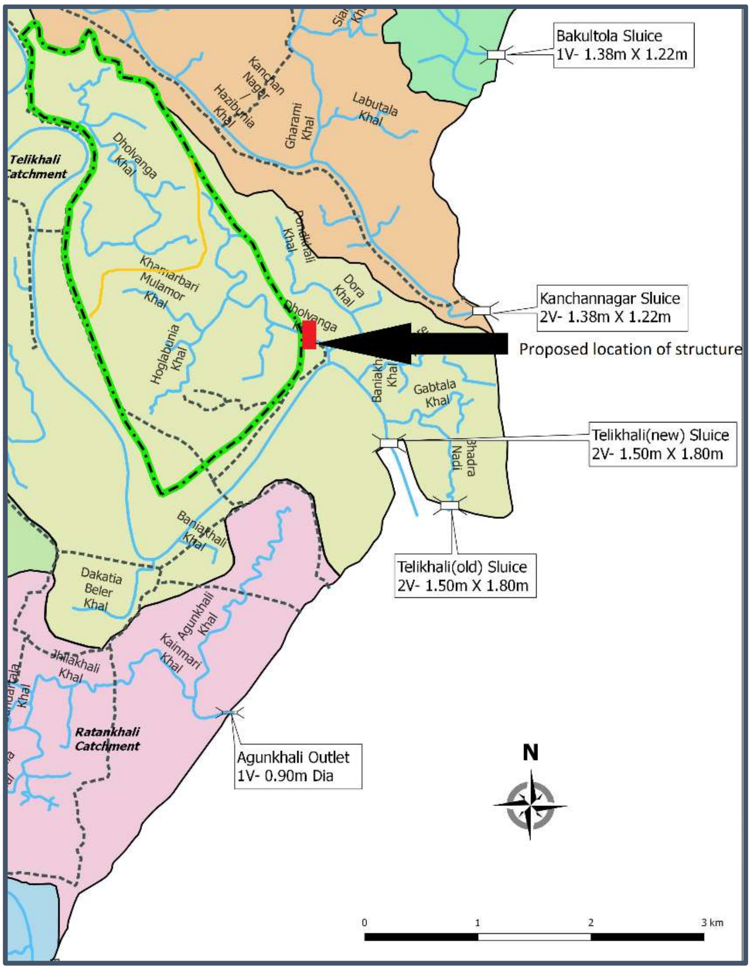


Figure 1 Indication of the drainage area (dotted green line). It may be possible that the drainage area is smaller and only consists of the area below the yellow line.The potential location of the structure is marked with the red block.

1.2.1. Culvert location

Figure 2 Orange lines indicate location of culvert

The culvert will be situated in the road along the canal.

1.2.2. Waterway data

Cross sections: For the cross section closes to the culvert location, see below. The canal is more narrow at the location of the culvert. All land and water levels in this document have been derived from the survey- which might not correctly display m+PWD.

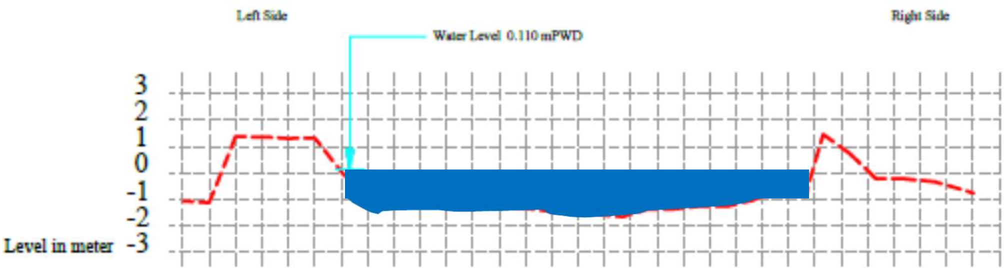


Figure 3 Cross section number 2, canal 1

2. Peak flow analysis

2.1. Method

The methods and toolus used in this chapter are largely based on Volume III (chapter 18 – "Rainfall analysis") and Volume IV (Chapter 28.8 – "Design discharge computations for flat areas") of Drainage Principles and Applications [1]*.*

The water retention structure must be capable of draining the area during the monsoon. For the calculation of peak flow, the 'Rational method' is often used. However for flat areas (< 1% sloping surface), like polders, different methods are applicable. To reduce the number of assumptions to be made, a simplified hydrological method is used. This method assumes that the rainfall excess (rainfall (with return period T and with duration d) minus system storage) is spread evenly across the catchment, creating a depth of water (1d model) that needs to be drained before crop damage occurs.

2.2. Assumptions and limitations

2.2.1. System storage

A water depth of 200 mm (150 mm crop resistance, 50 mm storage in khals and field canals) may be stored in the system before crop damages occurs. If the storm event exceeds this depth, this is defined as the rainfall excess.

- *Crop resistance:* Drainage is most important during the monsoon season: (ground-) water levels are high already and water levels on the field may increase due to storm events. During the monsoon season, T. Aman rice is grown. The crop resistance of T.Aman rice depends on its variety and on the growth-stage. During various growth-stages of the rice, paddies are intentionally 'flooded' by about 70 mm tot 100 mm. During the most critical growth-stages, a water depth increase by more than 150 mm lasting for at least 7 days is considered harmful for most common varieties.

- *Open water storage:* It is assumed that 50 mm rainfall can be stored in the system of khals and field canals. To indicate the plausibility of this assumption the following example is given. If one assumes that two-third of this amount will be stored in the khal and one third in field canals, every meter of khal will store an additional 15 m^3 water. With an average width of 30-45 meter, this seems plausible (0.33 – 0.50 meter increase in water table).

2.2.2. Rainfall data

Rainfall data of the Bangladesh Meteorological Department have been used (station Khulna), comprising a time series of one day rainfall observation for 29 years (between 1984 and 2012).

- Frequencies are calculated based on depth intervals.
- The number of days that crops may resist their maximum depth of water (i.e. 150 mm + 50 mm khal storage) is assumed to be 7 days. Durations of 1, 2, 3, 5, 7 days storm events are computed from 1 day rainfall analysis for reference and are based on moving totals of summed 1-day rainfall observations.
- The return period of a storm that may exceed the capacity of the drainage structure is 5 years. Return periods of 1, 2 and 10 years are calculated for reference.
- The measurements of the Khulna station are valid for a certain area. The bigger the area and the higher the rainfall usually is (i.e. in the tropics), the lower the rainfall depth of water will

be. From figure 21 of Volume IV (chapter 28.8) of Drainage Principles and Applications [1], a factor of a = 0.65 may be derived (100 mm rainfall per day, 500 ha). To be on the safe side, a = 0.75 is assumed.

- From the acquired depth-duration-frequency tables, the duration of drainage is calculated in hours. The duration is acceptable if it is drained within 7 days (168 hours).

2.3. Results

The following depth-duration-frequency is derived:

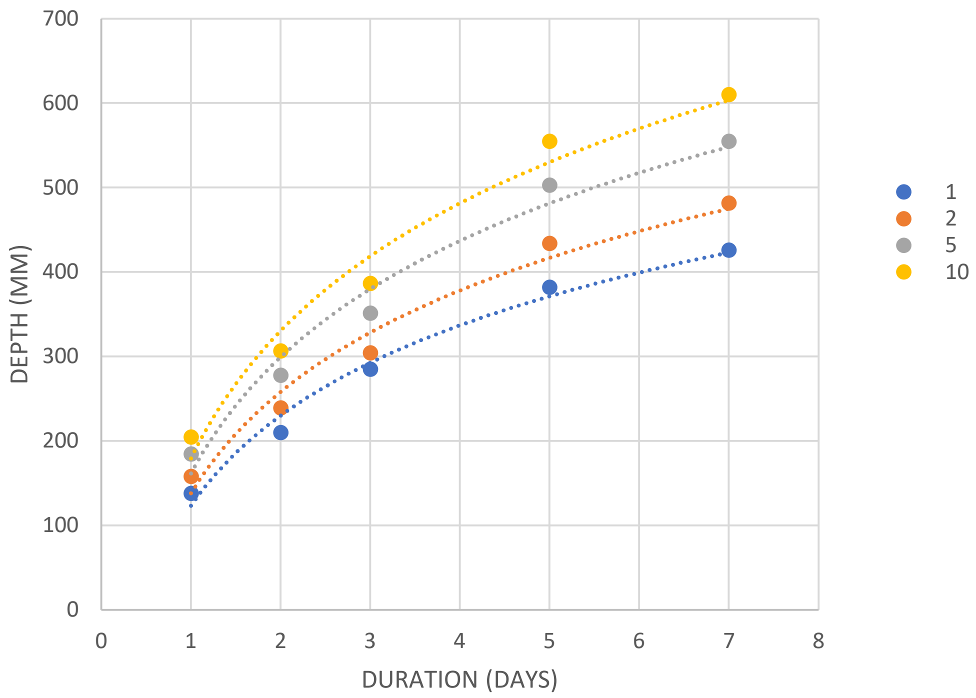


Figure 4 Depth-Duration-Frequency diagram for Khulna meteorological station.

