A

Project Report

ON

DESIGN OF DISTRIBUTARY HEAD REGULATOR AT RD 250 OF BHADANA CANAL

Submitted in partial fulfillment of the requirements for the award of degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

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MAY 2020

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CERTIFICATE

This is to certify that the project report entitled "Design of Distributary Head Regulator at RD 250 of Bhadana Canal" which is being submitted by Ritik Anand, Anant Kumar and Samyak Jain in partial fulfillment of the requirements for the award of degree of B. Tech. (Civil Engineering) to the Department Of Civil Engineering, Malaviya National Institute of Technology Jaipur, has been carried under my supervision and guidance. This work is approved for submission.

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ACKNOWLEDGEMENT

This project has been an important lesson for us. It has inspired and motivated us for going beyond textbooks to look for answers and reasons. Thus, it is important for us to show gratitude towards all those helping hands and minds without whose contribution we would have been able to achieve this feat.

We would give greatest regards to our supervisor **Dr. Ajay Singh Jethoo**, Department of Civil Engineering whose guidance and timely supervision kept us moving forward in this project work. He showed great support and boosted our confidence even during these exceptional times.

A big share of gratitude goes to our project partners whose contribution was of utmost importance for its completion. We would also thank **Dr. Mahender Choudhary,** Dept. of Civil Engineering, for his contributions throughout the duration of the project work.

We wish that this work inspires the people who study it and who have contributed to it. Last but not the least, we would thank all our seniors and colleagues whose insights and queries on this project kept us going and completing this work.

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ABSTRACT

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May 2020

Design of Distributary Head Regulator at RD 250 of Bhadana Canal

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The design of any hydraulic structure carries an estimate of the quantity of water it is going to operate under. A distributary head regulator is one of the most essential hydraulic structures in the irrigation system for the efficient and effective control of water flowing in the off taking channels. The location, layout and alignment of a head regulator depend upon several numbers of factors. Hence, the hydraulic design of a canal head regulator is a crucial step to ensure the safe operation of the channel which in turn, creates a positive impact upon the capital associated directly or indirectly with the structure.

LIST OF FIGURES

LIST OF GRAPHS

CONTENTS

CHAPTER 1

CANAL REGULATION

I. INTRODUCTION

The water that goes into the main canal from the river has to be distributed into several branches and distributaries in conformation with the relative urgency of demand in different channels. This process of distribution is termed as “regulation”. To circulate the water effectively; the discharge has to be controlled to a desired value. This is achieved by the help of regulator structures. Canal regulation structures are those hydraulic structures which are constructed to control the discharge, flow velocity, or supply level in the irrigation channel. These structures are important for efficient working and the safety of the irrigation channel network.

II. CANAL REGULATION WORKS

Canal regulation structures are hydraulic structures that are constructed to control the discharge, flow velocity, or supply level in an irrigation channel. These structures are essential for the efficient working and also, for the safety of an irrigation channel, by giving total control over the canal. Canal regulation structures can be categorized as follows:

Canal fall: The canal fall (also ‘fall’/ ‘drop’) regulates the supply level in a canal by compensating the change in its bed elevation facilitated by the difference in the ground slope as well as the canal slope.

(i) **Canal escape:** Canal escape transfers the extra discharge when the safety of a canal is compromised due to heavy rains or closing of outlets by the farmers.

(ii) **Distributary head regulator:** This regulates the supply to an off taking channel from the parent channel.

(iii) **Cross regulator:** This structure regulates the water level of the main channel and the discharge flowing downstream of another hydraulic structure.

III. CANAL FALL

A canal fall is a hydraulic structure made across a canal to decrease its water level. This is delivered by compensating the change in bed elevation of the canal facilitated by the difference in ground slope as well as canal slope. The need of a fall arises because usually, the available ground slope is greater than the designed bed slope of a canal. Hence, an irrigation channel which is in cutting in its head reach soon gets into a condition when it has to be entirely filling.

An irrigation channel in embankment has the following shortcomings:

(i) greater construction and maintenance cost,
(ii) more seepage and percolation losses,
(iii) the adjacent area may get flooded due to any possible rupture in the embankment,
(iv) Struggles in irrigation operations.

Therefore, an irrigation channel must not be located on high embankments. Falls are, thereby, introduced at suitable locations to decrease the supply level of the irrigation channel. The canal water immediately downstream of the fall structure carries very high kinetic energy which, if not abandoned, may scour the bed and banks of the canal downstream of the fall. This would also risk the safety of the fall structure. A canal fall must be provided with measures to dissipate excess energy which is the result of constructing the fall.

Fig. 1 Canal Fall

IV. CANAL ESCAPE

A canal escape is a structure to dissipate off the excess water from a canal. A canal escape basically serves as a safety mechanism for the canal system. It maintains protection of the canal against any possible risks due to excess supplies which may be due to either error in releasing water at headworks, or a heavy downpour due to which there may be sudden decrease in demand, forcing the farmers close their outlets. The excess supply makes the canal banks endangered to breaches and, so, provision for disposing of excess supply as canal escapes at desired intervals along the canal is suitable and necessary.

Apart from, emptying the canal for repairs and maintenance and taking out a part of sediment deposited in the canal can also be achieved with the help of the canal escapes. The escapes are commonly of the following types:

(i) **Weir or surface escape**: These are weirs or flush escapes constructed either with bricks or concrete with or without crest shutters that can dispose of surplus water from the canal.

(ii) **Sluice escapes:** Sluices can also be used as surplus escapes. These sluices can empty the canal rapidly for repair and maintenance and, sometimes; act as scouring sluices to help in the removal of sediment.

Location of escape depends on the availability of suitable drains, depressions or rivers with their bed level at or below the canal bed level for disposing of surplus water through the escapes, directly or through an escape channel.

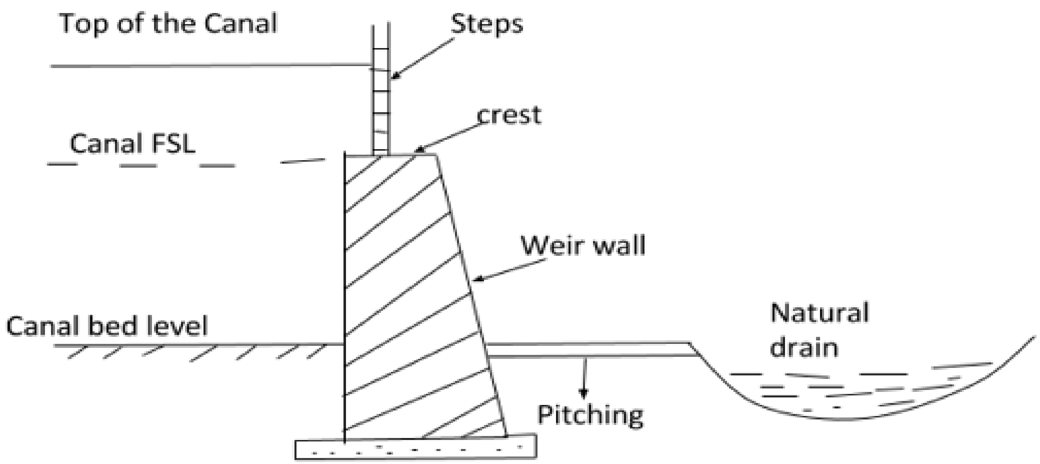


Fig. 2 Canal Escape

V. DISTRIBUTARY HEAD REGULATOR

It is the structure at the head of canal off taking from a reservoir, which can consist of number of spans made by piers and operated by gates. They are normally aligned at 90° to the weir. Approximately up to 10º are considered suitable for smooth entry into canal. The functions of canal head regulator are:

1. To supply water into the off taking canal.
2. To control the discharge into the canal.
3. To measure the discharge passing into the canal from design discharge formula and observed head of water over the crest.
4. To moderate the silt entry into the canal. In times of heavy floods, it should be closed else high silt quantity will enter into the canal.

VI. CROSS REGULATOR

A cross regulator is a structure constructed across a canal to control the water level in the canal upstream of itself i.e. the main canal, and the discharge passing downstream of it for any of the following purposes:

1. To supply water to off taking canals located upstream of the cross regulator.
2. To facilitate water escape from canals alongside with escapes.
3. To regulate water surface slopes in association with falls for helping the canal achieve regime slope and section.
4. To moderate discharge at an outfall of a canal into another watercourse.

Generally, a cross regulator is constructed downstream of an off taking channel because the water level upstream of the regulator can be increased, whenever necessary, to help the off taking channel draw its needed supply even if the main channel is carrying lower supply.
The cross regulator is required in the irrigation systems that supplies water to distributary and

field channels by rotation method and need to provide full supplies to the distributaries even if the parent channel is carrying less supply than full supply. They may be combined with bridges and falls for economy and other special variations.

Therefore, a cross regulator regulates the supply in parent channel, and a distributary head regulator controls the supply of an off taking/branch canal.

Fig. 3 Head Regulator

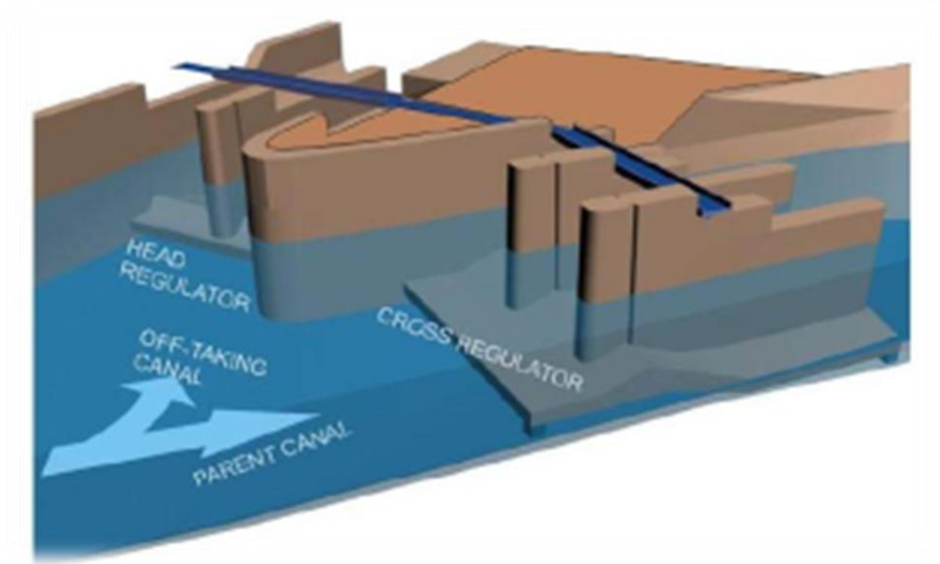


Fig. 4 Cross Regulator

CHAPTER 2

INTRODUCTION TO CANAL REGULATORS

I. OVERVIEW

A canal derives its part of water from the pool behind barrage through a structure known as canal head regulator. Since, it is also a regulation structure for regulating the amount of water passing into the canal; it is also part of diversion works.

