Canal Regulator

By

Dr G Sreenivasulu

Canal Regulator

- Regulators are required on a channel to regulate the supply of water.

- It is a structure at the head of canal taking off from a reservoir may consists of number of spans separated by piers and operated by gates.
- Regulators are normally aligned at 90° to the weir. Up to 10'' are considered preferable for smooth entry into canal. These are used for diversion of flow. Silt reduces carriage capacity of flow.

Canal Regulator

Head Regulator

- Constructed at the head of a distributary (or a branch canal) to control and to regulate the flow of water into the distributary.

Cross Regulator

- Constructed across the parent channel at the d/s of the offtake point of the off-taking canal.
- It raises the water level in the parent channel when its discharge is less than the full supply discharge.

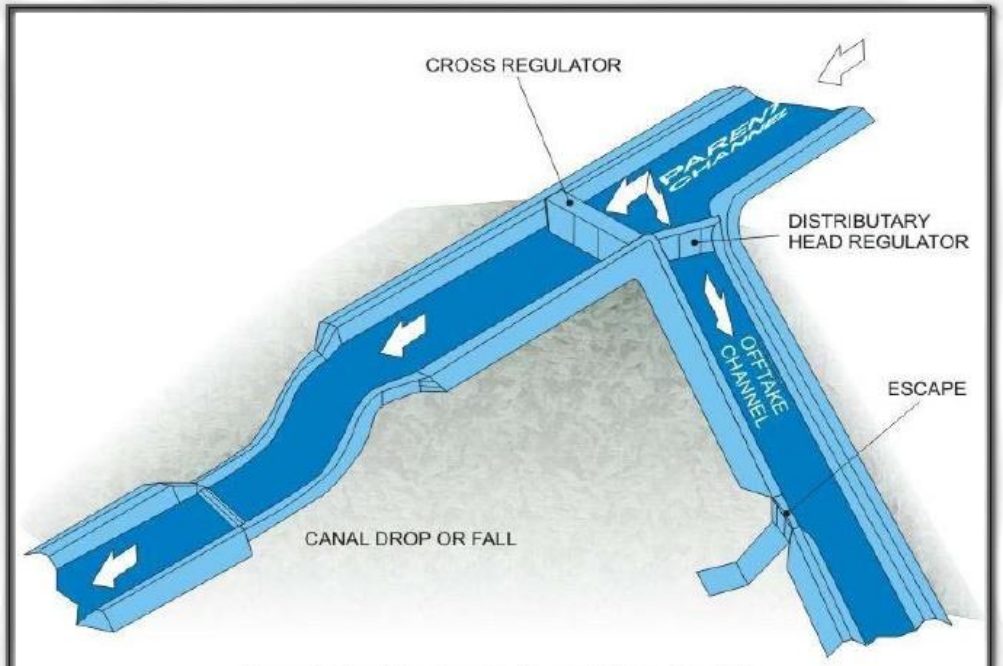


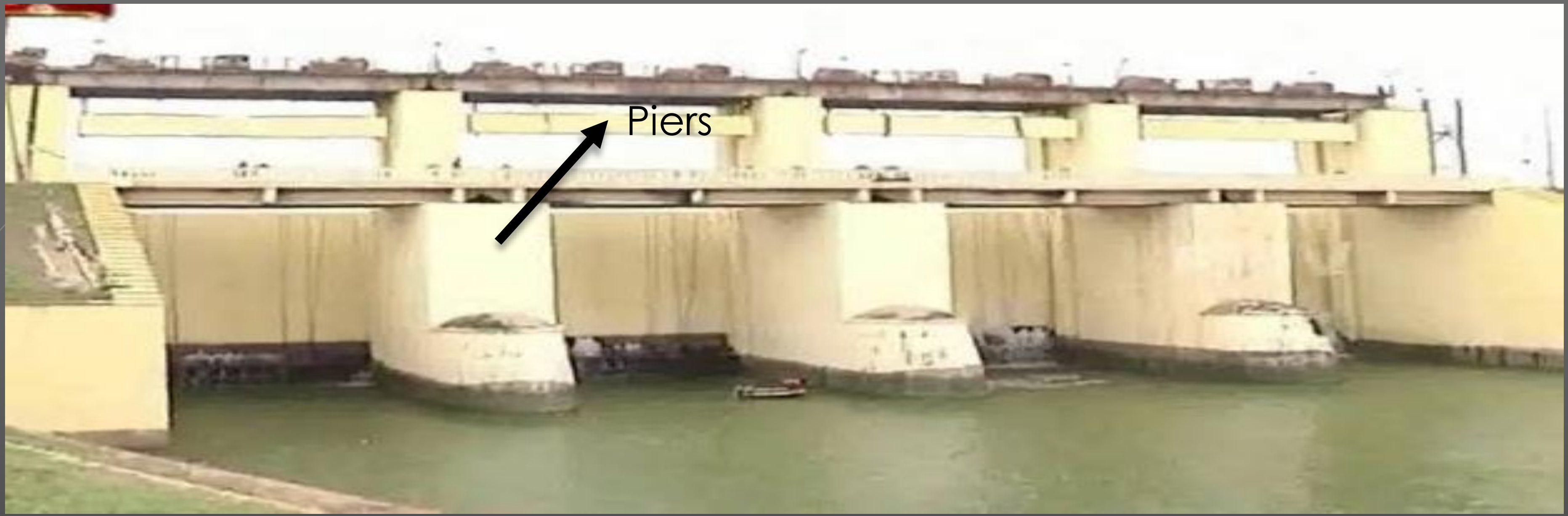
Figure 1. Canal structures for flow regulation and control

Functions of Head Regulator

- To admit water from the parent canal into the off taking canal.
- To regulate the supplies into the canal.
- To indicate the discharge passed into the canal from design discharge formula and observed head of water on the crest.
- Used for shutting the supply into the off-taking channel when water is not needed or during maintenance works.
- To control the silt entry into the canal. During heavy floods, it should be closed otherwise high silt quantity will leave to the canal.