These values are corrected for scale effects, resulting in values shown in Table 1:

Table 1 Storm depths (mm) based on Khulna station rainfall analysis. Corrected for scale effects with alpha = 0.75.

	Storm Duration (days)				
return period (years)	1	2	3	5	7
1	104	158	214	287	320
2	119	179	228	325	361
5	139	208	263	377	416
10	154	230	290	416	458

From these storm depth figures, 200 mm is subtracted as system storage. The remaining storm depth (416 minus 200 = 216 mm) needs to be drained within 7 days. The required drainage time depends on the drainage capacity of the system. This results in Table 2.

Table 2 Drainage capacity and required drainage time.

drainage capacity (mm/hr)	Required drainage time of 216 mm (hr)	Required drainage time (days)

3	72	3
2	108	4.5
1.5	144	6
1.25	173	7

Table 2 shows that a drainage capacity of 1.25 mm/hr is sufficient to drain the catchment in about 7 days, given a 5 year return period storm, a 7 day storm duration and a correction for scale-effects of the rainfall depth of alpha = 0.75 .

2.4. Culvert discharge capacity

The peak design flow is based on a catchment size of 400 hectares and a minimum of 1.25 mm/hr drainage capacity (see section 2 on "Peak flow analysis"). Based on this, the required discharge capacity Q amounts to Q= 1.4 m^3/s. This is increased by 50% to 2.1 m^3/s to account for tailwater tidal influences.

3. Data

3.1. Water levels

Water levels have not been monitored. In Figure 5 the average low and high tide over the months can be found. From these water levels, tail water at the culvert location may be derived. It is expected that these are dampened by about 1.5 meter because of the small sluice opening downstream of the proposed water retention structure. Tailwater is unknown but likely to vary between -0.50 to + 0.50 m.p.w.d. Under extreme wet conditions the tailwater may get as high as +0.80 m.p.w.d. Land elevation in the polder is around 0.70 m.p.w.d.

Head water design water levels need to include that upstream water levels are likely to be 10 cm higher, which is conservative as bed slope is around 0,01 m/km.

Under extreme dry condition the tail river bed is considered dry, so a tailwater height of -1.60 is assumed for stability calculations.

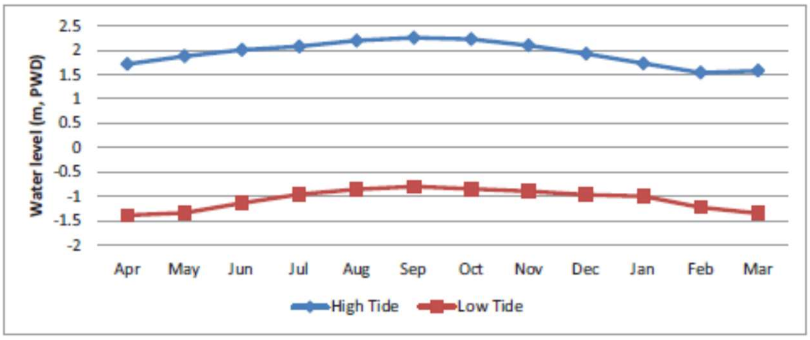


Figure 5 Average water levels at high and low tide for Dumuria (Upper Bhadra river), source: EIA P29

3.2. Roadway data

It is likely that the road over the culvert will be used by larger motorized vehicles as a new road will be constructed by the Union Parishad on the north bank of the khal. The road (on culvert) level is +1.50 meter. The road will be 4 meters wide. The culvert barrels are therefore also 4 meters in length. On both sides 2 meter aprons with wing walls have been designed. It is expected that light traffic will cross the bridge (5 kN/m2)

3.3. Subsoil characteristics

The following soil characteristics have been derived from the soil test report (Annex 6)

Depth (m.b.s.l)	***0-15***	***15-18***
SPT classification (blows)	Soft (<4)	Medium (4-8)
Dry / saturated weight (kN/m3)	13,7 / 18,5	-
Cu (D_{60}/D_{10}) and	40	-
Cc $(D_{30})^2/(D_{10} * D_{60})$	1.11	-
Liquid Limit	50-54	-
Plasticity index	23-26	-
Cohesion (kPa)	5	
Undrained shear stress	15	
Shearing angle (°)	25	
Comments	Well graded Above A-line and plastic, low likelihood to be dispersive Organic (peat) particles found	
Classification of soil	Organic or Fat Clay	

The cohesion and shearing angle have been derived from standard figures from Eurocode. The soil test contains direct shear tests, but the results are conflicting and therefore discarded.

4. Design criteria

4.1. Load scenarios

The load scenarios are grouped in hydraulic design scenarios and other (stability) design scenarios.

Table 3 Load scenarios for hydraulic and stability mechanisms

Criteria	**Likelihood**	**Headwater**	**Tailwater**	**Water level crest**
		m.p.w.d.	*m.p.w.d.*	*m.p.w.d.*
Hydraulic	Usual	n.a.	+0.50	n.a.
	Extreme	n.a.	+0.80	n.a.
Sliding + Resultant Location	Usual	+0.60	-0.50	+0.60
	Extreme	+1.50	-1.60	+1.50
Flotation	Usual	+0.60	-0.50	+0.60
	Extreme	+ 1.50	-1.60	+1.00
Allowable bearing capacity + seepage	Extreme	+1.50	-1.60	+1.00
Slope stability	Usual	+0.60	+0.50	+0.60
	Unusual	- 0.40	-0.50	+0.60
	Extreme	+1.50	+0.80	+1.00

4.2. Hydraulic design

The hydraulic design criteria of the USBR manual [1] are followed.

4.2.1. Scour prevention and energy dissipation

To prevent riverbed erosion, appropriate proportioning of vent size in relation to the discharge capacity is required. The allowable flow velocity is calculated through USDA SCS 1977’s [3] allowable flow velocity method. From the figures below, the allowable flow velocity is determined as follows:

Allowable flow velocity (m/s) = V_{basic} * A*B*C*D.

Where

V_{basic}	=	Basic velocity
A	=	Correction factor for void ratio
B	=	Correction factor for frequency of design flow
C	=	Correction factor for design water depth
D	=	Correction factor for alignment

The basic velocity is based on CH (fat clay), the void ratio is assumed 1.0 (due to well graded soil), the frequency of design flow is more than 10%, the design water depth is 2.0 meter and the curve radius:water surface width ratio is larger than 20.

