# LECTURE NOTES

## Irrigation and Hydraulic Structures

## (CIV- 604)


Semester:6th, B.Tech.

Department: Civil Engineering

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# CHAPTER-4

# *Diversion Headworks*

## DIVERSION HEADWORKS:

**Selection of site and layout, parts of diversion head-works, types of weirs and barrages, design of weirs on permeable foundations, control of silt entry into canal, silt excluders and different types of silt ejectors**.

## 1.1 Definition

A structure constructed at the junction of the source (river, dam, canal) and the off taking canal.

## 1.2 Types of Headworks

The different types of headworks are as follows:

1.2.1 Diversion Headworks

- diverts the required supply from the source channel to the off taking channel
- water level in the source channel raised to the reqd. level
- reduces the need of excavation in the head reach
- command area is served better by flow irrigation
- should be capable of regulating the supplies into the off taking channel; all supplies when demand is keen & supplies are less
- control sediment entry

1.2.2 Storage Headworks

- fulfill requirements of the diversion headworks
- in addition, store excess water when available and release when demand exceeds supplies

1.2.3 Temporary Headworks

- bunds constructed across the river every year after floods
- replaced with permanent headworks when demand of water increases

1.2.4 Permanent Headworks - all important headworks

## 1.3 Location of Headworks on Rivers

Rivers have four stages: (i) rocky, (ii) boulder, (iii) trough ( or alluvial), and (iv) delta

Rocky stage: far away from command arca; length and, therefore, cost of main canal increases, so is unsuitable for headworks

Delta Stage: irrigation demand is less and, also, nature of river (flat slopes, braiding) poses other problems, hence unsuitable

Boulder and alluvial stages - both suitable

The favorable features of boulder stage for headworks are:

- initial cost is less
- local availability of stones
- smaller width of river ( therefore, weir)
- smaller scour depths (reduce the depth of cut-off)
- close proximity of higher banks (less training works)
- canal will have number of falls – can be utilized for power generation
- construction of temporary bunds (for initial period) possible
- will require large number of cross-drainage structures
- considerable loss of water through subsoil flow in the river bed and from the head reach of the main canal - crucial during periods of short supply

Hilly regions usually have wet climate and, therefore, irrigation demand is, generally, small to begin with and may increase later. In alluvial regions the demand for irrigation is high right from the beginning.

## 1.4 Site Selection for Headworks

River reach should be:

- straight and narrow
- well-defined and non-erodible high banks
- preferably deep channels on both banks and shallow channel at the centre

Based on considerations of suitability of site for different components of headworks following points are important:

- weir (barrage) - minimum length for economy, uniform flow for proper functioning
- under sluices - presence of deep channel to ensure adequate supply to the off-taking canal
- canal alignment - capable of serving its command area without much excavation
- sediment – off taking channel sited on the downstream end of the outer side of the bend

## 1.5 Diversion Headwork Components

- Weir (or barrage)
- Undersluices
- Divide Wall
- Fish Ladder
- Canal Head Regulator
- Sediment Excluder and Sediment Ejector
- River Training Works