Canal regulators are umbrella for cross regulator and the distributary head regulator structures for regulating the flow through a main canal and its off-taking distributary. It also facilitates to maintain the water level in the canal on the upstream side of regulator. Canal regulators being gated structures, can also be combined with bridges and falls for various other purposes too.

II. TYPES OF CANAL HEAD REGULATORS

The common types of canal head regulator methods are:

1. Still pond regulation:
2. Open flow regulation
3. Silt control devices

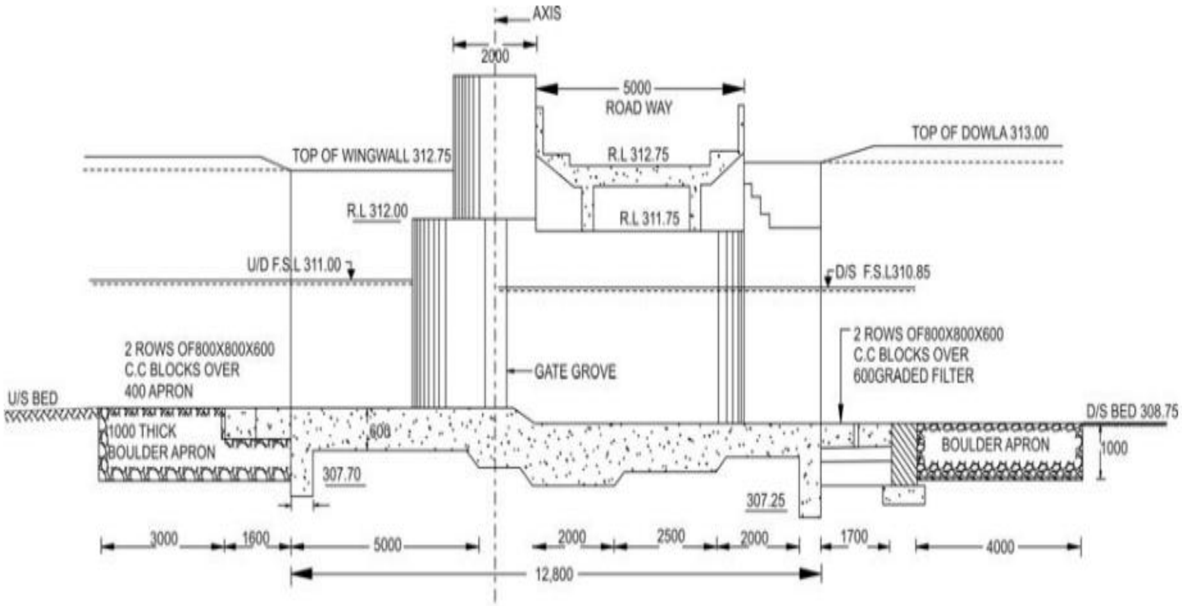


Fig. 5 Typical Section of Head Regulator

A. STILL POND REGULATION

Here, water is obtained by canal from still pond on upstream. Water more than canal requirements are not allowed to pass below the clean gates. Rate of water in the pocket is very much low; silt gets deposited in the pocket.

In still pond case, all the gates of the undersluice bays are kept closed so as to restrict the discharge flowing into the pocket to be same as the canal outgoing. Only the specified discharge must be drawn into the canal and the excess river discharge should be exited through the river sluice bays, if available.

Since the undersluice bays are kept shut, the less velocity in the pocket leads to the sediment settlement and comparatively clear water enters the canal. But, the pocket gets filled with silt in this process after some duration. Then, the canal head regulator gates should be closed and the deposited silt must be ejected by opening the gates of the undersluice bays.

The canal intake could also be stopped during this de-silting operation taking about 20-24 hours. Post sufficient disposal of the deposited silt, again the head regulator gates are opened and undersluices shut. It is desirable where the crest of the head regulator is at an abundantly higher level than that of the upstream floor level of the undersluice bays. After the river stage reaches up to pond level, undersluice gates are opened to avoid overflow.

B. OPEN FLOW OR SEMI STILL OPERATION

In the semi-still-pond operation, the gates of the canal head regulator are kept open for disposal of the silt deposited in the pocket. The gates of the undersluice bays are kept partially open to the minimum required level so as to pass the bed material downstream. The discharge in surplus of the canal requirement is passed through the undersluice bays and silt excluder tunnels.

In the monsoon months, a constant watch is necessary to be kept over the sediment entering the head regulator, part of which may have to be ejected through a sediment extractor, if there, provided in the canal. Also, it has to be made sure that sediment deposition takes place up to the level that can be washed out early in the winters when the full demand arises.

For these conditions to be maintained, the following actions are required:

1. At least once a day, sediment charge is observed for both suspended sediment and bed load in low floods immediately downstream the head regulator, below the silt ejector, if there, and at other sensitive points downstream. The frequency of observations may have to be increased if the conditions change to medium and high floods.

2. The cross section of the canal might have to be taken at some risky points to keep an eye on the extent of sediment deposition occurring in the canal.

3. With the help of gauge observations, water surface slopes at the critical points in the head reaches of the canals have to be monitored regularly.

4. The ponding upstream of power stations must be restricted to the required level so as to avoid dangerous sediment deposition.

5. The canal may even have to be closed from the head in the following circumstances:

• During medium or high flood, exceeding specified sediment charge and then re-opening when the sediment charge drops down below the safe limit. Since the specified limit is governed by the silt carrying capacity of the canal, so it would vary from project to project and must be estimated based on actual data or experience of the engineer.

• The maximum permissible bed level is reached by sediment deposition at the critical points. This limit along with the sediment charge beyond which the canal gates are to be kept shut, may have to be fixed according to monthly variations during the monsoon period so as to be able to satisfy the irrigation/power demands.

The cross flows and vortex formations cause deep scours on both the upstream and downstream of the barrage, leading to erosion or drowning of cement concrete blocks and loose stone aprons, and harming the nose and shanks of guide bunds. Hence, visual inspection of the direction of current and vortex formation during low and medium floods are made. The effects of different patterns of gate operation are observed carefully on the formation of vortices, the engineer-in-charge should efficiently select the correct pattern which leads to only least scour and least shoal formation.

The engineer-in-charge may also have to monitor these shoal formations, changing network of spill channels pattern, etc., which lead to uneven distribution of flows in different bays, cross flow near the barrage floor ends, etc. The shoal formations very near to the barrage can be washed out by efficient gate operation methods.

The pond level is maintained at the minimum required to feed the canal with the needed discharge by suitably operating the gates. Higher pond maintained, higher would be the extent of shoal formation.

C. SILT CONTROL DEVICE OR POST MONSOON OPERATION

The observations of sediment concentration and cross section of the critical points on the canal have to be continued but at less frequent intervals till satisfactory conditions have been achieved. Still or semi-still pond operations have to be continued till the water becomes sufficiently clear with help of sediment excluders or sediment extractions, depending on the excess water available.

When a canal is first opened, a low supply is made to run for at least few hours and the depth should slowly be raised according to the demands. The rate of filling and lowering of the canal must be prescribed and these should not be violated.

Silt is removed from water entering into canal, constructed in the bed in front of canal head regulator. They are designed such that so the silt remains still and the top and bottom layers of flow are kept separate with the least minimum disturbances. The top water moves into canal while the bottom, silt rich part passes through under sluices. There are several tunnels resting on the floor of the pocket of varying lengths. The length of tunnel near the head regulator is equal to the width of head regulator. Hence the tunnel is of different length. The capacity of tunnel is about 20% of canal discharge. The minimum velocity 2-3 m/s is ensured to prevent deposition in tunnel and is kept the same as sill level of canal regulator.

- **Silt extractor or silt ejector:**

  It is a device by which the silt that has already entered the canal is collected or removed. It is constructed on the canal at some point away from head regulator. The horizontal diaphragm is above the canal bed and the canal bed slightly lowered below the diaphragm. Under diaphragm, tunnels are laid which extent the heavily silted bottom water tunnel. There should not be any disturbance of flow at the intake point.

  Sediment rich waters are diverted by curved vanes. The water moves towards the escape chamber: a steep slope to escape channel is given. The streamlined vane passage speeds up the flow through it, thus deposition of silt is avoided (reducing section area increases the flow velocity). The tunnel discharges the water at outlet end via escape channel.