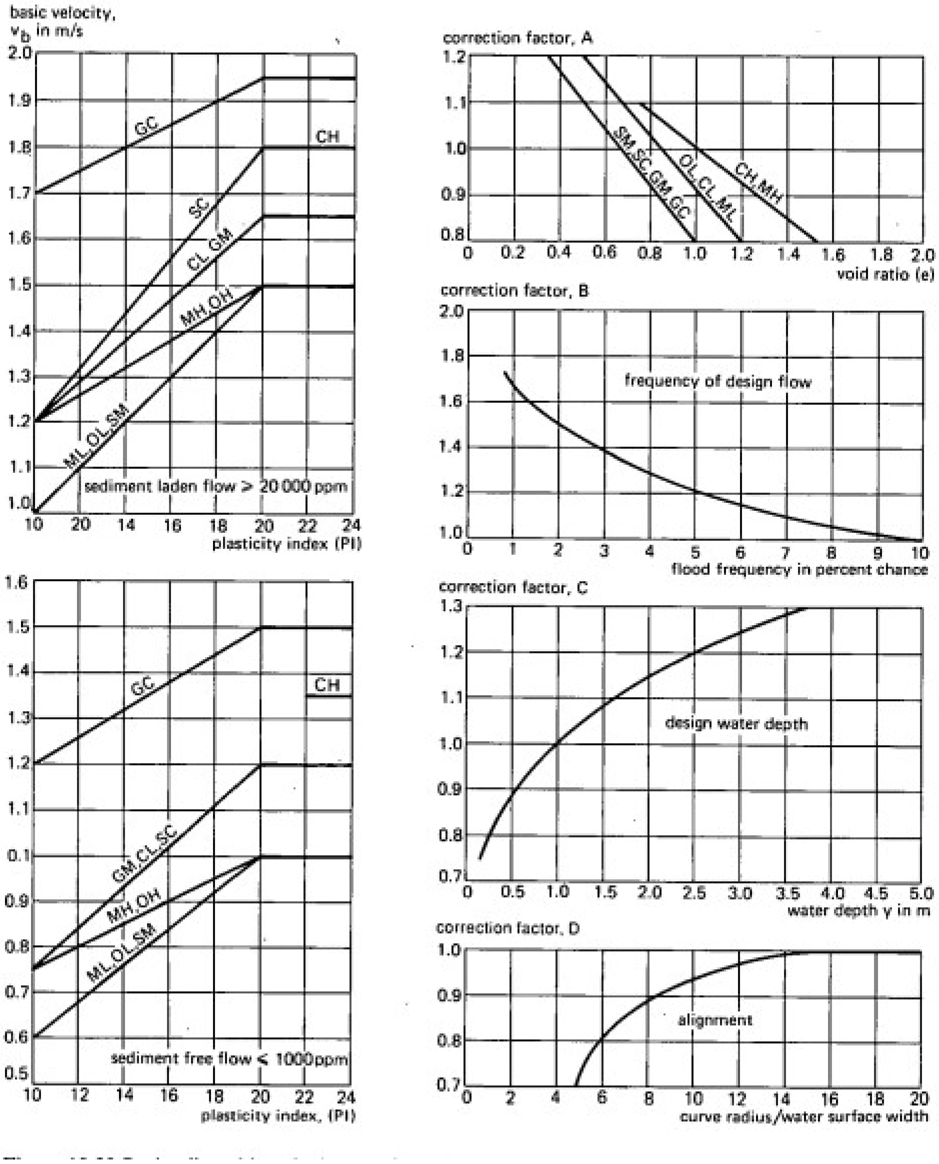


Figure 6 USDA SCS 1977 [3] Allowable Flow Velocity method, flow velocity and correction factors.

If flow velocities are expected above 2 m/s, further protective measures for energy dissipation or bed protection are required.

4.2.2. Minimizing head loss

The head loss is to be minimized to maintain sufficient free board and a minimal increase in head water level under design discharge capacity. Flow conditions (inlet or outlet controlled) need to be determined. With nomographs from FHWA [4] head water losses should be estimated.

Under usual flow conditions, head loss should be such that the free board over the entire canal length is maintained. The free board is required to be 0.10 m at the culvert location so that at upstream locations the canal does not overflow (freeboard is nearly 0.00 m). Under extreme conditions, the head water should not overflow the construction.

Scenario	Discharge (m3/s)	dHW requirement
Usual	2.1	<0.10
Extreme (flow velocity 2 m/s)	7.2	<0.70

Note that the extreme scenario discharge is arbitrary and based on the allowable flow velocity of 2 m/s.

4.3. Stability Design

Design criteria have been defined in accordance with USACE 1110-2-2100 [5]. There is limited site information as foundation strength data and load condition data cannot be established with a high level of confidence. The structure is classified as a normal structure as no loss of life is expected in case of failure.

4.3.1. Sliding

The Factor of Safety for sliding is considered as follows (modification of USACE 1110-2-2100 [5], using effective width and length to make a more conservative estimate):

$$FSs = \frac{l'w'}{lw} \frac{N \tan \varphi}{T}$$

N = force acting normal to the sliding failure plane under the structural wedge.
φ = angle of internal friction of the foundation material under the structural wedge.
l = length of the structural wedge.
l' = effective length of the structural wedge in contact with the foundation
w = width of the structural wedge.
w' = effective width of the structural wedge in contact with the foundation
T = shear force acting parallel to the base of the structural wedge.

The following scenarios are applicable

Site information category	*Usual*	*Unusual*	*Extreme*
Limited	*3.0*	*2.6*	*2.2*

4.3.2. Flotation

The safety factor for flotation is considered as follows (USACE 1110-2-2100 [5]):

$$FSf = \frac{\text{Ws} + \text{Wc} + \text{S}}{U - Wg}$$

WS= weight of the structure, including weights of the fixed equipment and soil above the top surface of the structure. The moist or saturated unit weight should be used for soil above the groundwater table and the submerged unit weight should be used for soil below the groundwater table.
WC= weight of the water contained within the structure
S = surcharge loads
U = uplift forces acting on the base of the structure, 0.8 * depth of structure under HW
WG = weight of water above top surface of the structure.

Site information category	*Usual*	*Unusual*	*Extreme*
All categories	*1.3*	*1.2*	*1.1*

4.3.3. Resultant location

The limits on the resultant location are is use for evaluation of rotational modes of failure. These have the requirements listed below (USACE 1110-2-2100 [5]):

Site information category	*Usual*	*Unusual*	*Extreme*
All categories	*100% of base in compression*	*75% of base in compression*	*Resultant within base*

100% base of compression is assumed to be maintained if:

$l' > 2/3\ L$

where:

l' = effective length

L = Length

The eccentricity of the force should be 1/6 of the length of the structure.

4.3.4. Allowable bearing capacity

Allowable bearing capacity is analyzed in accordance with EM 1110-1-1905 [6]. A safety factor of at least FS = 2.5 should be achieved. The minimum allowable bearing capacity of the subsoil should be:

$$\text{Allowable bearing capacity}_{minimum} = F_{downwards} * FS_{bearing\ capacity}$$

Where:

$F_{downwards}$ = The downward force of the culvert self-weight, and soil and water on the culvert surfaces

$FS_{bearing\ capacity}$ = Safety factor for allowable bearing capacity

Soil improvement will be made with sand, having the following qualities:

Cohesion (kPa)	0
Undrained shear stress	-
Shearing angle (°)	30

4.3.5. Seepage

Percolation seepage is the mechanism where backside erosion along the interface of the structure and soil may occur because of high hydraulic gradients and little openings between the soil and the structure. Lane's weighted creep ratio applies here.

$$C_{lane} = L_{creep} / H$$

Where:

C_{lane} = Lane's weighted creep ratio

L_{creep} = Creep length, $((L_{horizontal}/3) + L_{vertical})$

H = Head difference

Lane's recommended weighted creep ratios are listed below in Figure 7, a ratio of 2.0 :1 is deemed appropriate given the subsoil. However, there will be sand in the foundation as well. It is therefore assumed that a ratio of 1:3.5 should be sufficient for percolation underneath the structure

Material	Ratio
Very fine sand or silt	8.5:1
Fine sand	7.0:1
Medium sand	6.0:1
Coarse sand	5.0:1
Fine gravel	4.0:1
Medium gravel	3.5:1
Coarse gravel including cobbles	3.0:1
Boulders with some cobbles and gravel	2.5:1
Soft clay	3.0:1
Medium clay	2.0:1
Hard clay	1.8:1
Very hard clay or hardpan	1.6:1

Figure 7 Lane's recommended weighted creep ratios

4.3.6. Slope stability

Failure of the earthen cross dam may be of threat to the overall stability. Slope stability is calculated in accordance with EM-1110-2-1902 [7]. The following criteria are applicable.

	Usual	*Unusual – rapid drawdown*	*Extreme*
Safety factor	*1.5*	*1.3*	*1.4*

The Bisshop method for slope stability calculation will be used. Slip planes at the most relevant location (upstream vs downstream) should be presented. An earthen structure with a 1:2 slope will be constructed by the community. Traffic loads are negligible.

4.4. Structural design

The culvert will need to comply with rebar requirements commonly prescribed in manuals. The United States Bureau of Reclamation manual [2] for small hydraulic structures provides guidelines with standard prescriptions. The basic requirements are covered here.