Functions of Cross Regulator

- To raise the water level in the parent channel to feed the off-taking channel.
- To shut the supply in the parent channel on its d/s for repairs.
- Usually a bridge is combined with cross regulator for communication.
- Helps in absorbing fluctuations in the canal system and in preventing the possibilities of breaches in the tail reaches.
- Useful for the effective regulation of entire canal system.


Piers


Shutters
D/S Wing
Walls

Introduction

- Regulators across canals are necessary to maintain water levels in the canal along a particular reach.
- Generally they are constructed below a major off-take, or at a place where the canal hydraulic particulars change.
- Below a major take-off, the dis-charge in the canal gets reduced and so the canal section is reduced by either reducing the depth of flow or by reducing the bed width or both.
- In order to regulate the flow from one reach to another, the regulators with shuttering arrangements to control the flow, play most important part.
- A bridge-cum-regulator is essential with enough clear vent way to pass the necessary discharge into the canal from its upstream side to the downstream side.

Design a regulator-cum-road bridge with the following data:

Hydraulic particulars of canal upstream:

- Full supply discharge: 20 cubic meters/second
- Bed width: 15 meters; Bed level: + 20.00
- F.S. depth: 2.00 meters; F.S.L: +22.00
- Top level of bank: 23.00
- The right bank is 5 meters wide and left bank is 2 meters wide

Hydraulic particulars of canal downstream:

- Full supply discharge: 16 cubic meters/second
- Bed width: 15 meters; Bed level: 20.00
- F.S. depth: 1.75 meters; F.S.L: +21.75
- Top level of bank: +22.75
- Top widths of banks are the same as those on the upstream side. The regulator carries a road way single lane designed for L.R.C. loading class ‘A’. Provide clear freeboard of one meter above F.S.L. for the road bridge.
- Good foundation soil is available at + 19.00
- Assume the ground level site as + 22.00

Design Steps

- Ventway Of The Regulator
- Fixing The Ventway By Drowning Method
- Downstream Of Regulator
- Roadway
- Pier
- Shutters
- Abutments
- Wing Walls
- Solid Apron For The Regulator
- Revetments

VENTWAY OF THE REGULATOR

- Quantity of water to be passed through the regulator into the downstream of canal is 16 cubic meters/second.
- Depth of water in the canal below is 1.75 meters.
- Depth of ventway is therefore 1.75 meters. Applying the formula

$Q = C_d A\sqrt{2gh}$ (Submerged orifice formula)

- where Q is the discharge in cubic meters/second = 16 m^3/s

  C_d = Coefficient of discharge = 0.75 (assume)

  A = Area of vent in square meters, and

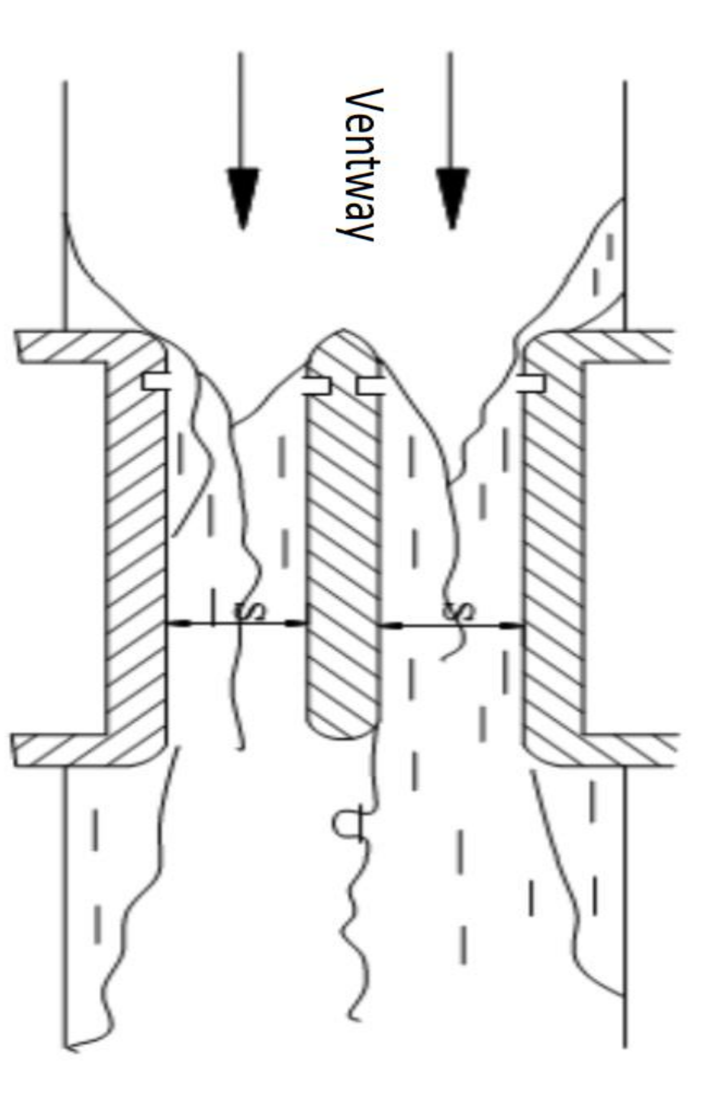
  h = difference in water elevations in meters = 0.25 m.

$\therefore 16 = 0.75A\sqrt{2 \times 9.8 \times 0.25}$

$\therefore A = \frac{16}{0.75\times\sqrt{4.9}} = 9.64\ sq.m.$

Height of the vent = 1.75 m.