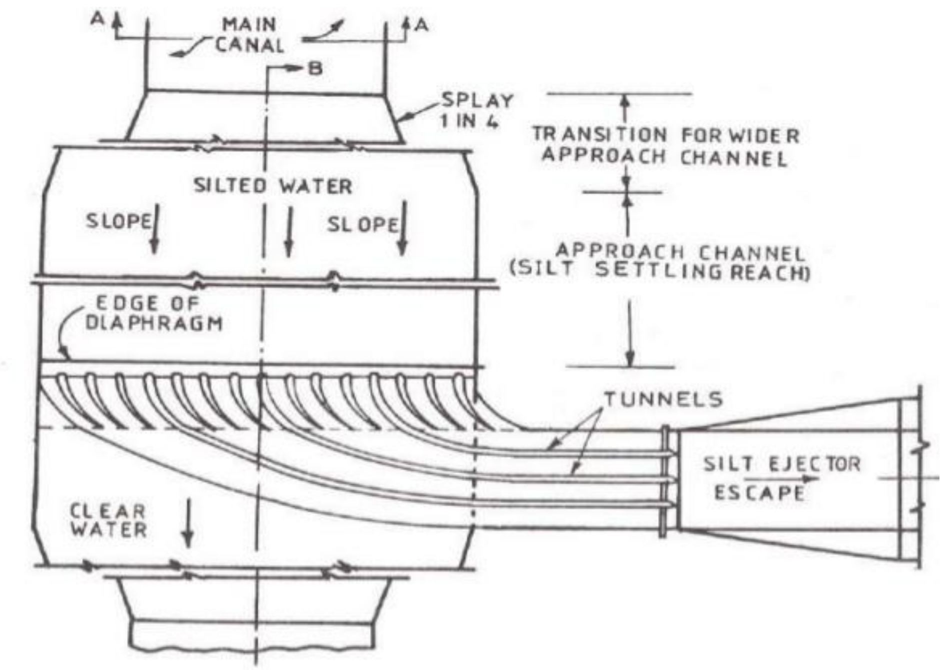


FIG. 6 PLAN OF A
SILT EXCLUDER

FIG. 7 TYPICAL
SILT EXCLUDER

III. ALIGNMENT OF DISTRIBUTARIES

The angle at which a distributary canal separates from the parent canal has to be carefully decided. The most suitable angle is when the distributary takes off smoothly (curves), as shown in Figure 12. Another option is to provide both channels (distributary and main) at an angle to the original direction of the parent canal. When it becomes compulsory for the parent canal to follow a straight alignment, the edge of the canal is prioritized over the centre line when deciding the angle of off-take. To prevent entry of excess silt deposition at the mouth of the off-take, the entry angle is recommended as to be in range 60º and 80º. For the hydraulic designs of cross regulators, we have to refer to the Bureau of Indian Standard code IS: 7114-1973 “Criteria for hydraulic design of cross regulators for canals”.

The water that enters in to the distributary canal from the parent canal may also receive suspended sediment load. The distributary should be designed such that it draws sediment proportional to its flow and thus, maintaining no silting in either the parent canal or itself. To achieve this, following three types of structures have been suggested.

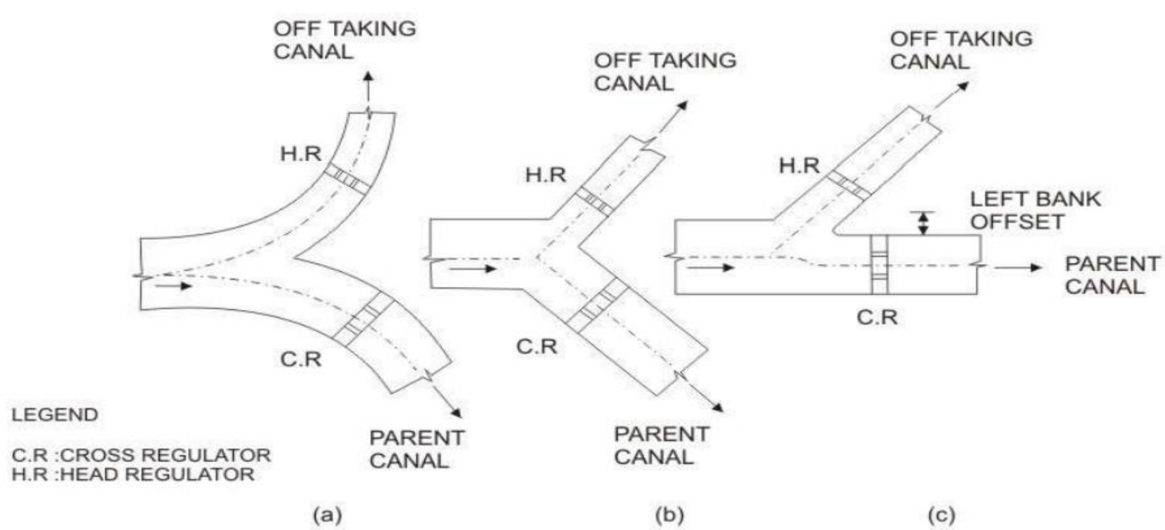


Fig. 8 (a) Smooth off take (b) Both inclined to original flow (c) Parent Canal flows straight with reduced width

IV. LOCATION

The location of diversion work influences the location of canal head regulator. The head regulator should be positioned as near to the diversion structure as possible and if available, preferably at the end of the outer curve which is a convex bend. This is because it will minimize the sediment entry into the off taking distributary.

As per the code, the preferred location of the head regulator is adjacent to the abutment of the diversion structure. However it is not possible in all cases to locate it there, due to some relief features like hills, etc. In those cases, the head regulator has to be located upstream close to the periphery of the pond. But this must not be very distant from the main structure. For smaller discharge requirements, it is also possible to provide the head regulator as an opening in the wing wall of abutment.

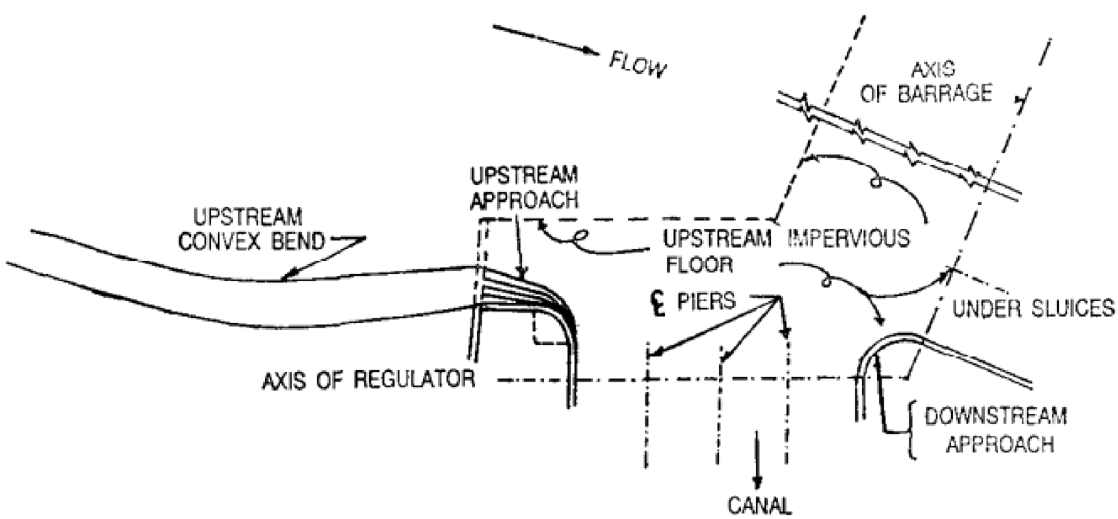


Fig. 9 Canal Head Regulator downstream a convex bends

V. LAYOUT

As per code, the canal head regulator must be so aligned that silt entry into the canal is minimum and it avoids backflow or formation of stagnant zones in the pocket. For these results, the axis of canal head regulator is suggested to be placed at an angle of 90º to 110º with respect to the axis of the diversion work. This angle can be confirmed by model studies. A typical layout of the canal head regulator is given in Fig. 14.

Although this angle is recommended by code, the final layout is invariably tested by model studies that check the various flow combinations of the undersluice gates and the canal regulator gates. The head regulator can be constructed in several ways like, independent of the abutment and separated from it by means of appropriate joints and seals or also it can be monolithic with it. The abutments of regulator can themselves be independent from its floor by longitudinal joints and seals or even be monolithic with the floor of raft of the head regulator and the whole structure can be designed like a trough section (Fig. 15).

The water through a head regulator is regulated usually by vertical lift gates. But, nowadays radial gates are also becoming common. These gates are preferred for headworks which have a comparatively greater difference in elevation between pond level and the canal full supply level. Usually, a road bridge is also designed across a head regulator for transportation or for inspection purposes and it is connected by road to the bridge as desired across the main barrage structure. An operating platform across the head regulator has to be provided for operating the gates.

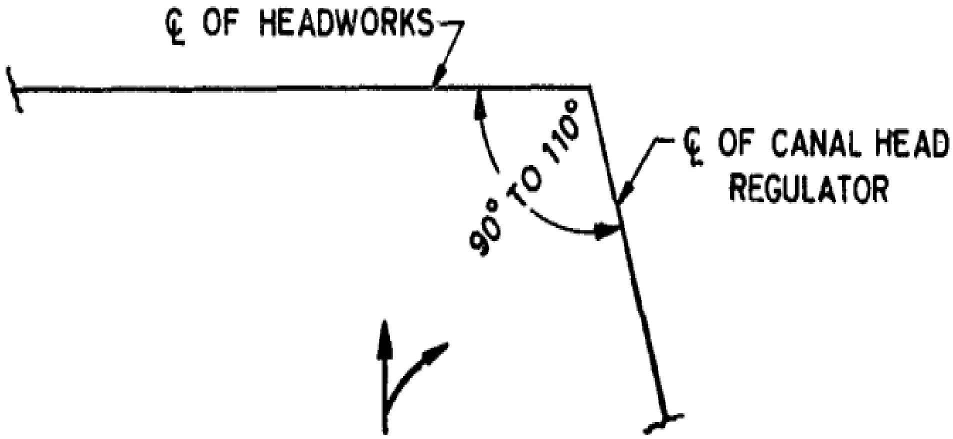


Fig. 10 Alignment of Head Regulator

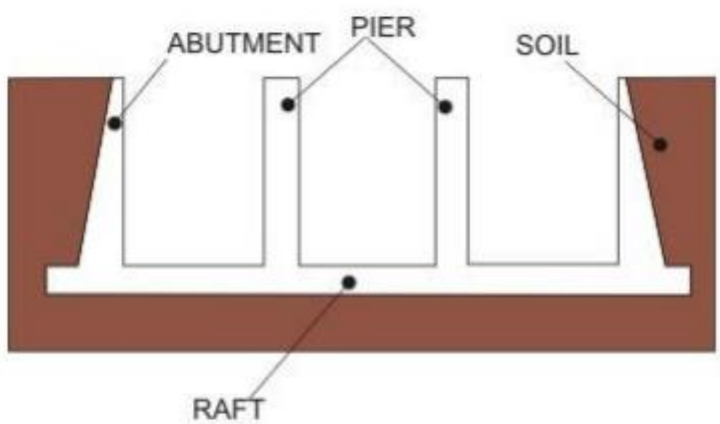


Fig. 11 Head Regulator as monolithic trough section

CHAPTER 3

HYDRAULIC DESIGN

Before beginning a hydraulic engineering project, we need to estimate how much water is involved. This problem is dealt and explained via hydraulic design of the structure.