4.4.1. Allowable stresses

In USBR, the allowable working stresses used are 12,400 kN/m^2 compression for concrete and 165,000 kN/m^2 tension for reinforced steel.

4.4.2. Minimum reinforcement requirement

Minimum reinforced should be 12 mm diameter bars, at 12 inch spacing or reinforcement of similar strength. The required gross cross sectional areas of the concrete to be reinforced are listed below:

- Single layer
  - Not exposed to direct sunlight: 0.25%
  - Exposed to direct sunlight: 0.30%
- Double layer:
  - Adjacent to earth: 0.10%
  - Not adjacent, not exposed 0.15%
  - Not adjacent, exposed 0.20%

Spacing should not exceed two times the thickness of the member for stress bars.

4.4.3. Minimum wall and slab thickness

Cantilever supporting wall thickness requires a minimum thickness for ease of concrete placement and insurance of good bond between reinforcement and the concrete. The minimum thickness should be 1 inch per foot of height for walls up to 8 meter height. Walls higher than 8 feet, should be 8 inch thick plus ¾ inch for each foot of wall height greater than 8 feet.

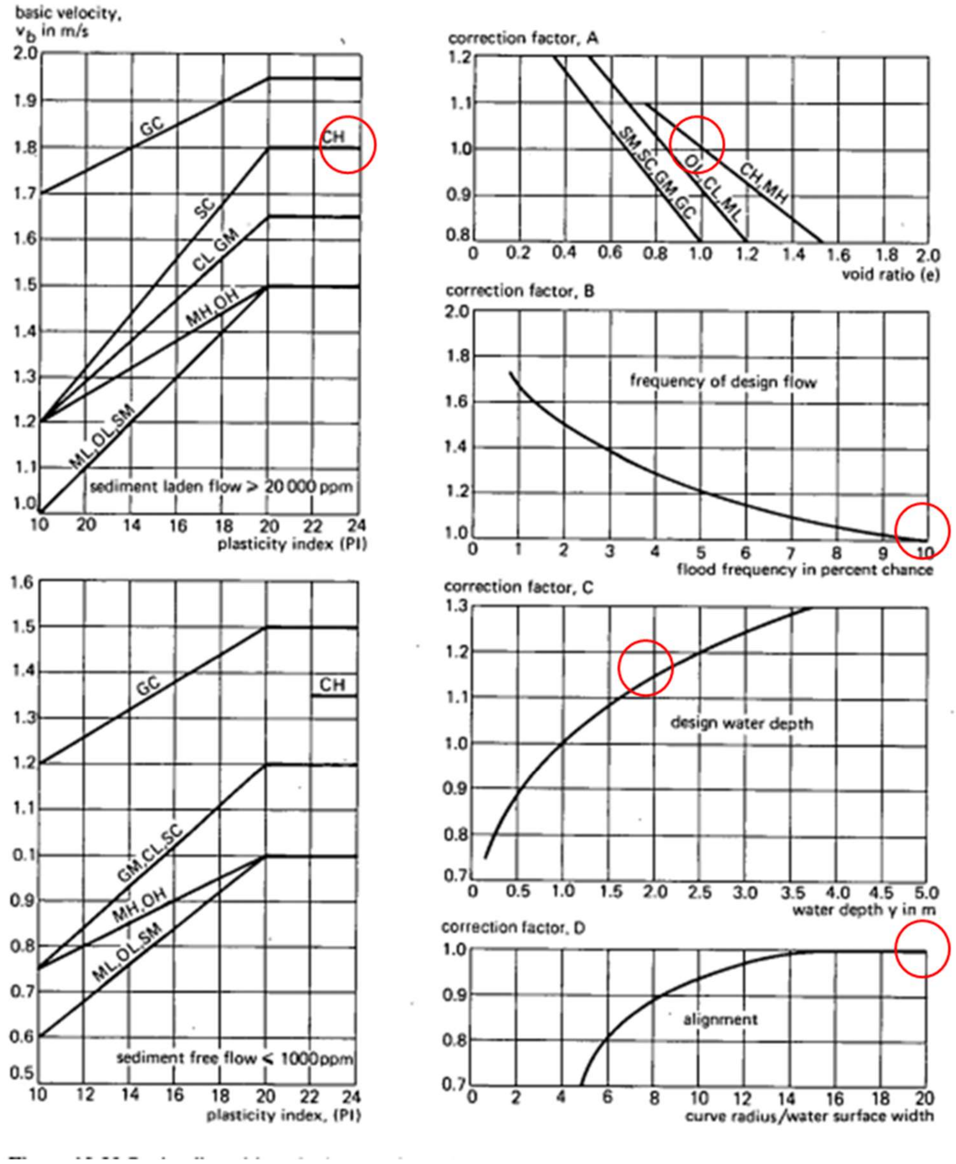
Top and bottom slab thickness should be such to facilitate good structure integrity and should at least be 10 inch.

5. Analysis

5.1. Hydraulic design analysis

5.1.1. Scour prevention and energy dissipation

Allowable flow velocity V = 1.8 * 1.0*1.0*1.15*1.0 = 2.07 m/s, which translates into roughly 2 m/s. See below for quantifcation of factors determining flow velocity.



5.1.2. Minizing head loss

Under extreme hydraulic conditions, the culvert flows full and is outlet controlled. With nomograph 15A (FHWA, Hydraulic Design of Highway culverts, 2005), head losses can be determined. These losses are then added to the tailwater (TW) height to obtain the Head Water (HW) level. This is a simplification of energy balance equations:

HW = E + TW

Where:

HW = Headwater depth
E = Hydraulic Depth, caused by energy loss over the culvert
TW = Tail Water Depth

The table below lists the head water loss derived from nomographs. These nomographs can be found in appendix 4.

Scenario	Discharge (m3/s)	dHW requirement	dHW analysis
Usual	2.1	<0.10	<0.05
Extreme	7.2	<0.70	0.35

Head water loss is sufficiently low to allow for sufficient discharge during high tailwaters. Also during extreme high tail water, there is sufficient freeboard to allow for high discharge capacity and by that reducing the threat of cross dam overtopping.

The discharge capacity of the culvert is such that it is not likely that the allowable flow velocity (see previous paragraph 5.1.1) will be exceeded.

5.2. Stability design analysis

5.2.1. Sliding

For the unusual and for the extreme scenario calculations have been made.

			Extreme	Usual
Head water above invert	HW	m.p.w.d.	+1.50	+0.60
	TW	m.p.w.d.	-1.60	-0.50
Width	W	m	4	4
Length	L	m	8	8
Specific weight	Yk	kN/m2	17	17
Effective shearing angle	angle	Degrees	30	30
Horizontal force	Fw	kN	153	70
Vertical force	Vd	kN	1224	1224
Eccentricity height	Eh	m	1.90	1.45
Eccentricity width	Ew	m	0.24	0.02
Eccentricity length	EL	m	0.24	0.02
Effective width	w'	m	3.52	3.95
Effective length	l'	m	7.52	7.95
Drained sliding resistance	Rhd	kN	586	685
	SF		**3.8**	**9.5**
	SF required		**2.2**	**3.0**

5.2.2. Flotation

The following table lists the inputs for the calculation of the safety factor.

		T	G	Down	Up	
		Volume	kN/m3	(kN)	(kN)	(kN)
					Extreme	Usual
WS	Roadfill (4m)	18	14.0	245.7		
	Concrete top slab	3.6	25.0	91.4		
	Concrete bottom slab	9.8	25.0	245.0		
	Culvert vertical wals	4.5	25.0	112.5		
	Culvert vertical walls perpendicular	1.1	25.0	27.4		
	Collars	9.4	25.0	235.0		
	Front walls	2.8	25.0	68.8		
	Wing walls	4.1	25.0	103.1		
	Cutoff walls	3.0	25.0	75.0		
	Other (MS, railing etc)		20.0	20.0		
	Total Down			**1224**		
U	Water	20	(HW+0.35)-TW*9.81		676	265
WG	Water	6.0	(HW)*9.81		-182	-129
	Total Up				**494**	**135**
				SF	2.48	9.05

5.2.3. Resultant location

The resultant location is defined below. In Extreme and Usual scenarios there is sufficient surface contact between the culvert and the soil.