- Length of Vent = $\frac{9.64}{1.75} = 5.5\ m.$
- Instead of having one span of 5.50 meters, it is better to adopt smaller spans both for economy of the top roadway and also for the convenience with which the smaller shutters can easily be operated. So adopt two spans of 2.75 meters each.
- From the above, it can be seen that the canal water way has considerably constricted. The ratio of constriction is $\frac{5.5}{15}$ i.e., nearly 37 per cent.
- Note :
  - Any constriction of less than 60 to 50 per cent is considered too severe and not desirable as eddies are formed both upstream and downstream during flow and may cause considerable dynamic scours in rear.
  - To avoid this trouble, the sill of regulator is raised and length of vent correspondingly increased to restrict the percentage of constriction to not less than 50 per cent.



- Therefore, assuming a linear waterway of 50 per cent, i.e., 7.50 m., the height of vent way required would be $\frac{9.64}{7.5} = 1.3$ meters (approximately), i.e., the sill has to be raised by 1.75 - 1.30 = 0.45 meters above bed level, i.e. the sill of regulator has to be fixed at + 20.45. This will give 3 vents of 2.50 meters long each, the height of vent being 1.30. The rise in sill is to be limited to 0.4 of the upstream full supply depth.

- Ventway arrived at by using the sluice discharge formula above, is found to give excessive waterway. Based on model studies, the Central Water and Power Commission recommends the use of the following relationship

$$Q = C\, B_t D^{\frac{3}{2}}$$

where

C is a coefficient depending upon the drowning ratio (upstream and downstream of regulator)

B_t = Clear throat width between abutments

D = Depth of crest below upstream total energy line

Drowning Ratio	Value of C in Formula $Q = C\ B_t D^{\frac{3}{2}}$	
	In F.P.S System	In Metric System
100 %	1.90	1.050
95 %	2.46	1.358
90 %	2.70	1.490
85 %	2.86	1.580
80 %	2.98	1.645
55 %	3.12	1.723
25%	3.14	1.733

FIXING THE VENTWAY BY THE DROWNING RATIO METHOD

- Upstream of regulator:
  - Discharge: 20 cubic meters/second
  - Bed width: 15 meters
  - F. S. depth: 2 meters
  - Considering side slopes 0.5H:1V
  - Area of waterway (15 + 1) × 2 = 32 sq. meters.
  - ∴ Velocity developing in the canal 0.63 m/sec.
  - Bed level: 20.00
- Elevation of total energy line = 20 + 2.0 + $\frac{0.63^2}{2 \times 9.80}$ = +22.02
- ∴ Depth of submergence over sill = 22.02 - 20.45 = 1.57 m.

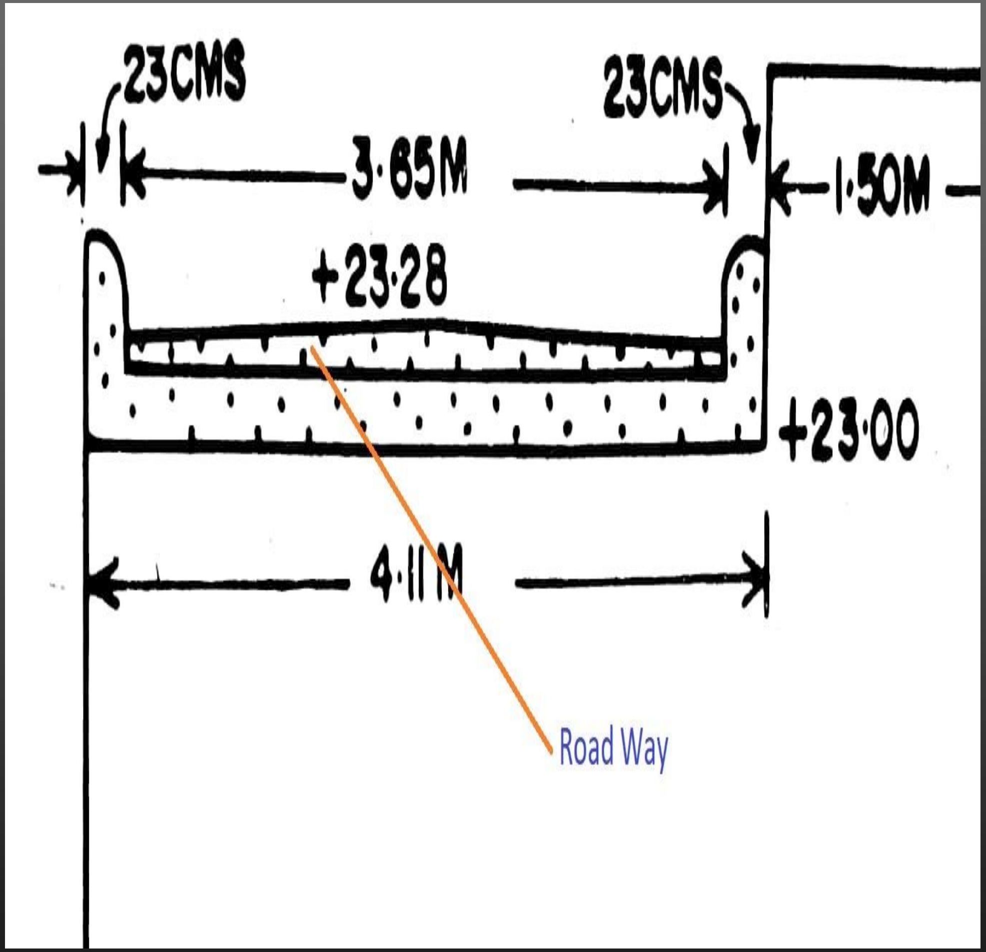
FIXING THE VENTWAY BY THE DROWNING RATIO METHOD

- Downstream of regulator:
  - Discharge: 16 cubic meters/second
  - Bed width: 15 meters
  - F. S. depth: 1.75 meters
  - Considering side slopes 0.5H:1V
  - Area of waterway (15 + 1.75/2) × 1.75 = 27.79 sq. meters.
  - ∴ Velocity developing in the canal 0.57 m/sec.
  - Bed level: 20.00
- Elevation of total energy line = 20 + 1.75 + $\frac{0.57^2}{2\times 9.80}$ = +21.77
- ∴ Depth of submergence over sill = 21.77 - 20.45 = 1.32 m.