I. DEFINITION OF VARIOUS TERMS USED

(i) **F.S.L -** Full Supply Level means the level of the water surface when the water storage is at maximum operating level when not affected by flood.

(ii) **Wing wall-** The wing walls prevent scour, soil erosion, retain the embankment adjacent to the culvert, control grade elevations and direct water flow.

(iii) **Apron-** It is an impermeable covering of the bottom of a reservoir adjacent to a dam or some other water-retaining hydraulic-engineering structure. An upstream apron is used to increase the path length of the water seeping through beneath the structure and to reduce the uplift pressure on the bottom of the structure.

(iv) **Sill Level -** Sill Level which refers to the bottom of canal sluice(s) and represents the level up to which a dam can be emptied by flow through gravity. The storage above sill level is known as live storage and that below it is termed dead storage.

(v) **Pond Level-** Pond level is the level of water, immediately to upstream of the barrage. This is required to help the entry of water into the canal with its full supply. The pond level has to be decided judiciously so that the required water can be drawn without any trouble.

(vi) **Crest level-** It is the top most level above which water passes over the sill level.

(vii) **Pier -** A pier is an elevated structure that rises above a body of water and usually projects out from its shore, typically supported by piles or columns, and provides access to offshore areas above water.

(viii) **Abutment-** It refers to the substructure at the ends of a bridge span or dam whereon the structure's superstructure lies.

(ix) **Full Supply Discharge** - The maximum designed capacity of the canal is termed as full supply discharge.

(x) **Bed Level-** The canal bed level lies above the drainage bed level so canal is to be constructed above drainage.

(xi) **Exit Gradient-** The maximum value of hydraulic gradient which results in highest seepage velocity occurring across smallest square of flow net.

II. ELEMENTS OF HYDRAULIC DESIGN

As per IS-6531:1994, "Canal Head Regulators - Criteria for design", the hydraulic design of a canal head regulator consists of the following:

- Fixation of pond level of the pool behind the barrage
- Fixation of crest level, width and shape of sill
- Fixation of waterway, number and width of spans and height of gate openings, requirement of breast wall, etc.
- Shape of approaches and other component parts
- Safety of the structure from surface flow condition
- Safety of the structure from sub-surface flow conditions, and
- Energy dissipation arrangements

III. DESIGN DATA

Name of Project: Design of Distributary Head Regulator at RD 250 of Bhadana Canal

D/S Full supply discharge of Canal(cumecs)	**42.000**
D/S Full supply level of Canal	**170.000**
D/S Bed level of Canal	**165.000**
D/S Bed width of Canal(m)	**8.000**
U/S bed level of Canal	**165.000**
U/S F.S.L. of Canal	**170.000**
Safe exit gradient for canal bed material	**1/7**
Lacey's silt factor	**0.65**
Inlet velocity at U/S (m/s)	**1.150**
Exit velocity at D/S (m/s)	**1.150**

IV. DESIGN STEPS

A. FIXATION OF POND LEVEL

The pond level in the upstream of the canal head regulator is calculated by adding the working head to allow the canal design discharge through the regulator with the water level as the full supply level plus head losses in the regulator. If in some situations there is a restriction on the pond level, the full supply level is determined by subtracting the working head from the pond level.

E28 | =J17

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2	**NAME OF PROJECT :**				Design of Distributary Head Regulator at RD 250 of Bhadana Canal									
3														
4														
5	**DESIGN DATA :**													
6														
7	1	D/S Full supply discharge of Canal								**42.000**	Cumec			
8														
9	2	D/S Full supply level of Canal								**170.000**	m			
10														
11	3	D/S Bed level of Canal								**165.000**	m			
12														
13	4	D/S Bed width of Canal								**8.000**	m			
14														
15	5	U/S bed level of Canal								**165.000**	m			
16														
17	6	U/S F.S.L. of Canal								**170.000**	m			
18														
19	7	Safe exit gradient for canal bed material								**1/7**				
20														
21	8	Lacey's silt factor								**0.65**				
22														
23	9	Inlet velocity at U/S								**1.150**	m/s			
24														
25	10	Exit velocity at D/S								**1.150**	m/s			
26														
27	**(1)**	**FIXATION OF POND LEVEL, CREST LEVEL AND WATERWAY :**												
28		Pond level=		U/S F.S.L=	**170.000**	m								
29		Generally the crest level of the distributory head regulator is kept .3 M TO 1 m higher than its U/S floor level.												
30														

Fig. 12 Design Data and Pond level

B. CREST LEVEL, WIDTH AND SHAPE OF SILL

The sill crest level and waterway are dependent on one another. The sill level should be fixed by subtracting the head over the sill from the pond level as needed to pass the full supply discharge into the canal at a specified pond level. To gain control on the silt entry in the canal it is advisable that the sill of the head regulator is maintained higher than the sill of the under-sluices without any upper limit but minimum 1.2 to 1.5 meters.

If silt excluders are provided, then the crest level of the sill should be kept at about 0.5 meters higher than the top surface of the silt excluders. The required head over sill, H, for passing a discharge Q, with an effective waterway L, has to be worked out from the following formula, which is meant for flow that is uncontrolled (without any gate control).

$$Q = C_d\, L_e\, H_e^{\,3/2}$$

Where Q = discharge in m^3/s

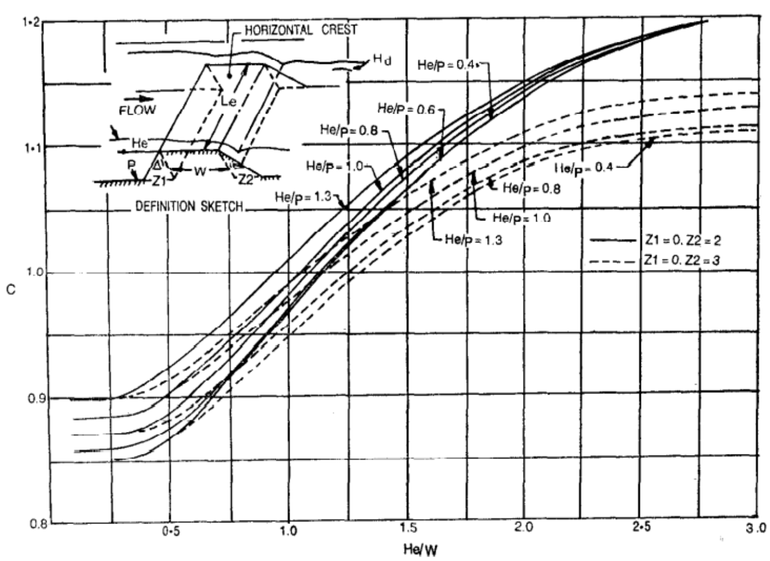
C_d = coefficient of discharge

Le = effective waterway

He = required head over crest for passing discharge Q, in meters

The coefficient C_d is not constant but depends on many factors such as head above sill, shape and width of sill (W), upstream slope (Z_u) and downstream slope (Z_D) of the sill, height above the upstream floor (P) and roughness of the surface.

IS 6531 : 1994



Graph 1. Recommendation for Coefficient of Discharge for varied H_e, P and W

Here, we have adopted crest level as 0.5m above the upstream floor level.

H32 | =J15+J31

	A	B	C	D	E	F	G	H	I	J
27	(1)	**FIXATION OF POND LEVEL, CREST LEVEL AND WATERWAY :**								
28		Pond level=		U/S F.S.L=	**170.000**	m				
29		Generally the crest level of the distributory head regulator is kept .3 M TO 1 m higher than its U/S floor level.								
30										
31		Adopting 0.5m above the floor level				=		165.000	+	0.5
32						=		165.500	m	
33										

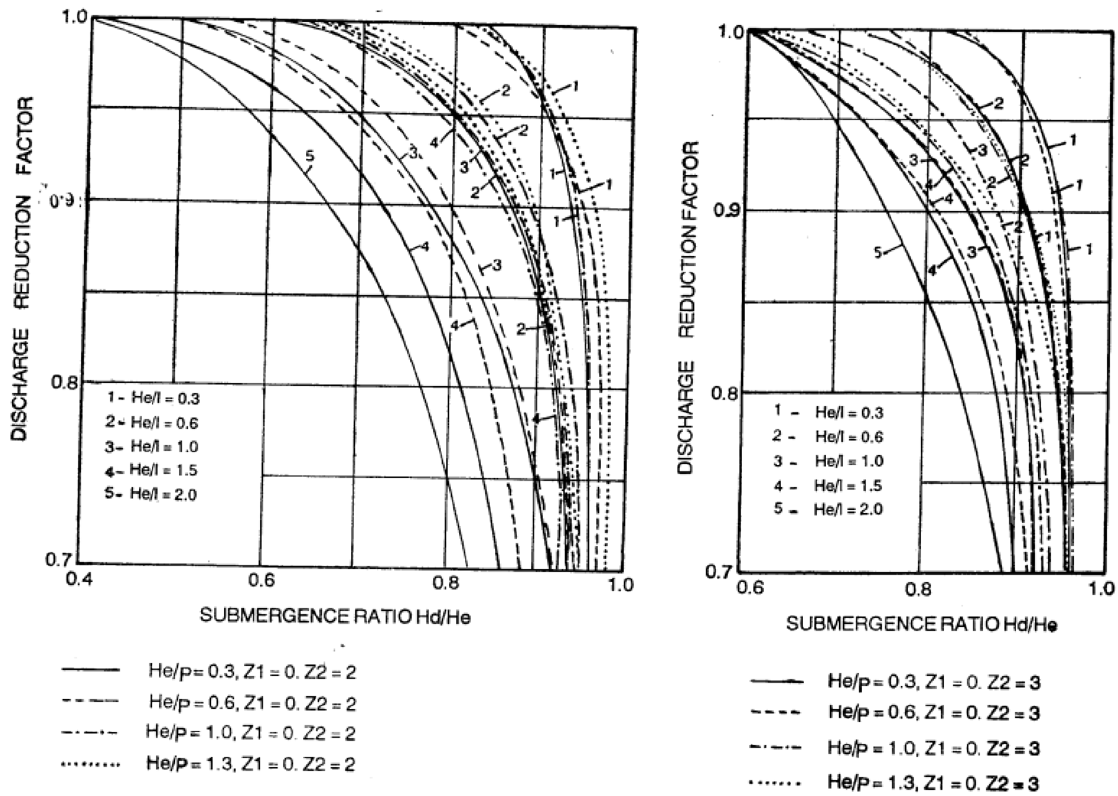
Fig. 13 Crest Level

Further, the calculations of H_e is as follows;