			Extreme	Usual
Head water above invert	HW	m.p.w.d.	+1.50	+0.60
	TW	m.p.w.d.	-1.60	-0.50
Width	W	m	4	4
Length	L	m	8	8
Horizontal force	Fw	kN	153	19
Vertical force	Vd	kN	1224	1224
Eccentricity height	Eh	m	1.9	1.45
Eccentricity width	Ew	m	0.24	0.02
Eccentricity length	EL	m	0.24	0.02
Effective width	w'	m	3.52	3.95
Effective length	l'	m	7.52	7.95
Effective Length / Length	**> 0.66**		**0.94**	**0.99**

5.2.4. Allowable bearing capacity

The minimum allowable bearing capacity of the subsoil is:

Allowable bearing capacity $_{\text{minimum}}$ = $F_{\text{downwards}}$ * FS $_{\text{bearing capacity}}$ = 1428 * 2.5 = 3570 kN

The undrained bearing capacity of the clay is 2062 kN. See appendix 5 for calculations. This is insufficient and therefore sand piling is a practical solution:

- Sand piles of 8 inch diameter with 18 inch spacing are proposed.
- If the full subsoil was replaced with sand, the drained bearing capacity would be 8386 kN.
- The replacement ratio of the sandpiles is about 19%.

Therefore, the final bearing capacity will be 0.81 * 2062 + 0.19 * 8386 = 3809 kN. This allowable bearing capacity is sufficient.

5.2.5. Seepage

The design of the culvert has been modified to accommodate a weighted creep ratio of 3.5 for percolation underneath the structure. There will be two collars, each extending 1 meter under the structure, and 1.5 meter on the sides. The cut-off walls, wing walls and front walls are dimension to contribute to the increased creep path. L_{creep} for percolation underneath the structure surface is:

(8/3) + (1.35*2+2*1.00+1.00*4) = 11 meter. C_{lane} is then 11/3.1 = 3.5

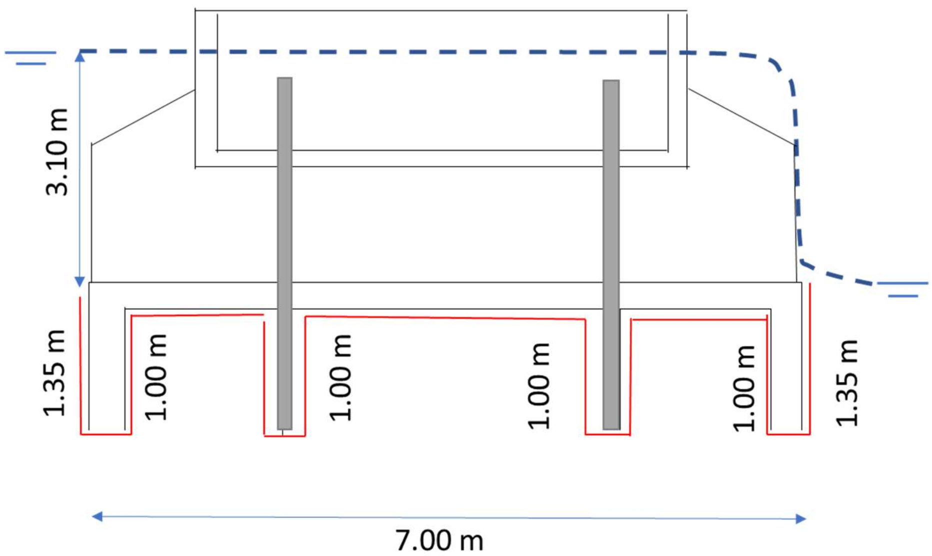


Figure 8 Creep path underneath the structure indicated by red line.

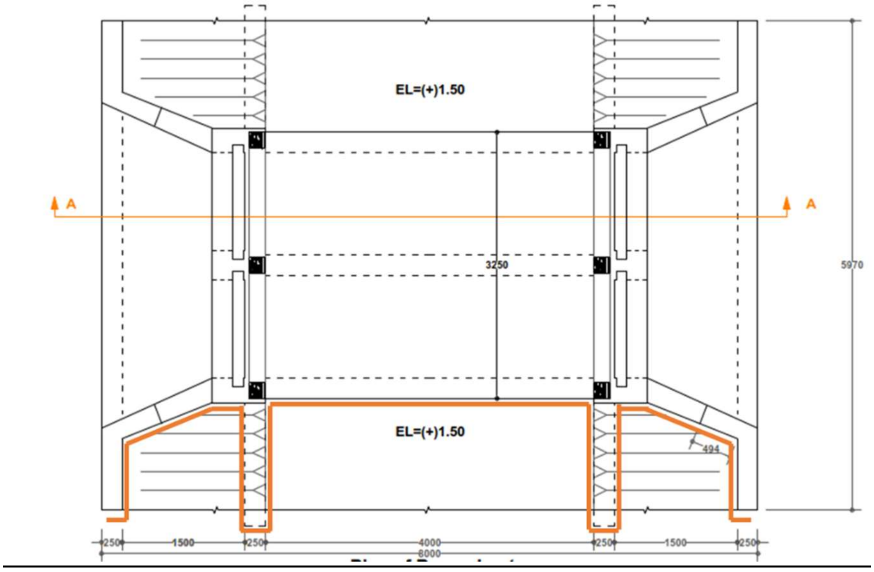


Figure 9 Creep path alongside the structure indicated by red line

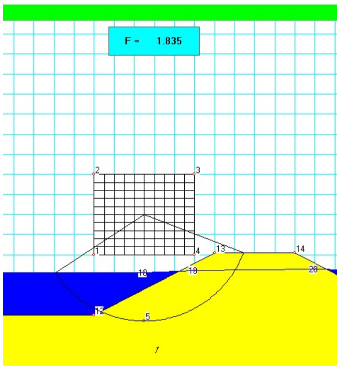
Piping is the mechanism where backward erosion (not necessarily following the structure-clay interface) underneath or on sides of the structure may cause stability problems. The subsoil is well graded and plastic, so physically less susceptible to piping. There is no likely path through the soil medium that will result in backward erosion. For a complete check, an analysis is performed here. Again, the weighted creep ratio for piping is analysed. L_{creep} is defined similar to percolation, but after undercutting the cut-off wall the creep path goes straight to the other cut-off wall.

L_{creep} for piping underneath the structure (taking a shortcut through the soil) is 2 times the horizontal distance:

C_{lane} is then (1.35*2 + 2*8)/2.6 = 7.2 > 3.5.

5.2.6. Slope stability

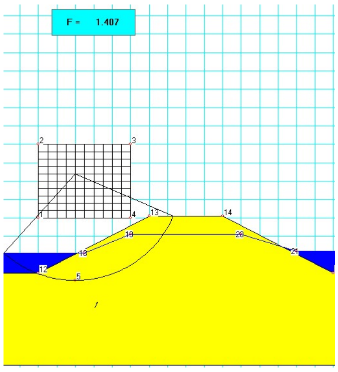
An initial analysis of slope stability (Bisshop), on a 1:2 slope has been performed resulting in a safety factor of 1.6 – see figure below.



Usual

SF > 1.5

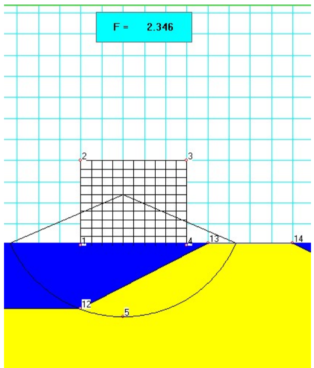
SF = 1.81



Unusual: rapid drawdown

SF >1.3

SF = 1.41



Extreme, high headwater and tailwater

SF > 1.5

SF=2.35

Figure 10 Result of initial slope stability analysis (Bisshop).

5.3. Structural design analysis

A summary of the requirements is listed below.

Table 4 Summary of structural design criteria

	Required	Design
Allowable stresses	n.a.	n.a.
Minimum reinforcement, adjacent	0.10%	0.39%
Minimum reinforcement, not adjacent, not exposed	0.15%	0.39%
Minimum reinforcement, not adjacent, exposed	0.20%	0.39%
Wall thickness of head wall and wing wall	9 inch	10 inch
Top slab	10 inch	10 inch
Bottom slab	10 inch	14 inch

6. Detailing

6.1. Inclination of head and wing walls

Contact between soil and the culvert is key to performance of the culvert with respect to stability, especially seepage. Poor compaction, consolidation or drying of the soil may have a negative impact. To mitigate these effects, the head and wingwalls will be slightly inclined, which increased the likelihood of good culvert-soil contact.