- Drowning ratio = $\frac{1.32}{1.57}$ x 100 = 84%
- Corresponding value of C = 1.58 (from table)
- $B_t = \frac{16}{1.58 \times 1.57^{3/2}} = 5.146\ m$
- Including end contractions, provide 6.00 m waterway.
- In this case, adopt a water way of 6.00 meters making it as 3 vents of 2.00 meters each with the sill of the regulator kept at canal bed level only.

ROADWAY

- The roadway consists of a clear width of 3.65 meters (12 feet clear) between kerbs, each of which will be 23 cms (9 inches) wide. It will be a through R.C. slab directly resting over the piers and abutments. The slab will be continuous over piers and adopting I. R. C. ‘A’ class loading, single lane of traffic, a slab thickness of 20 cms will be more than enough. Detailed design of road slabs is not attempted here.
- The bottom of the road slab is kept one meter above the upstream side F.S.L., i.e. at level + 23.00.
- Top level of the road slab with a 7.5 cms, thick wearing coat will be +23.275 or 23.28.
- On either side of the roadway, steel hand-rails as shown in figure may be provided.



Pier

- The pier has to be checked for stability. The forces acting on the pier are as follows:

  (a) Weight of pier itself

  (b) Weight of roadway with the live load

  (c) Horizontal thrust transmitted by the shutters on either side of the pier.

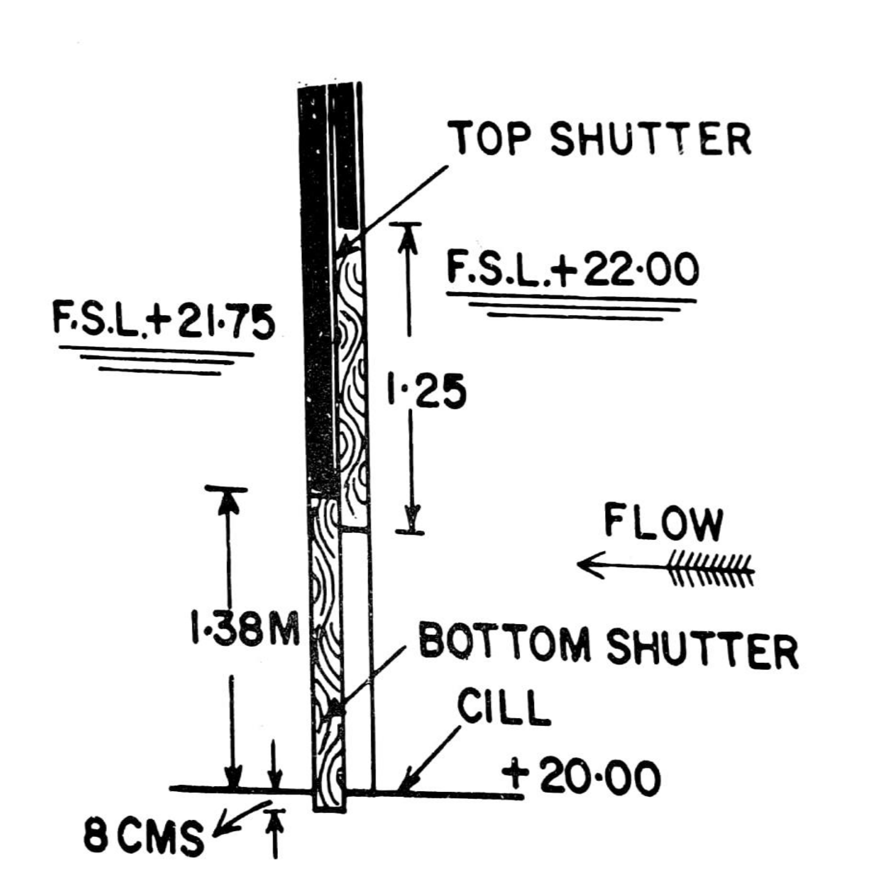
- Under these, the pier must be stable. Generally, the weight of pier and roadway give the stability to the pier in overcoming the horizontal thrust. So, the worst case is to check the stability of the pier when there is no live load on the road with the regulator shutters completely closed, water on the upstream side at F.S.L. and no water downstream. The live load on the roadway will increase the stability of the pier.