	A	B	C	D	E	F	G	H	I	J	K
34		He	=		F.S.L. of U/S		-	crest level			
35			=		170.000		-	165.500			
36			=		4.500	m					
37											
38		**Width of waterway** can be found out using the formula									
39			$Q = C L_e H_e^{3/2}$								
40											
41		Also, C varies with the ratio of			H_d / H_e	and can also be determined by model studies					
42											
43		H_d	=	Depth of tail water above crest =				F.S.L. of D/S		-	Crest level
44							=	4.500			
45											
46		Therefore,		H_d / H_e	=	1					
47											
48		Hence	C =	1.82	(For sharp crest free fall)						
49											
50		Width of waterway=			L_e	=	2.4175	m			
51		But it should not be less than at least 60% of the offtaking canal i.e.									
52		=	60% of	8.000	=	4.8	m				
53		Adopting,	**4.8**	m as **Effective Width of waterway**							
54											

Fig. 14 Effective waterway and head over crest

A typical set of curves for finding C_d at different values of H_e/P but for $Z_1=0$ and $Z_2=2$ is shown below. Different sets of curves are available for $Z_1=0$ and $Z_2=3$, the details of which may be found in IS: 6531-1994. Also, as the submergence increases, that is H_d/H_e tends to 1, the coefficient of discharge C_d also reduces. (Here, H_d is the downstream water depth above crest and H_e is the upstream total head above crest). The discharge reduction coefficients for various degrees of submergences are shown in Graph 2.



Graph 2. Variation of Discharge Reduction Factor for submerged flow

When the outflow is controlled by partial opening of the gates of the head regulator, the discharge formula for submerged sluice flow has to be used, which is as follows

$Q=2/3(2g)^{1/2} C_d L_e (H_1^{3/2} - H_2^{3/2})$

Where Q = discharge (in m^3 /s)

C_d = coefficient of discharge

L_e = effective waterway (in meters)

H_1 and H_2 = total heads to the bottom and top of orifice

The width of the sill has to be kept according to the requirements of gates, trash rocks and stop logs subject to a minimum of 2/3 He, where He is the total upstream head above crest. The edges of the sill have to be rounded off with a radius equal to He. The upstream face should generally be kept vertical and the downstream sloped at 2H:1V or flatter.

The design is done for the worst of the following two conditions:-

a) Full supply discharge is passing down both the channel with all the gates of cross regulator and head regulator fully open.
b) The discharge in the parent channel is low but the offtake channel is running full, and its FSL is maintained by the partial opening of the gates of the cross regulator.

DETERMINATION OF WATERWAY; NUMBER AND WIDTH OF SPANS

The waterway should be adequate to pass the required discharge through the head regulator without difficulty. After deciding the effective waterway the total waterway between the abutments including the piers have to be estimated from the following formula

$L_t = L_e + 2(N\,\kappa_p + \kappa_a)\,H_e + W$

Where L_t = total waterway

L_e = effective waterway

N = number of piers

κ_p = pier contraction coefficient

κ_a = abutment contraction coefficient

H_e = head over crest, and

W = total width of all piers

Recommended values of κ_p are as follows:-

a) For square nose pier with corners rounded with a radius equal to about 0.1 of the pier thickness: κ_p = 0.02
b) For rounded nose pier: κ_p=0.01
c) For pointed nose pier: κ_p =0.00;

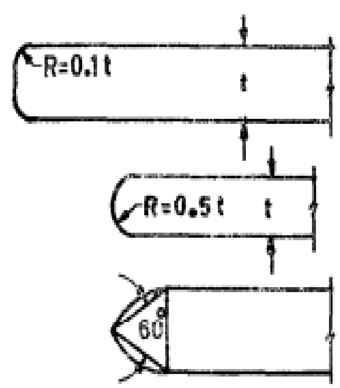


Fig. 15 Values of κ_a

Recommended values for κ_a are:-

a) For square abutments with head walls at 90° to the direction of flow:

$\kappa_a = 0.2$

b) For rounded abutments with head walls at 90° to the direction of flow for $0.5H_e > T > 0.15H$,

κ_a, = 0.1

c) For rounded abutments where $r > 0.5\ H_e$, and head wall is placed not more than 45° to the direction of flow:

Where r= abutment rounding radius.

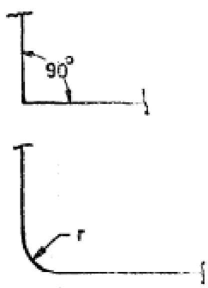


Fig. 16 Values of κ_p

E65 | f_x =C53+2*E36*(D60*D58+D59)+D63

	A	B	C	D	E	F	G	H	I	J	K
44							=	4.500	m		
45											
46		Therefore,		**H_d / H_e**	=	1					
47											
48		Hence	C =	1.82	(For sharp crest free fall)						
49											
50		Width of waterway=			L_e	=	2.4175	m			
51		But it should not be less than at least 60% of the offtaking canal i.e.									
52		=	60% of	8.000	=	4.8	m				
53		Adopting,	**4.8**	m as **Effective Width of waterway**							
54											
55		Total width of waterway ,			x						
56		**$L_T = L_e + 2\ (N\ \kappa_p + \kappa_a) * H_e + W$**									
57		Adopting									
58		κ_p	=	0.01	(Rounded nose pier)						
59		κ_a	=	0.2	(Square Abutments)						
60		Number of piers =		0							
61											
62		Width of sill		=2/3*He							
63		**W** =		3	m						
64											
65		Hence	L_T	=	9.6	m					
66		Adopt	**10**	m							
67											

Fig. 17 Total Waterway (No. of piers = 0)

C. LEVEL AND LENGTH OF DOWNSTREAM FLOOR

For the critical flow condition, q and H_L are worked out. Then E_{f2} is found from plate 10.1. The level at which jump would form, i.e. the level of downstream floor is given by d/s TEL - E_{f2}. Neglecting velocity head, D/S TEL= D/S FSL.

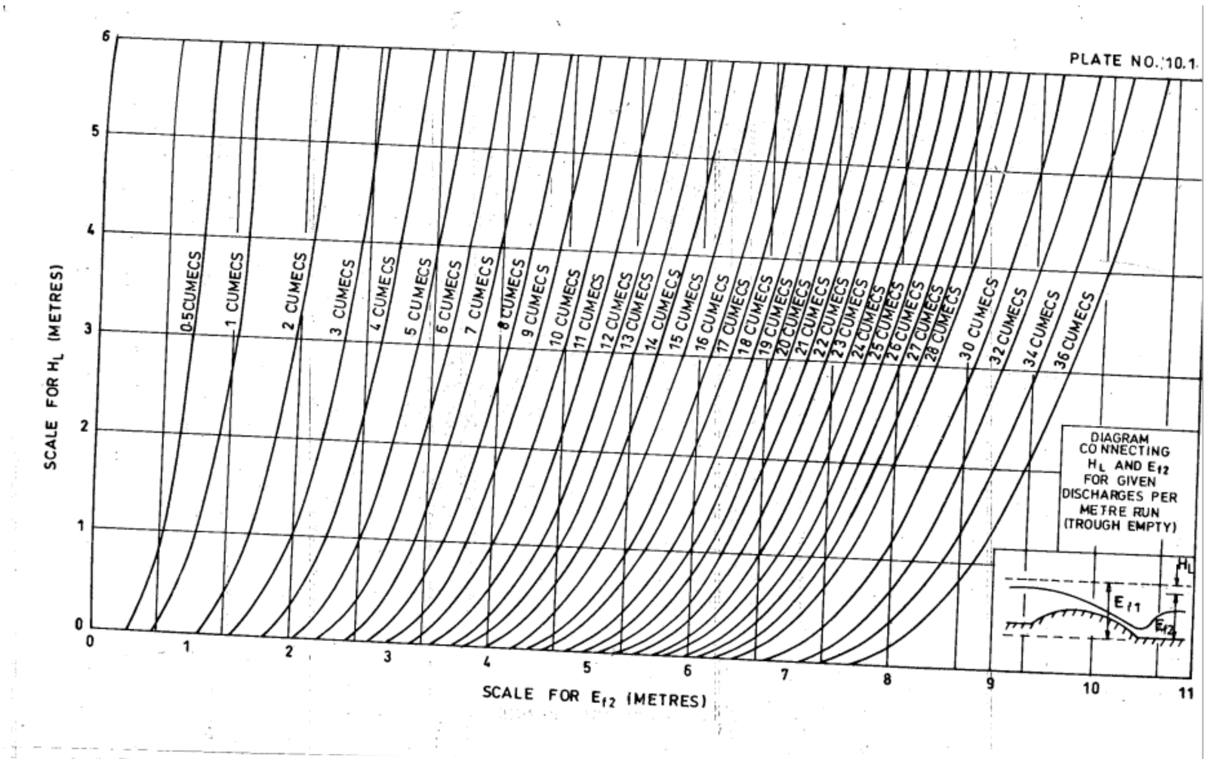
Hence, level of D/S floor = D/S FSL - E_{f2}.