6.2. Turfing

Fine dressing and close turfing of the slopes of the approach embankment with 75mm thick, good quality durba or charkanta sods of size 200mm x 200mm, with all leads and lifts, including ramming, watering until the turf grows properly, maintaining etc completing as per direction of TA staffs.

6.3. Lift gate and lift mechanism

M.S. Vertical lift gate of size 1.2m x 1.5m (4nos) shutter 8mm thick M.S. skin plate and stiffener with minimum 75mmx75mmx10mm M.S. angle as frame, horizontal & vertical beam, 75mmx25mmx12mm P-type rubber seal, fixed with 10mm dia x 63.5mm M.S. counter shank bolts with nuts and 40mmx10mm M.S. strip as clamp drilled spaces @ 150mm c/c, stem attachment with proper thread, nut, cotter pin and washer as per approved design including the cost of all materials of proper grade & brand new with a prime coat of red-oxide where necessary as per specification and direction of TA staffs. Manufacturing, supplying and Installation of Hand Wheel type lifting device (4 nos) for slide gate with 63mm dia steel shaft, 108mm outer dia bronze nut taper roller bearing SKF-50216 etc. as per approved design including supply of all components, labour with a prime coat of red-oxide where necessary etc. complete including the cost of all materials as per specification and direction of TA staffs. M.S. Work in plates, angles, channels, flat bars, Tees etc. including fabricating, machining, cutting, bending, welding, forging, drilling, revetting, embedding anchor bars, staging and fitting, fixing, local handling etc. comlpete with energy consumption and supply of labours including the cost of materials as per design, specification and direction of TA staffs.

7. Construction

7.1. Safety

A meeting has been organized on construction safety before mid-March.

For construction site safety, helmet, hand gloves, apron and first aid kit has been supplied to the site for safety of the workers. Sign board has been placed in different location to notify neighbor about the construction and for the trench that has been dug, fence has been provided in one part specially where people move along with a signboard.

7.2. Compaction of soil

Compaction is ideally done between 20-40 % moisture content. Compaction will be done in layers of 0.15 m maximum and under close supervision of TA-staff. Local tools will be used for compaction.

Compaction is ideally done between 20-40 % moisture content. Compaction will be done within the initial lead of 30m and all lifts including throwing the spoils to profiles in layers of 0.15 m maximum in thickness, clod breaking up-to a maximum size of 0.1m, benching the side slopes, stripping/ploughing the base of embankment and borrow pit area, dug bailing, bailing out water, rough dressing and 0.15m cambering at the center of the crest etc. under close supervision of TA-staff. Local tools will be used for compaction.

8. Operation and maintenance

Operations of the structure is key to its success. There will need to be an agreement on operations, and specifically on the following;

- The neighboring high lands (south west of the structure, Gajendrapur Uttar) need water at the end of the Aman season, while the northwestern lands upstream (part of Gajendrapur Uttar, Hajibunia need drainage. This requires careful planning. Therefore, an agreement is required between hilgh land low land owners for proper planning.
- The khal would be able to store more water if the low-lying areas (see green in figure below) have sufficient embankment height along the canal, facilities to drain or irrigate their land. Their access to irrigation water would also increase dramatically.
- If the khal is being re-excavated in future, it should be at least 30m away from the structure otherwise it will be harmful for the structure, it should be monitored.

Maintenance

- Small maintenance work such as greasing the gate, maintaining the approach road such as repairing ghogs, maintaining the turfing etc should be done on a regular basis as per requirement.

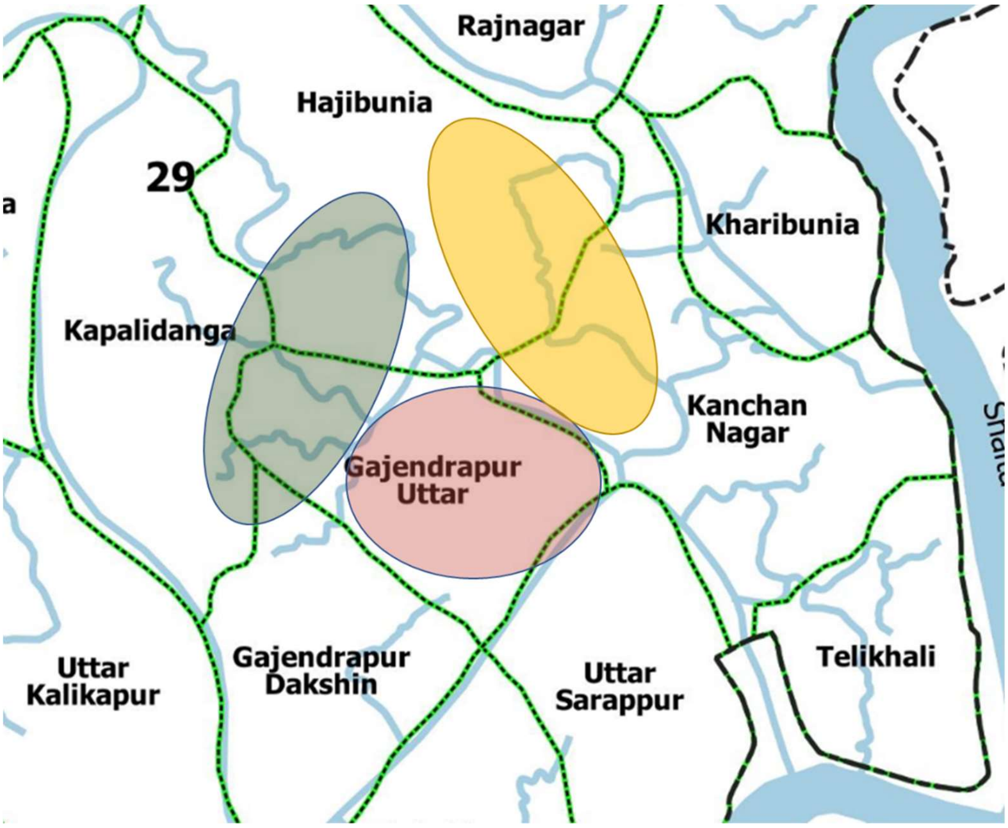
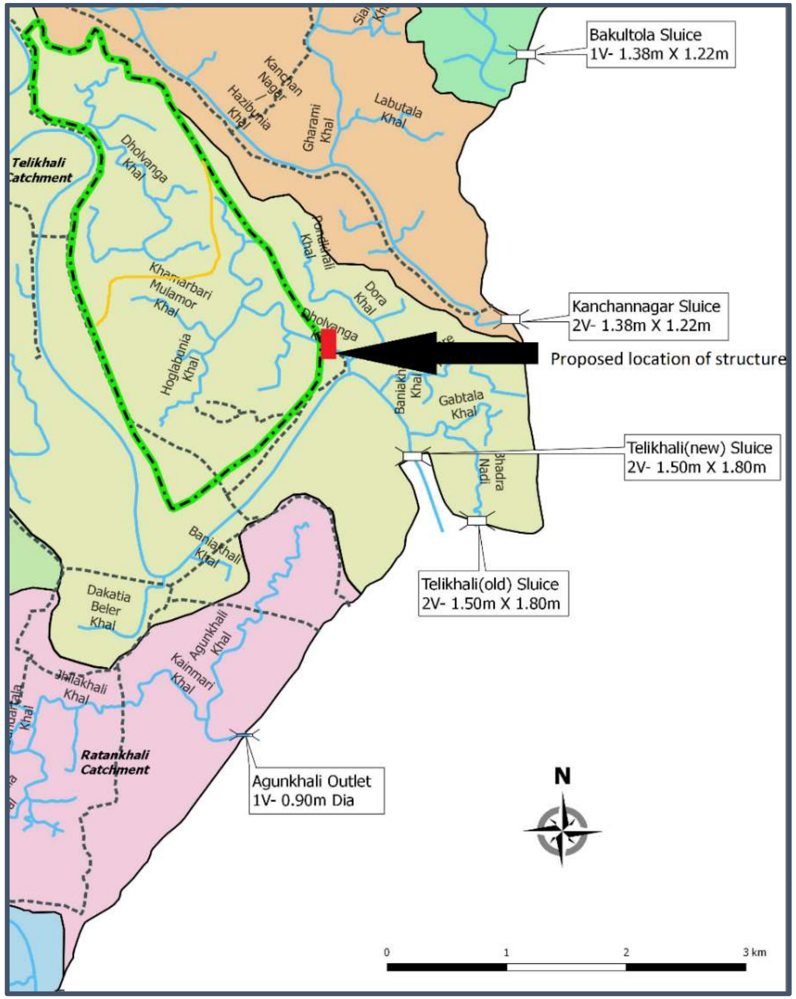