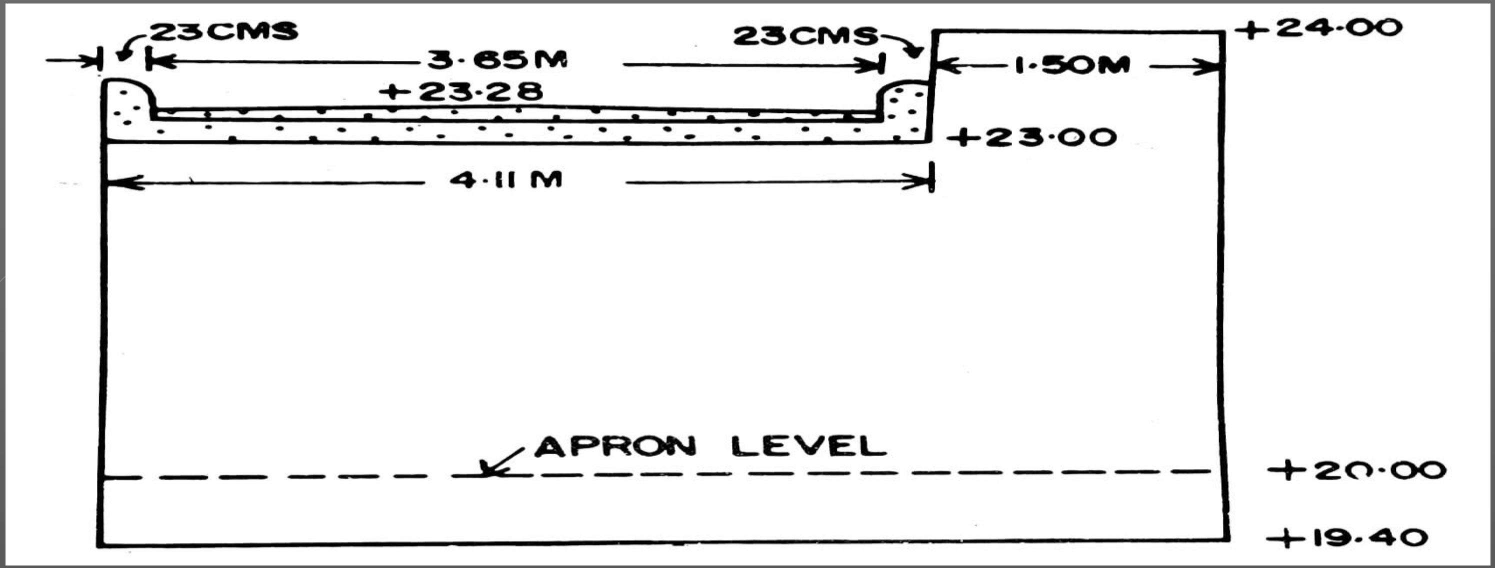
- LENGTH OF PIER :
  - Maximum length of pier will be to cover the roadway with its kerbs, with additional length for the shutter operating platform.
  - Assuming 1.50 meters as the width required for the shutter operating platform, the length of pier required (omitting the cut waters) is 3.65 + 2 x 0.23 + 1.50 = 5.61 meters.
  - The top of pier under the road slab is at a level of +23.00.
  - The top of pier under the shutter operating platform will be higher and this depends upon the height of shutter to be used.

Shutters

- The dimensions of the ventway are 2.00 and 1.75 meters.
- Downstream F.S. depth is 1.75 meters whereas the upstream F.S. depth is 2.00 meters. The shutter top is to be at least 30 cms above the upstream F.S.L. Assuming that the shutter rests in a 7.5 cms deep groove in the sill, the total height of shutter is to be 2.00 + 0.30 + 0.08, i.e., 2.38 meters
- If a single shutter is provided, when a ventway is to be clearly opened, the bottom of shutter will have to be lifted clear over the upstream F.S.L. Assuming that the bottom of shutter is lifted say 25 cms, above the upstream F.S.L. the top of shutter will be at a level of 22.00 + 2.38 + 0.25, i.e., 24.63.
- Assuming a clearance of 30 cms above the shutter to the bottom of the hoisting platform, the pier has to be raised to a level of 24.63 + 0.30 = + 24.93, i.e., this portion of the pier will be 1.65 meters above road level. This will look awkward. This difficulty can be obviated to some extent by adopting a two tier shutter, bottom shutter being 1.38 meters high and the top shutter being 1.25 meters with 25 cms as the overlap between the shutters. They will be arranged in two grooves operating side by side.

- The arrangement of shutters is shown in Figure 1. Each shutter is operated separately by a hollow screw non-rising stem type in an independent groove. When the ventway is to be operated fully, both the shutters will be lifted clear above upstream F.S.L.
- In that contingency, the bottom tier requires more clearance than the top shutter and bottom of the operating platform will have to be at + 22.00 +0.25 + 1.38 = 23.63 or say the top of pier for the portion need be at a level of + 24.00. This is very reasonable and can be adopted.





- The stability of pier is now checked for these levels (Figure 2).
- Hard ground is available at 19.00
- Assuming a thickness of 60 cms for the apron, the top of foundations for piers and abutments can be fixed at 19.40
- The bottom of foundations will be at 18.80.
- Thickness of pier is 1.00 meter.
- The load taken by the pier will be for a length of 2.00 + 1.00 = 3 meters of lineal roadway.

Loads

(1) Weight of road slab = $3.00 \times 4.11 \times \frac{20}{100} \times 2400$ = 5918 kg.

Kerbs = $2 \times 3.00 \times \frac{23}{100} \times \frac{30}{100} \times 2400 = 994\text{kg.}$

Wearing coat = $3.00 \times 3.65 \times \frac{(5+7.5)}{2 \times 100} \times 2400$ = 1643 kg.

Total = 8555 kg.

(2) Weight of pier under the road portion = $4.11 \times 1.0 \times 3.6 \times 2100$ = 31072 kg.

(3) Weight of the pier under the operating platform

= $1.50 \times 1.00 \times 4.60 \times 2100$ = 14490 kg.

(4) Water thrust on the pier (horizontal thrust)

= $1000 \times \frac{2^2}{2} \times 3.00$ = 6000 kg.

- Taking moments of all forces about toe :

Description	Force in kg.		Lever arm (meters)	Moment in kg.(meters)
	Vertical	Horizontal		
1. Weight of road slab	8555	-	2.05	17538
2. Weight of pier under the road	31072	-	2.05	63698
3. Weight of the pier under the operating platform	14490	-	4.86	70421
4. Horizontal thrust	-	6000	0.67	-4020
5. Total vertical force	54117		Net moment =147367	

- Arm of resultant = $\frac{147637}{54117}$ = 2.73 meters.
- Eccentricity = $\frac{5.61}{2}$ -2.73 =0.07 meters.
- Allowable eccentricity = $\frac{5.61}{6}$ = 0.94 meters.

Hence, the resultant falls with in middle third and no tension develops in masonry of pier and length of pier is quite enough.