Microsoft Excel - Design of head regulator.xlsx

	A	B	C	D	E	F	G	H	I	J	K	L	M
70	(2)	**LEVEL AND LENGTH OF DOWNSTREAM FLOOR**											
71													
72		Q=	42.000	cumecs		and							
73		L_e =	4.8	m									
74													
75		Discharge intensity=		q=	Q/ Le								
76			=	8.75	cumecs/m								
77													
78		Head loss=		U/S FSL - D/S FSL									
79		=		0.000	m								
80													
81		In weirs, regulators and other hydraulic structures over or through which the flow passes down, energy dissipation is important aspect.											
82		It calls for suitable design of downstream works like sloping glacis, horizontal floor or cistern and other energy dissipaters.											
83													
84		Head Loss	$H_L=(D_2-D_1)^3/(4D_1D_2)$										
85													
86		where	D_1	is the pre jump depth									
87		=	U/S FSL - U/S BED LEVEL										
88		=	5.000										
89													
90		Since head loss = 0											
91		$D_2=D_1$											
92		hence **Length of Cistern Floor required** = 5(D2-D1)											
93		i.e. , = 0 m											
94		This is not in consideration with a minimum of 2/3b											
95		where	b = α d										
96													
97		Location of Cistern Floor would be at =			D/S FSL -		E_{f2}						
98													
99		E_{f2}	can be determined from Blench Curves										
100		For q= 8.75m and HL= 0											
101		E_{f2}	=	3	m								
102													
103		**RL of Cistern Floor =**		167.000	m								

Fig. 18 Level and Length of D/S floor

If the level of D/S floor for the worst condition works out to be higher than the D/S bed level of the channel, the floor is provided at the bed level itself.



Graph 3. Blench Curves (Plate 10.1) for E_{f2}

In this case head loss is zero. Hence $E_{f1} = E_{f2}$ which is equal to 3 meters corresponding to a discharge of 42 cumecs.

Since the D/S floor length calculated here is 0 m, which is not in consideration with a minimum of (2/3b) where b= α d, we will calculate it in the step for calculating the total floor length.

We hence, conclude that R.L. of the cistern floor = 167.000 meters.

D. DEPTH OF SHEET PILES FROM SCOUR CONSIDERATIONS

As per IS 6531:1994, on the upstream side of the head regulator, cutoff should be provided and taken to the same depth as the cut-off stream of diversion work. For head regulators located on non cohesive and erodible foundations, the unlined portion of the floor has to be protected against scour. However, if the head regulator is located on non-erodible beds, then these precautions may not be necessary.

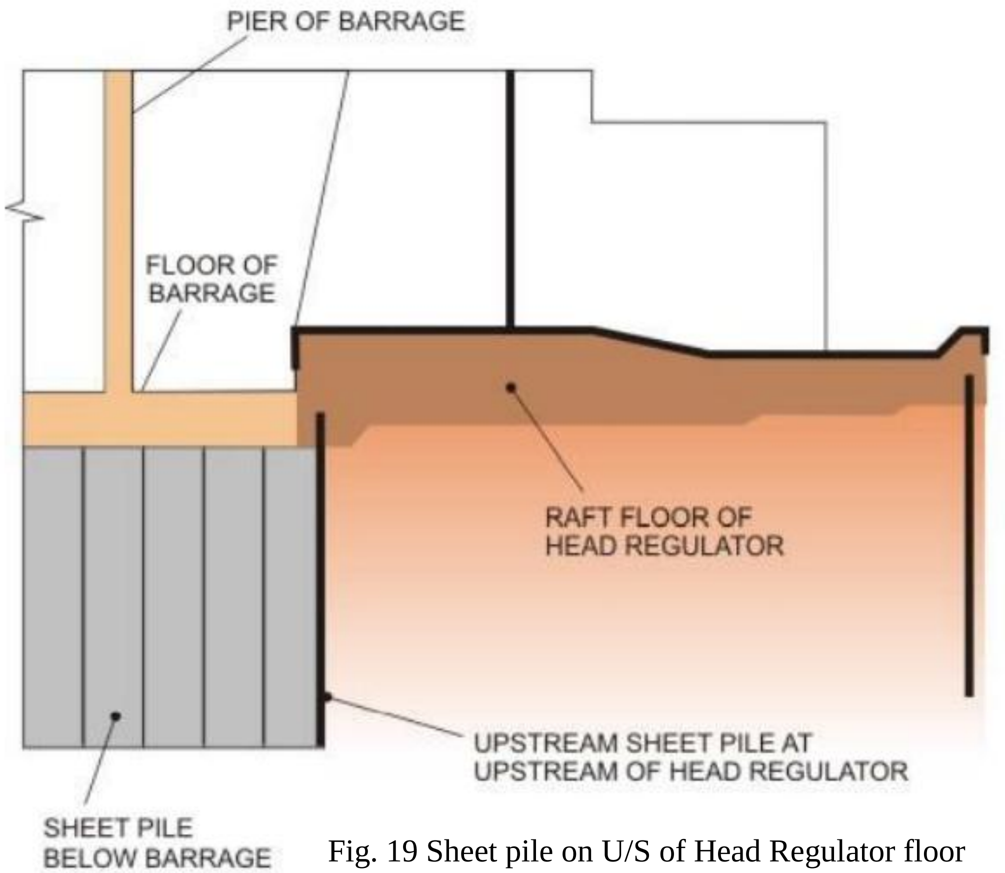


Fig. 19 Sheet pile on U/S of Head Regulator floor

Here, we have considered the anticipated scour as 1.25R on the U/S side and 1.5R on the D/S side, where R= depth of scour and is calculated by $R = 1.35(\frac{q^2}{f})^{1/3}$;

q= Discharge intensity

f= Lacey's silt factor.

Microsoft Excel - Design of head regulator.xlsx

	A	B	C	D	E	F	G	H	I	J	K	L
105												
106												
107	**(3)**	**DEPTH OF SHEET PILES FROM SCOUR CONSIDERATIONS**										
108		U/S SHEET PILE										
109		As per IS 6531:1994, on the upstream side of the head regulator, cutoff should be provided to the same depth as the cut-off										
110		stream of diversion work, if it exists or may be calculated as below										
111		Discharge intensity 'q'			=	8.75	cumecs/m					
112		Depth of Scour 'R'			=	6.616561	m					
113		Anticipated Scour		1.25R	=	8.270701	m					
114												
115		**R.L. of the bottom of the scour hole=**				170.000	-	8.2707011				
116					=	**161.729**	m					
117												
118		D/S SHEET PILE										
119												
120		Discharge intensity 'q'			=	8.75	cumecs/m					
121		Depth of Scour 'R'			=	6.616561	m					
122		Anticipated Scour		1.5R	=	9.924841	m					
123												
124		**R.L. of the bottom of the scour hole=**				170.000	-	9.9248414				
125					=	160.075						
126												
127		Minimum depth of D/S Cutoff below bed level=					$y_d/2 + 0.5$					
128												
129		where	y_d	is water depth in D/S in metres								
130				=	2.5	+ 0.5	=	3	metres			
131		R.L. of the bottom of the scour hole (Min. 1 m belowcistern bed)							166.000			
132												
133		Provide	sheet pile down to elevation =			160.075	m					
134												

Fig. 20 Sheet pile Calculations

The depth of scour increases in the direction of flow, therefore the scour depth is more on the D/S side rather than the U/S side.

The minimum depth of D/S cut off below bed level is given by (IS 6531:1994)

$(y_d/2 + 0.5)$ m where d = water depth in meters corresponding to full supply discharge.

Satisfying these two criteria, the final depth of sheet pile is calculated to be 161.729 m on U/S side and 160.075m on D/S side.

E. TOTAL FLOOR LENGTH AND EXIT GRADIENT

The floor shall be subjected to the maximum static head when the full supply is being maintained in the upstream for running the parent channel and there is no flow through the distributary head.

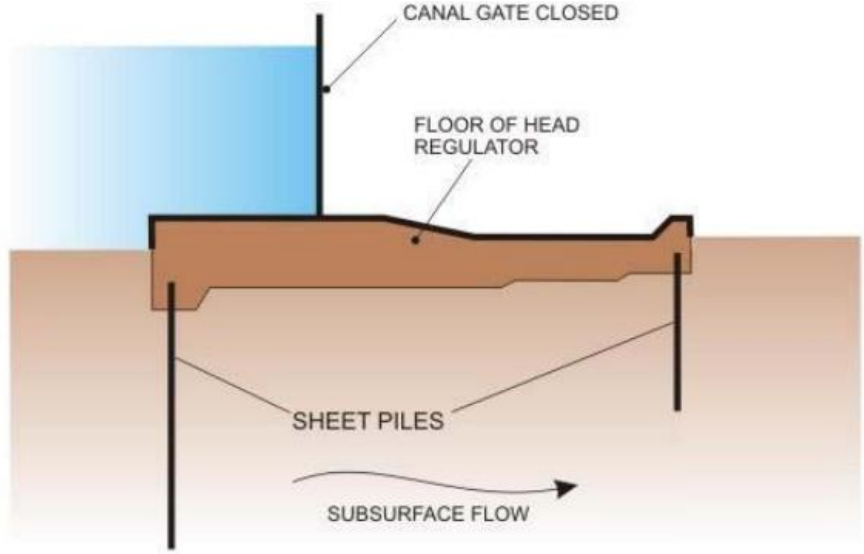


Fig. 21 Critical sub-surface flow

The exit gradient of the uprising seepage flow on downstream of the solid apron is calculated by the formula