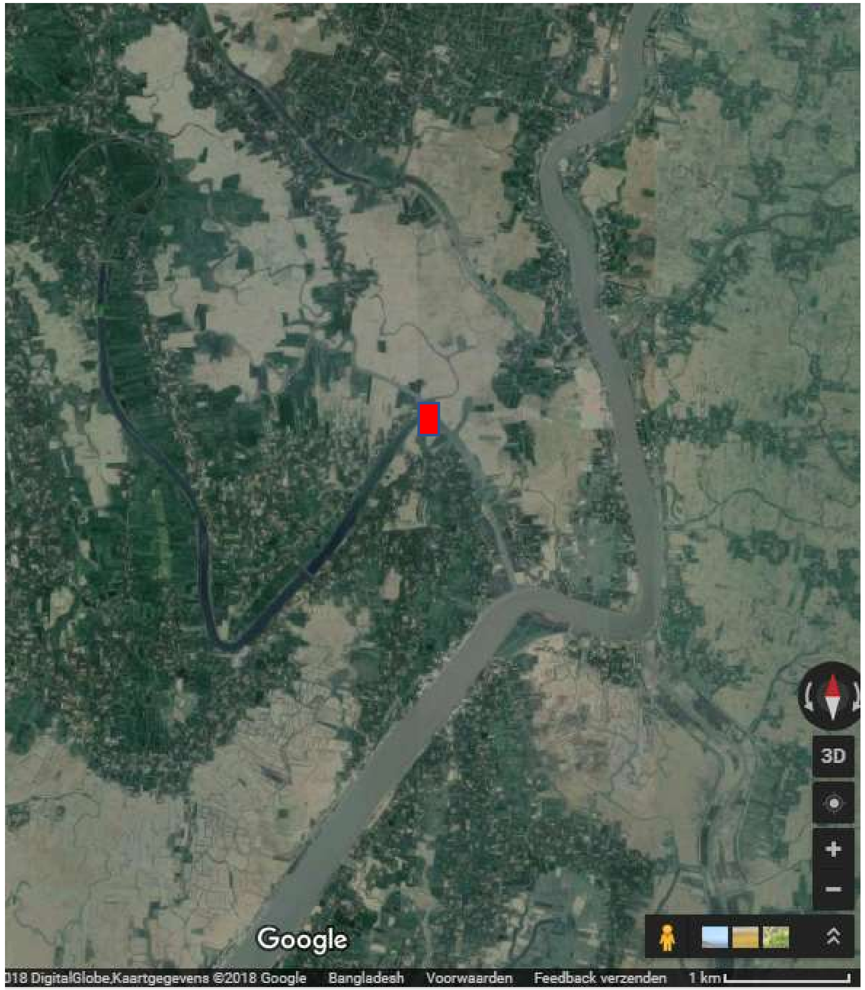
Figure 11 Configuration of WMGs. Red indicates high land (higher than 1.20 m.p.w.d), yellow indicates medium land (0.80 – 1.20 m.p.w.d.) and green indicates less than 0.80 m.p.w.d.

Responsibility for operations and maintenance is developed with

Safety during operation and maintenance has been considered in the design. For example, the platform for the people of the community to work has been discussed with the designer. The community is used to this working platform (similar to sluices) so it has been incorporated in the design.

Annex 1 Location, catchment





Green line demarcates catchment area. Yellow line demarcates other possible catchment area.

Annex 2 Satellite imagery

Boro season crop growth. 22/2/2016

14/3/2018 Boro season

27/11/2014 Aman season

15/11/2016 Aman season

Annex 3 Irrigated area

Assumptions

For the calculation of irrigated area, the daily irrigation demand and water resources are quantified. The following assumptions and limitations are applied

- Boro is the preferred crop by farmers. This gives a conservative estimate of the irrigated area.
- With respect to irrigation requirement in the first months of the Rabi (winter) crop: no water is needed to saturate the ground for planting, transplanting and tillering as this is possible by 'flushing', using the main sluice. The irrigation demand is about 60 days, mostly in March and April.
- Evapotranspiration (ET_0) is about 3 mm/day for vegetables
- Growth stage is mid-season to end of season, giving an crop factor of about 1.15
- The percolation and seepage loss (L) is estimated at 5 mm/day (clayey soils)
- Precipitation (P) during April is about 100 mm. Effective precipitation (P_e) can be modelled with P_e=0.8P-25. This results for April in 55 mm per month and 30 mm in March.
- The khal system can be modelled as a reservoir 30 meters wide (on average) and a length of 2.5 km (surface area: 7.5 ha), with stream bed level at z= -1.5 meter
- It is be assumed that water levels can be raised up to +.5 meter, which is about 0.6 meter higher than average water levels and about 1.6 meter higher than dry season water levels.

Results

The irrigation demand is the following:
$I = ET_0 \times Kc + L - P_e = 3 \times 1.15 \times 30 + 5 \times 60 - 85 = 417 \rightarrow \pm 400$ mm.

The khal storing capacity is:
S = Volume= length x width x depth = 2500 x 30 x 1.5= 112,500 m^3.

It is also expected that groundwater levels will be kept higher because drainage of the area is reduced. If groundwater is on average .50 meter higher, this will account for an estimated extra 100 mm (20% void ratio) water availability. This is especially important in later stages of the crops (when roots have been developed).

Theoretically, the irrigated area for Boro would be:
$Area_{irrigated;boro}$= S/I = 112,500 m^3 / (0.400 m - 0.100 m) = 375,000 m^2

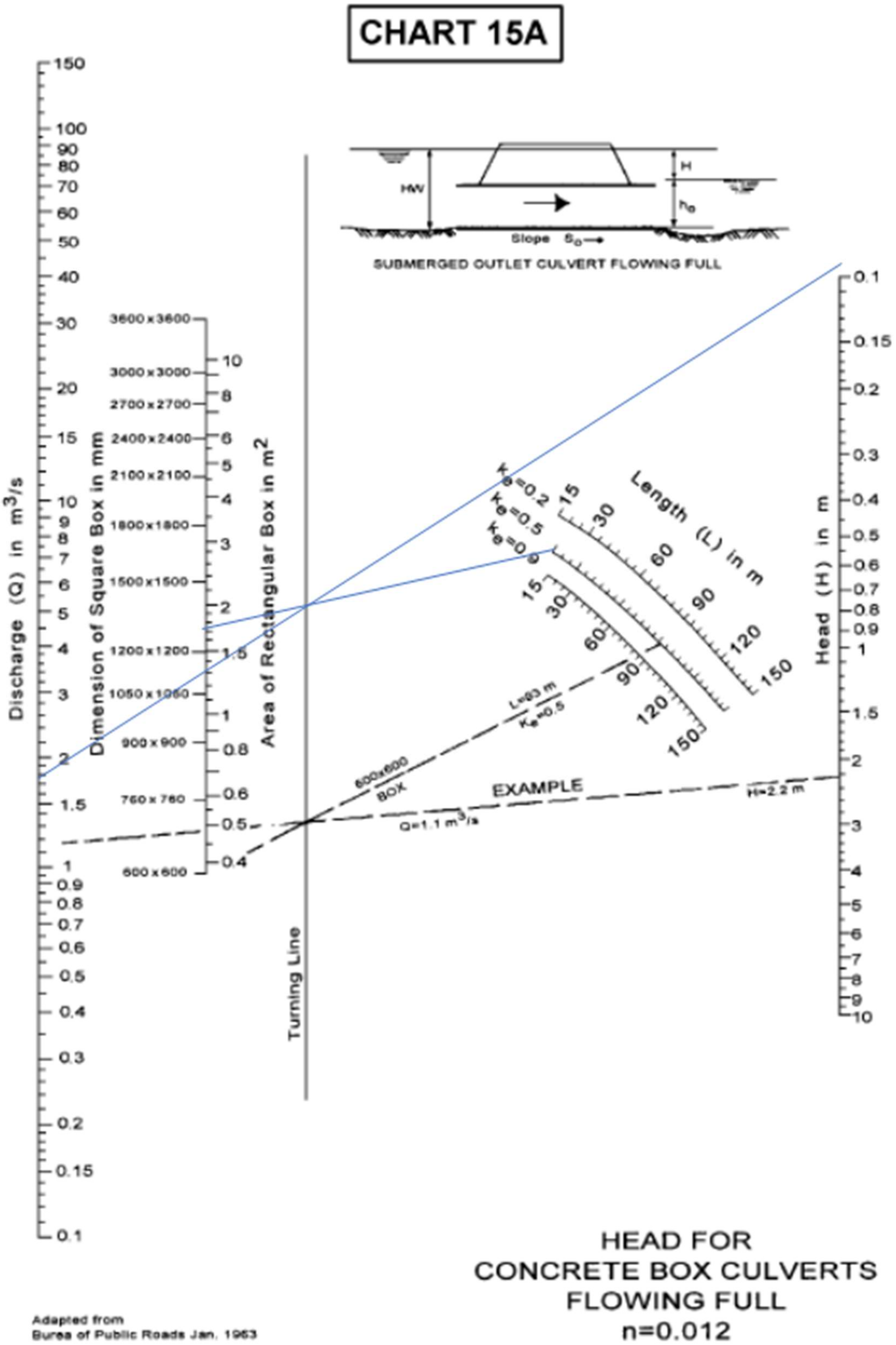
When other, less demanding, rabi crops are grown, this area may be increased.