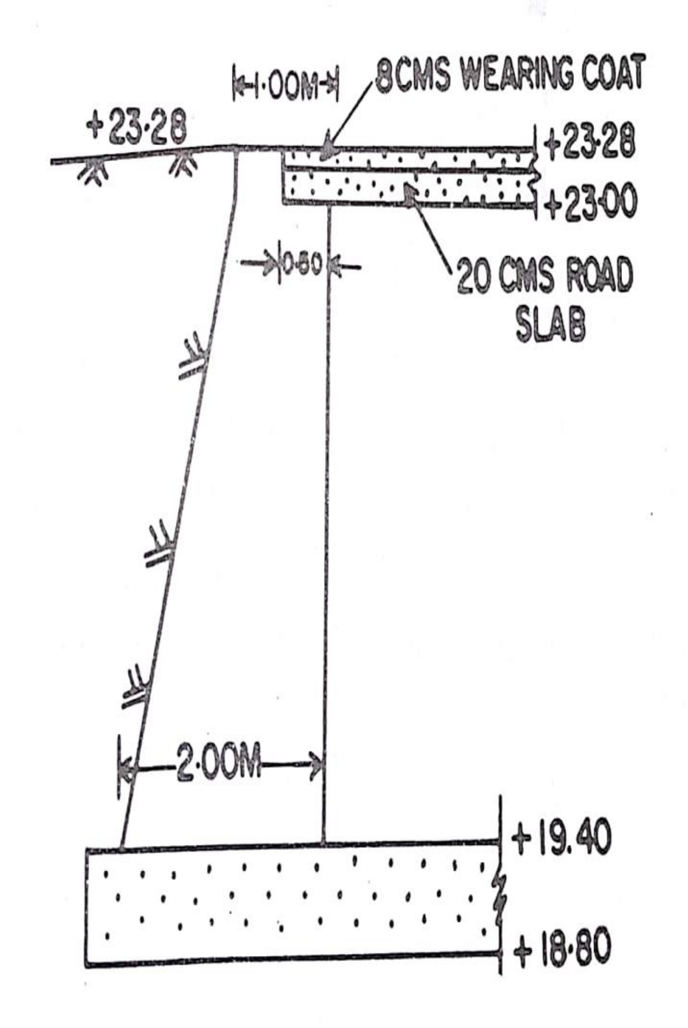
- Maximum compressive stress at the toe,

$$= \frac{54117}{1.00\times1000\times5.61} \times \left(1+ \frac{6\times0.07}{5.61}\right) = 10.36\ tonnes/sq.meter.$$

This is with in safe limits of masonry. Hence the design is safe and the length of pier as proposed can be adopted.

Abutments

- The top level of abutment is + 23.00,i.e., the bottom level of the R.C. slab of the roadway. The bottom of foundation concrete is + 18.80. Adopting 60 cms thick foundation concrete the top of foundation concrete is + 19.40.
- The height of abutment is thus+23.00-19.40=3.60m
- The abutment will have its front face vertical to facilitate the working of the regulator shutters in the vertical grooves, inserted in the front face of the abutment. The abutment carries a vertical load, being that due to dead and live loads transmitted by the road slab.
- Keep the top width of abutment as 1.00 meter out of which 50 cms will be bearing for the R.C.slab. The bottom width may be kept at 2.00 meters.



Wing walls

- The wing walls both on the upstream and downstream side of the regulator will be of the sloping type, sloping from +23.28, i.e, junction with abutment to +23.00 (i.e.) top of bank level on the upstream side and +22.75 on the downstream side.

Top of wall: 23.28

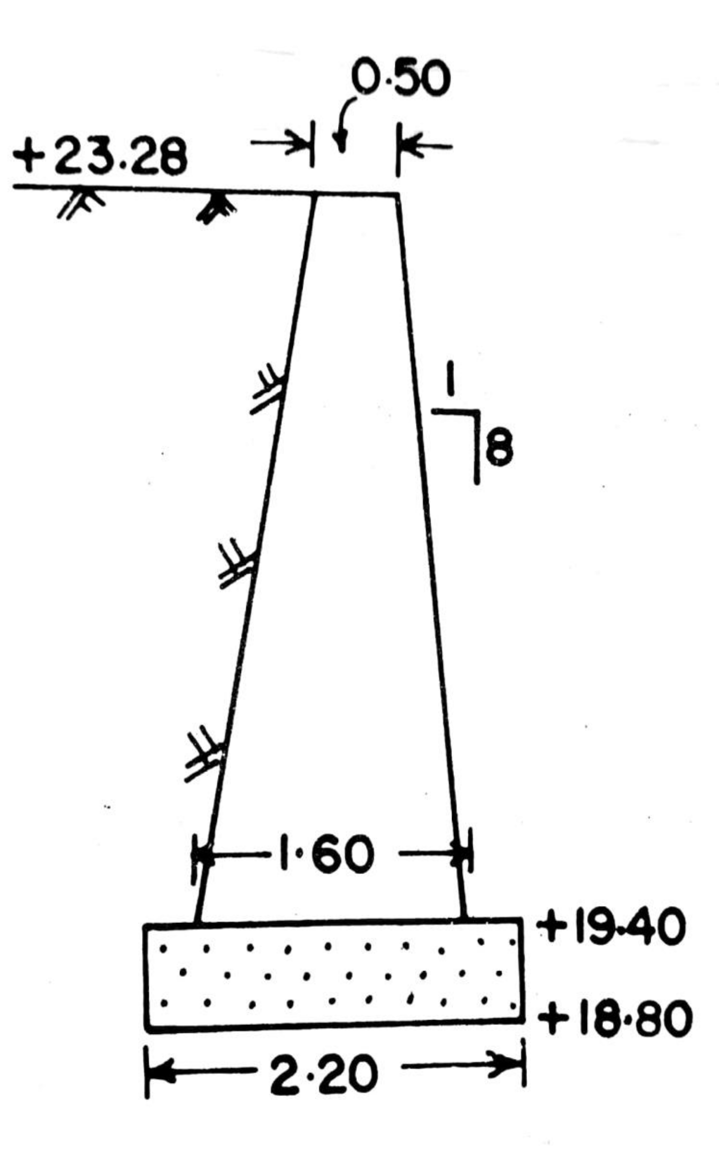
Top width: 50 cms

Top of foundation concrete: 19.40

Height of wall = 3.88 meters.