$G_E = H/(d * \pi * \sqrt{\lambda})$

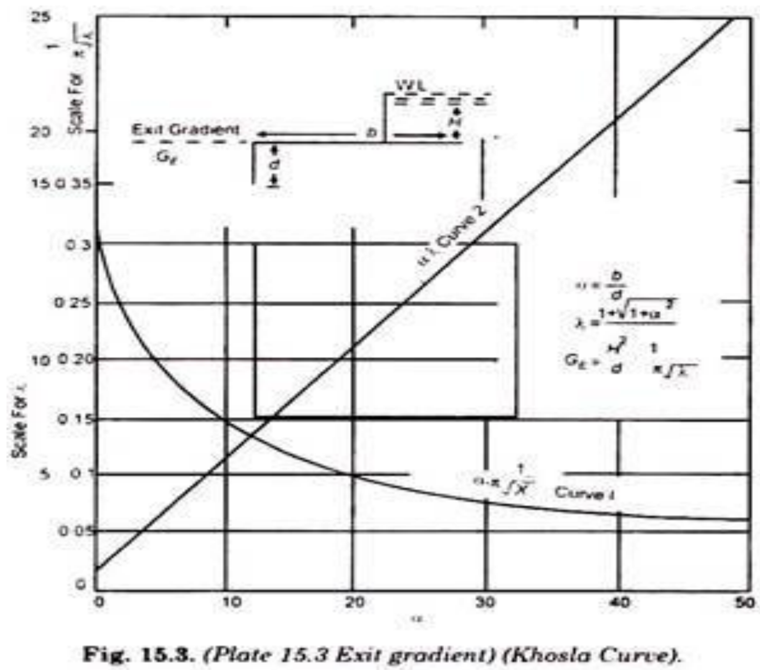
Where G_E= Safe exit gradient

H= Maximum static head

d= depth of D/S cutoff

The exit gradient is ensured safe according to the type of bed material as per the guidelines. The total length of solid floor and depth of downstream cutoff (or sheet-pile), which are inter-related have to be determined from the conditions of Khosla's exit gradient curve. But, we must remember that the total floor length can be reduced by increasing the depth of the downstream cut-off and vice versa, but increase in the depth of downstream cut-off should result in an increase in the concentration of uplift pressures, more significantly in the downstream half portion of the floor.

$\lambda = (1 + \sqrt{1 + \alpha^2})/2$ and α = b/d.



Graph 4. Khosla's Exit Gradient Curves

The required total floor length, "b", is calculated by the above two formulae and then rounded off to upper side.

Hence the total floor length is calculated as follows.

As per IS 6531, the recommended length of the D/S floor is 2/3rd of the total floor length which is 10 m.

Microsoft Excel - Design of head regulator.xlsx

	A	B	C	D	E	F	G	H	I	J	K
135	(4)	**TOTAL FLOOR LENGTH AND EXIT GRADIENT**									
136											
137		The floor shall be subjected to the maximum static head when the full supply is being maintained in the									
138		upstream for running the parent channel and there is no flow through the distributary head.									
139											
140		Maximum static head=			170.000	-	167.000				
141				=	3.000	m					
142											
143		Depth of D/S cutoff =			165.000	-	160.075				
144				=	4.92	m					
145											
146		Since		G_E	$=H/\pi\sqrt{\lambda}$						
147											
148		Hence	$1/\pi\sqrt{\lambda}$	=	$G_E d/H$						
149		where									
150			$\lambda = (1+\sqrt{1+\alpha^2})/2$		and	$\alpha = b/d$					
151											
152			G_E	= Safe exit gradient							
153			d	=depth of D/S cut-off							
154			H	=Maximum static head							
155											
156			$1/\pi\sqrt{\lambda}$	=	0.23						
157											
158		From Khosla's exit gradient curve				α =	3.02				
159											
160		Hence, requirememt of total floor length b= α d					b=	14.87	m		
161		Adopt floor length=		15	m						
162											
163		Therefore, length of D/S Floor= 2/3 * total impervious length									
164				=	10	m					
165											

Fig. 22 Total floor length

Downstream glacis length is taken in the ratio of 2:1. An extra of 3 m is provided to the upstream side as per IS 6531 Clause 4.7.2.1.

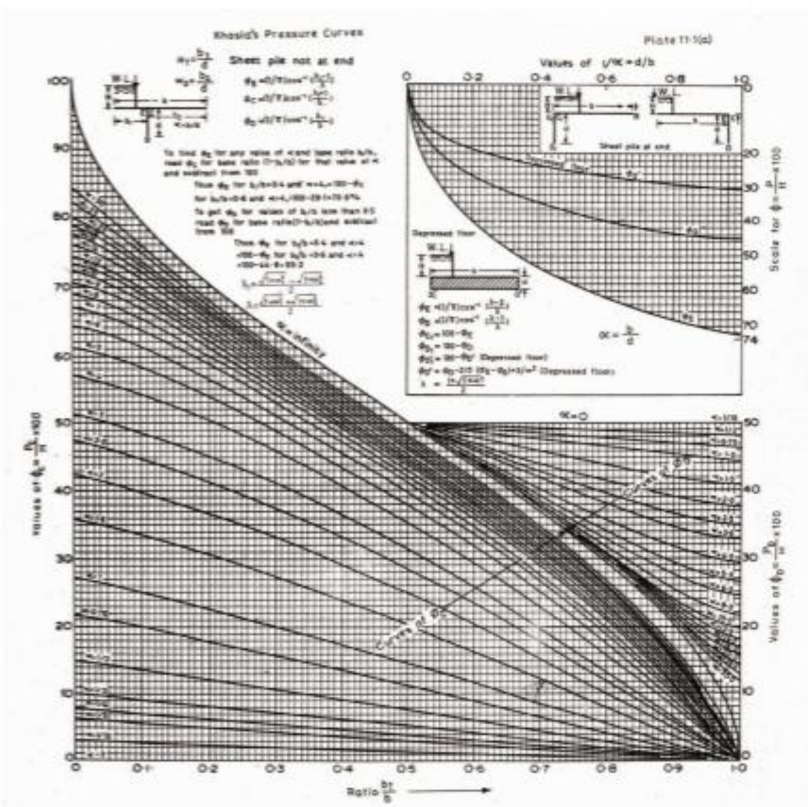
F170 | f_x | =2/3*(J17-H32)

	A	B	C	D	E	F	G	H	I	J
161		Adopt floor length=		15	m					
162										
163		Therefore, length of D/S Floor= 2/3 * total impervious length								
164				=	10	m				
165										
166		The floor length shall be provided as below :-								
167										
168		D/S horizontal floor =				10	m			
169		D/S glacis length with 2:1 slope =				1.00	m			
170		Length of Crest =				3	m			
171		U/S glacis length with 1:1 slope =				0.5	m			
172		U/S floor(extra 3m as per IS 6531) =				3	m			
173		**TOTAL=**				17.50	m			
174										
175		**Provide the total floor length=**				**17.50**	m			
176										
177										

Fig. 23 Total floor details

F. CALCULATION OF UPLIFT PRESSURE

Using Khosla's pressure curves we obtain values of φ_{E1}, φ_{C1} and φ_{C1} (Plate 11.1)



Graph 5. Khosla's Pressure curves

UPSTREAM PRESSURE

The calculations are done based on Method of Independent Variables. The complete profile into simpler parts and then calculations are performed

$\varphi_D = (1/\pi)\cos^{-1}(\frac{\lambda - 1}{\lambda})$ where $\lambda = (1 + \sqrt{1 + \alpha^2})/2$

The thickness of floor at upstream end is taken as 0.5 meter which is the nominal thickness.

	A	B	C	D	E	F	G	H	I	J
176										
177										
178	**(5)**	**CALCULATION OF UPLIFT PRESSURE**								
179										
180		**(i) Upstream cutoff**								
181										
182		Let the thickness of sheet pile = 0.5m								
183		b=	17.50	m						
184		d=	3.27	m						
185		1/α =	=d/b	0.187						
186										
187		From Khosla's Pressure Curve								
188		ϕ_{E1}	=	100%						
189		ϕ_{D1}	=	=100-ϕD						
190		ϕ_{C1}	=	=100-ϕE						
191										
192		**ϕ_D =**	$(1/\pi)\cos^{-1}(\frac{\lambda-1}{\lambda})$		λ=1+ $\sqrt{1+\alpha^2}$ /2					
193										
194		λ=	3.222							
195		Hence	ϕ_D =	0.258						
196		ϕ_{D1}	=	74.208						
197										
198		ϕ_E	=	0.376						
199		Hence	ϕ_{C1} =	62.361						
200		Assume	U/S floor thickness near cutoff			=	0.5	m		
201		Correction to ϕ_{C1} due to floor thickness				=	1.811	%(+ve)		
202										
203		*Correction due to D/S pile is neglected*								
204										
205		**ϕ_{C1}**	**(corrected)=**		**64.172**	%				
206										

Fig. 24. Uplift pressure (Upstream)

DOWNSTREAM PRESSURE

Similar calculations are made on the downstream side. In both the cases, the correction due to the mutual interference of sheet piles is ignored. The correction although is given by the formula

$$C = 19\sqrt{\frac{D}{b'}}\left(\frac{d+d}{b}\right)$$

Where b'= distance between the pile lines

D= Depth of pile line, measured below the level at which interference is studied

d= depth of pile under study

b= total floor length

F220 f_x =(D214-D215)/C210*E218

	A	B	C	D	E	F	G	H	I
206									
207		**(ii)Downstream Cutoff**							
208									
209		b=	17.50	m					
210		d=	4.92	m					
211		1/α =	=d/b	0.281					
212		λ=	2.346						
213		From Khosla's Pressure Curve							
214		ϕ_{E2}	=	45.314					
215		ϕ_{D2}	=	30.567					
216		diff.	=	14.748					
217									
218		Assume D/S floor thickness=			0.8	m			
219									
220		Correction to φE due to floor thickness=				2.3957	(-ve correction)		
221									
222		**ϕ_{E2}**	**corrected**	42.92	%				
223									

Fig. 25 Uplift pressure (Downstream)

G. FLOOR THICKNESS

The upstream floor thickness is taken to be 0.5 m as nominal thickness and thickness under crest is taken as 0.8 m.