Cost-benefit

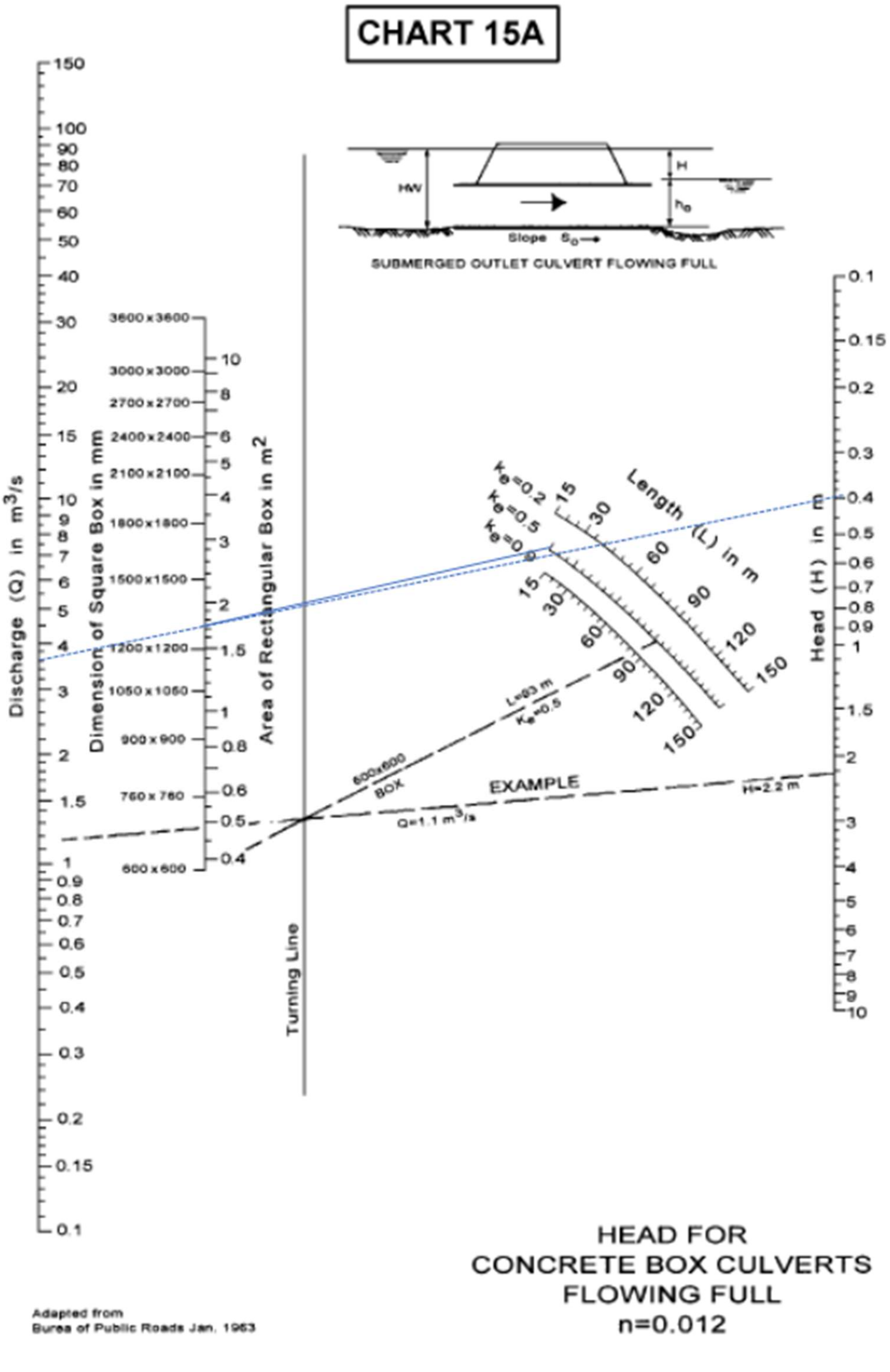
If 50 hectares (see previous paragraph) are to be irrigated, assuming that the yearly returns for the economy (net return + family labour + hired labour) are about 50,000 BDT per hectare (see crop budget Khulna TR26) for Hybrid Boro. The net returns per hectare are about 20,000 BDT. This results in a yearly net return of 50 x 0.2 lakh = 10 lakh, or a payback time of 2.5 years.

Annex 4 Culvert Nomographs

At 1 m/s flow velocity



At maximum flow velocity (2 m/s)



Annex 5 Bearing capacity

	SAND			CLAY
HW	3.1		HW	3.1
TW	0		TW	0
1a define force and effective width			*1a define force and effective width*	
B	4		B	4
L	8		L	8
Hd	153.1954		Hd	153.1954
Vd	1393.699		Vd	1393.699
Eh	1.6		Eh	1.85
Eb	0.175872		Eb	0.203352
EL	0.175872		EL	0.203352
b'	3.648256		b'	3.593296
l'	7.648256		l'	7.593296
1b estimate depth			*1b estimate depth*	
ae/b'	10.94477		ae/b'	10.77989
ze/b'	4.377907		ze/b'	4.311955
1c bearing capacity undrained			*1c bearing capacity undrained*	
su	na		su	15
Yk	21		Yk	17
b	0		b	0
Sc	1.095401		Sc	1.094644
ic	#VALUE!		ic	0.895503
lc	1		lc	1
lq	1		lq	1
	25.506			25.506
Oeff	0		Oeff	0
qu	#VALUE!		qu	75.60122
R	#VALUE!		R	2062.776
1d bearing capacity drained			*1d bearing capacity drained*	
c	0		c	5
	35			20
	0.610865			0.349066
	11.2			7.2
Oeff	0		Oeff	0
	45.9			14.8
	33.1			6.4
	45			3.9
	1.282122			1.191823
	1.273599			1.161851
	0.856899			0.858034
	0.886656			0.897335
	0.89008			0.913377

	0.89008			0.913377
	1			1
	1			1
	1			1
	1			1
	1			1
	1			1
qd	701.2038		qd	118.6784
R	19565.55		R	3238.135
	1 sandpile			0.032429
	all sandpiles			5.999417
	area			32
	replacement ratio			0.187482
	clay			26.00058
	improved			119.0514
	Improved bearing capacity			**3809.645**

Annex 6 Design drawings and cost estimate

Annex 6 Soil test report