Bottom width = 0.4%H = 1.55≅ 1.60 m

Adopt a section as shown in Figure 14.4

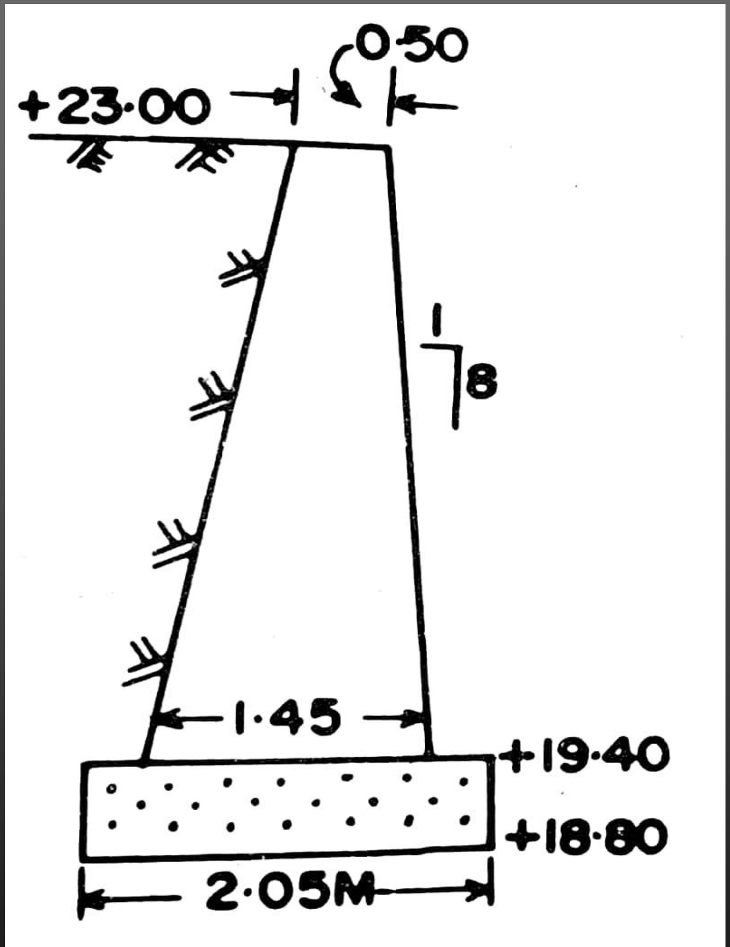


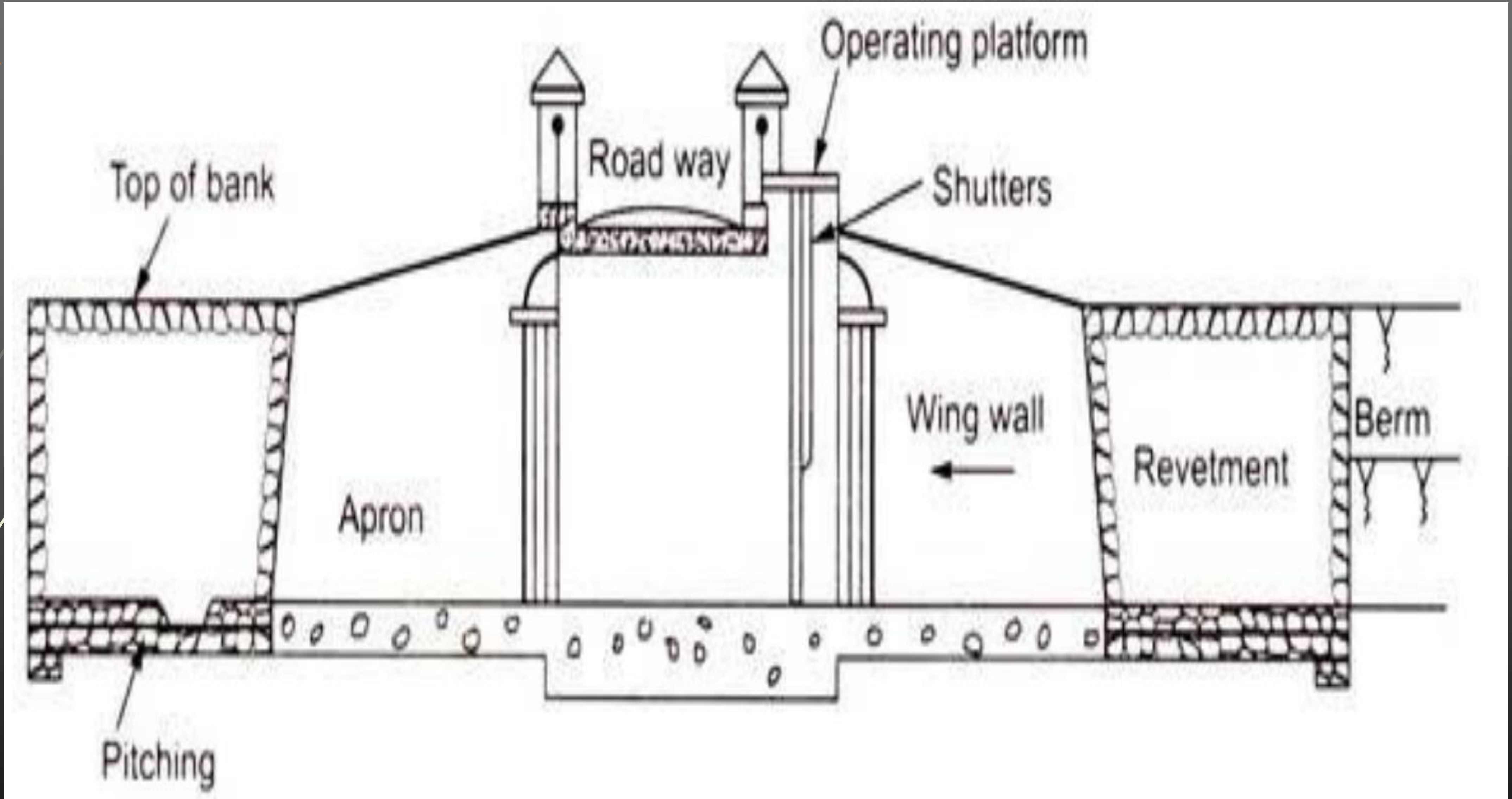
Section of Level Wing and Return

- The top level of level wings and returns on both sides will be at the respective T.B.Ls on either side. Since the difference in levels of T.B.Ls on either side is only 25 cms, the same section will be adopted on either side except that the top level of level wing and return on the downstream side will be kept at 22.75, and top level 23.00, top width 50 cms, top of foundation concrete + 19.40 for the upstream side.

  Height of wall = 3.60 meters.

- Adopt the section shown in Figure 14.5.





Operating platform
Road way
Top of bank
Shutters
Wing wall
Berm
Revetment
Apron
Pitching

Splay of wings on both sides

- This depends on the length of solid aprons provided on both sides of the regulator The canal bed width is 15 meters. At the end of solid aprons, the distance between masonry returns will be kept at 15 meters as shown in Plate 7.

Solid Aprons for the Regulator

- Solid aprons are required to prevent seepage when the regulator is closed with canal at F.S.L. on the upstream side and no water on the downstream. This solid apron will be laid with its top level at the canal bed level.
- Assuming the bed material of the canal as sandy and also the hydraulic gradient in that soil as $\frac{1}{10}$, we require 10x2 = 20 meters length of apron, as the head of flow is 2 meters.
- This 20 meters of floor is provided as 6.00 meters on the upstream side, 5.6 meters under the regulator and the balance downstream. The maximum uplift is experienced just downstream of shutter.

- Assuming that the shutters are located in the centre of the operating platform, the head lost in creep by the time the seepage reaches the shutter = 6+ $\frac{1.5}{2}$ = 6.75 meters.

  Head loss creep = $\frac{6.75}{10}$ = 0.675 meters.

  Residual uplift = 2-0.675 = 1.325 meters.
- Assuming that the tail water is at the downstream bed level the thickness of apron required = $\frac{1.325}{1.25}$ = 1.06 meters (or) say 1.00 meters.
- This can be gradually reduced to 60 cms thick at the end of the apron

  The upstream apron never experiences any uplift.

  So, the thickness of apron can be nominal and can be limited to 30 cms.

  Aprons can be in mass concrete.

Revetments

- Both upstream and downstream provide in continuation of solid apron some 5 meters in length of rough stone bed pitching 45 cms thick as shown in the drawing.
- Provide for the same length of rough stone revetments on the canal slopes to a thickness of 45 cms.
- Detailed bank connections are shown in the Plate7.
- In case of canal regulators, there is no necessity of checking the stability of pier for cross thrust. When one vent is flowing and the other vent is closed, the rear water backs up, and the water level will practically be same on both sides of the pier Hence, there is no cross thrust.