	A	B	C	D	E	F	G	H	I	J
224	**(6)**	**FLOOR THICKNESS**								
225										
226		Min. thickness of U/S floor=			0.5	m	Let			
227										
228		Thickness under crest=			0.8	m	Let			
229		Thickness under toe of glacis=								
230		% pressure=		=40.46+(66.32-40.46)/20*10=			55.06	%		
231										
232		Maximum Unbalanced head due to static head=					1.652	m		
233										
234		Dynamic head will be zero. Hence Static head is deciding one.								
235										
236		**AT TOE OF GLACIS**								
237		Thickness=		1.271	m	**Provide=**	**1.300**	m		
238										
239		**AT**	3	**m BEYOND TOE OF D/S GLACIS**						
240		% pressure=		51.42	%					
241										
242		Thickness=		1.187	m	**Provide=**	**1.200**	m		
243										
244		**AT**	6	**m BEYOND TOE OF D/S GLACIS**						
245		% pressure=		47.78	%					
246										
247		Thickness=		1.103	m	**Provide=**	**1.200**	m		
248										
249		**AT**	9	**m BEYOND TOE OF D/S GLACIS**						
250		% pressure=		44.13						
251										
252		Thickness=		1.018	m	**Provide=**	**1.100**	m		
253										
254										
255										

Fig. 26 Floor Thickness

The dynamic head considerations are ignored because head loss is zero. Hence, using the pressure calculations of previous steps we calculate the thickness of floor at intervals of 3 meters from the D/S glacis toe.

The % pressure is calculated using interpolation for length variation.

% pressure= $\varphi_{E2} + (\varphi_{C1}-\varphi_{E2})*(b-x)/b$

Where b= total floor length

x= distance from toe of glacis

H. DOWNSTREAM PROTECTION

As per code recommendation, the scour depth for which downstream protection is provided

D= (y_d/2 +0.6) meters

INVERTED FILTER AND C.C. BLOCKS

C.C. Blocks of suitable dimensions is provided so as to dissipate the kinetic head and protect D/S scouring. These are provided for the length of the inverted filter.

Assume the thickness of inverted filter as 600 mm and 600 mm as height of the C.C. blocks with gaps of 100 mm.

Length of inverted filter= 1.5 D (IS 6531 CLAUSE 4.6.4)

The graded inverted filter should conform to the following design criteria:

$$\frac{D15\ of\ filter}{D15\ of\ foundation} \geq 4 \geq \frac{D15\ of\ filter}{D85\ of\ foundation}$$

The subscript to D (15 or 85) means the grain size than which the percentage indicated by the subscript is finer.

LAUNCHING APRON

Provide 1.2m thick launching stone on length= 2.25 D cu. m/meter

This formula is derived with assumption that launching apron is at slope of 2:1 i.e. length of apron is $\sqrt{5}$ ~ 2.25 D.

256											
257											
258	(7)	**DOWNSTREAM PROTECTION**									
259											
260		The D/S protection shallbe provided for a scour depth(D)=									
261			y_d/2 +0.6=	1.85	m						
262											
263		***Launching Apron***		Provide 1.2m thick launching stone on length=				$\boxed{\text{2.25 D cu.m}}$	/metre		
264					=	3.469	m				
265											
266				**Provide**	**3.500**	m					
267											
268		***Inverted filter***		Provide	1.5D	=	2.775	i.e.	**2.8**	m length	
269											
270		***C.C. Blocks***		Let us provide C.C. blocks of size 0.7m * 0.7m *0.6m for a length of							
271				D= 1.5*	1.85	=	2.775	m			
272											
273			Provide	**4**	rows	**of size 0.7m * 0.7m *0.6m for a length of blocks with 10 cm**					
274			**gaps in between laid over an inverted filter of 0.6m thickness in a total length**							**3.1**	metres
275											

Fig. 27 Protection works

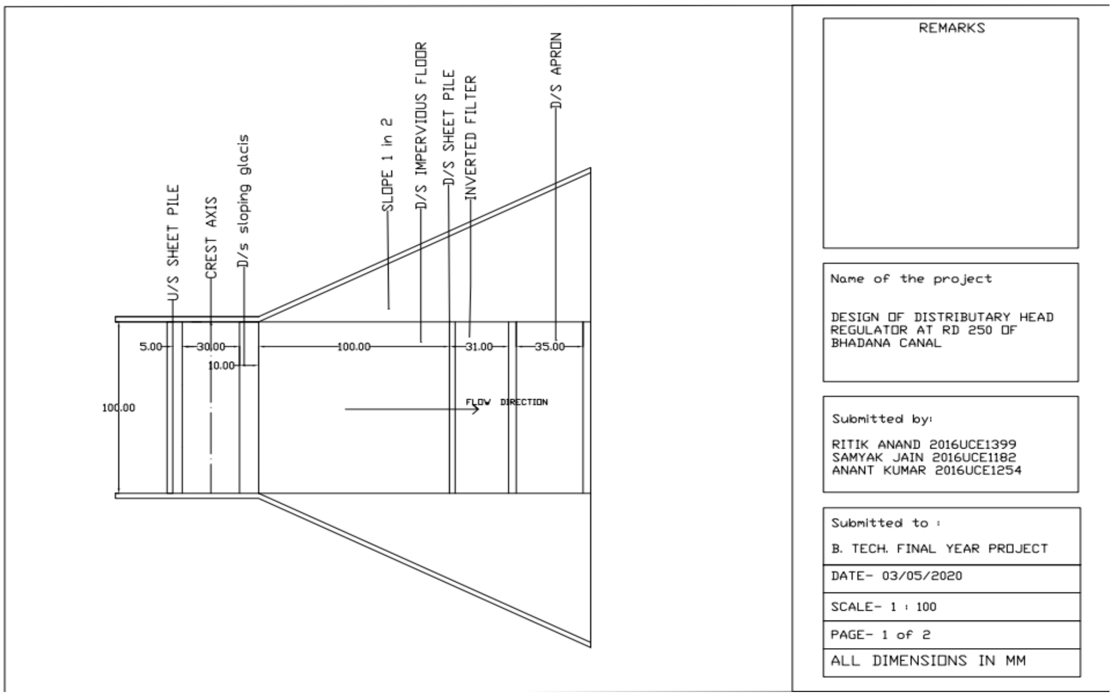
Hereby, the necessary steps of Hydraulic design are completed.

CHAPTER 4

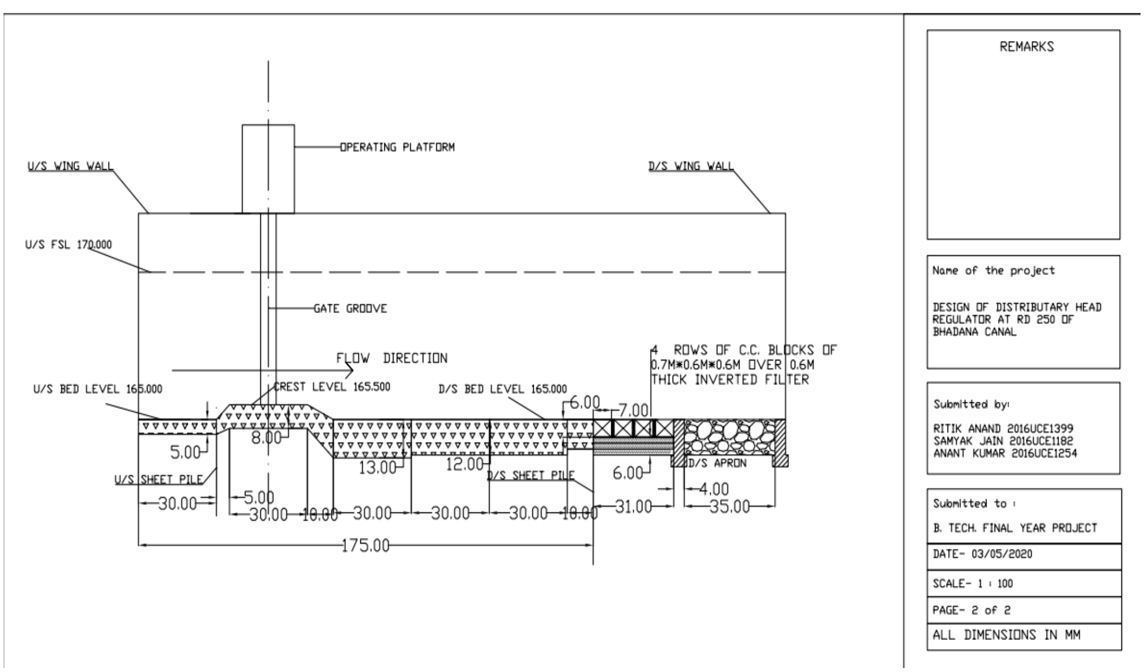
RESULT AND DISCUSSION

ELEMENTS	DIMENSION
RL Pond Level	170.000 meters
RL Crest level	165.500 meters
Effective Width of waterway	4.8 meters
Total width of waterway	10 meters
RL cistern floor	167.000 meters
RL of U/S sheet pile scour	161.729 meters
RL of D/S sheet pile scour	160.075 meters
Total floor length	17.5 meters
Impervious Floor length	10 meters
Thickness of D/S floor beyond toe of Glacis (0 to 3, 3 to 6, 6 to 9 and 9 to 10 meters)	1.3, 1.2, 1.2 and 1.1 meters respectively
Length of Inverted Filter	2.8 meters
Launching Apron	3.5 meters

As we see that there is no head loss as per given design data, the hydraulic design simplifies to the above results. The details of piers’ design and the shape of transitions from U/S side would be a further matter of study. The drawings are as followed.



1PLAN



2SECTION

CHAPTER 5

LIST OF REFERENCES

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3. NPTEL Module 4 Lesson 3
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