- In case of river and spillway regulators when all vents are closed and one vent open, there will be water standing against the pier on one side only. It is then necessary to check the pier for stability against cross thrust, and to provide enough thickness of pier to see that no tension is developed across the thickness of pier.

Arrangements of Energy Dissipation

- In the initial stages of opening of the regulator shutters, when there is no water in rear, the water will shoot out downstream till the tail water builds up. So it is possible in the initial stages for the bed to get scoured out. In order to dissipate this excess velocity, two or three rows of friction blocks may be provided on the solid apron. These will arrest the excess velocity and make the flow streamlined beyond the apron. This will eventually reduce scours downstream of the solid apron.
- The actual position and type of friction blocks can best be decided by hydraulic model experiments only.

General

- In case of river regulators where the head is high, it is necessary to guard the structure against piping action of the flow beneath the aprons. So, the exit gradients at the end of the D/S apron will have to be kept as low as possible. To achieve this we may have to provide a D/S cut-off cither by sheet piles or by mass concrete. To reduce uplift on the floor, an upstream cut-off also may be required. In all such cases, the pressure developing under the floor may be calculated by Khosla's method and thicknesses computed.

Specifications

- **Foundations** :
  - For regulators of smaller height and those that do not carry road slabs, a leaner proportion of concrete, say 1:4:8 will suffice.
  - the abutments and piers due to the road slab over them, the concrete has to be richer in proportion. Generally, C.C.:3:6 will do.
- **Upstream and downstream aprons** :
  - Imperviousness and weight are the prime considerations in solid aprons.
  - These can be in the proportion of mud mat, i.e. 1:4:8. Use of fly-ash will effect economy in the apron concrete.
- **Abutments, piers, wings and returns** :
  - Piers could be in course stone masonry in cement mortar1:4 and joints pointed with cement mortar I :3.
  - Alternatively, they could also be in mass concrete poured into form-work with cement concrete 1 4:8. Abutments, wings and returns can be in coursed rubble masonry and joints pointed with cement mortar 1 : 3.

- For piers and abutments, the top 30 cms height is made up with 1:2:4 cement concrete with the top surface rendered smooth, for the road slab to rest uniformly.
- **Road slab** :
  - In the present case, there is a continuous road slab over all the three spans. With the calculated reinforcement, the road slab and kerbs are laid in cement concrete 1:2:4 (M150)
  - The wearing coat is laid as a separate entity a long time after the road slab is laid. The wearing coat is laid in cement concrete 1: 1/2:3 (M 200).
  - With a maximum thickness of 7.5 cms at centre of road slab, sloping down to a thickness of 5 cms towards the kerbs.
- Weep holes:
  - These are left in the wing walls and abutments above canal F.S.L. with inverted filters, so as to drain off any saturation from the earthen embankment under the road.

Canal Regulator