## 1.6 Layout of Headworks

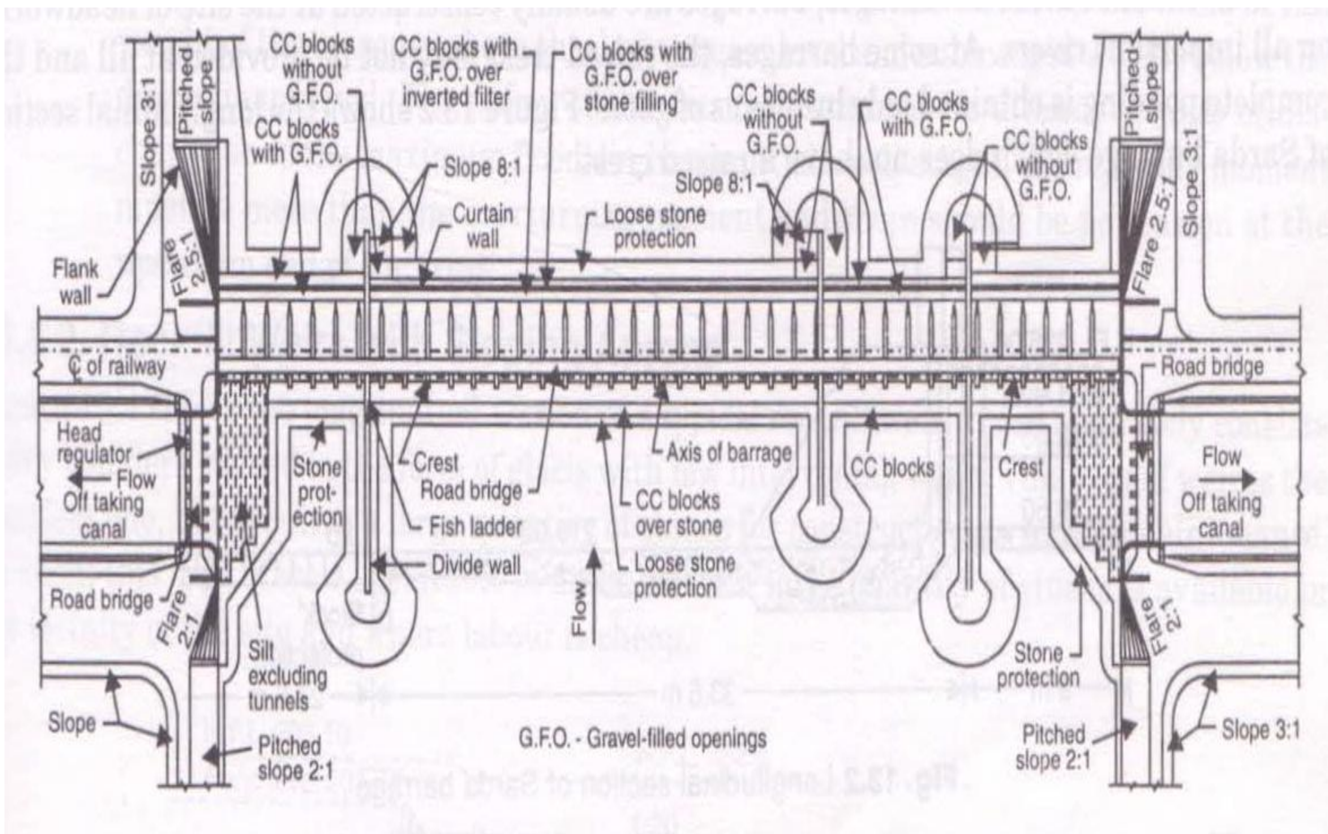



Figure 1. Typical layout of headworks

## 1.7 Weir (or Barrage)

1.7.1 Weir

- ungated barrier across a river
- raises water level in the river and diverts water into an off taking canal - on one or both banks of the river - just u/s of the weir
- usually aligned at right angle to the direction of flow - results in minimum length & normal uniform flow through all weir bays which minimizes the chances of shoal formation and oblique flow
- crest is raised above the river bed to raise the water level
- shutters at the top of the crest for further raising of water level and controlling pond level (difficult when pond level is higher than 2 m above the crest)
- provide gate-controlled weir - barrage

1.7.2 Barrage

- a gate-controlled weir with its crest at a lower level
- ponding up of the river for diversion is by means of gates
- offer better control on outflow and discharge in the offtaking canal
- afflux is small due to lower crest level of the barrage
- possible to provide a roadway across the river at small cost
- better control over sediment entry into canal
- Therefore, barrages are very common on all important headworks at times no raised crest as in Sarda barrage - ponding is by gates only design procedure is similar to that of weir

1.7.3 Types of Weirs

*1.7.3.1 Masonry weirs with vertical d/s face*

- masonry floor with a masonry crest on top of which shutters for ponding
- shutters dropped during floods to reduce afflux
- stability of crest examined for water level upto the top of shutter with no flow d/s when shutters dropped and water is on both sides of the crest

*1.7.3.2 Rockfill weirs with sloping aprons*

- simplest but requires large qty. of stones for constn. & maintenance

*1.7.3.3 Concrete weirs (or barrages) with glacis*

- on pervious foundation, only concrete weirs these days
- excess energy dissipated by means of hyd. Jump formed on glacis
- design based on Khosla's method and requires the knowledge of
- max. flood discharge & corresponding level around the weir site
- the stage - disch. Curve at the weir site
- the X-section of the river at the site

Based on the site conditions, general & economic considerations, decide

- afflux
- pond level
- min. waterway
- weir crest level

## 1.8 Undersluices (Sluice Ways or Scouring Sluices)

- Undersluices help in flushing the sediment deposited u/s of the canal head regulator on account of ponding up of water due to construction of weir across river
- gate-controlled openings in continuation of the weir with their crests at lower level
- located on the same side as the offtaking canal

- useful for passing low floods after meeting the requirements of the offtaking canal
- shutters (or gates) operated only for passing high floods during monsoon
- design procedure is similar to that of weir (use model analysis for major headworks)

Crest level of undersluice:

- generally coincides with the lowest cold weather level of the river bed at the weir site
- at least 1.2 m (2 m if sediment Excluder is provided) below that of the head regulator so that the sediment deposited u/s of the regulator does not enter the off taking canal. If needed, the crest level of the regulator is raised.

Discharge capacity of the undersluices is maximum of the following:

- twice the canal discharge - to ensure sufficient scouring capacity
- 10 - 20 % of the max. flood discharge - to reduce the length of the weir
- enough capacity to pass off low floods with w/s in the reservoir at pond level to avoid gate operation

## 1.9 Afflux & Waterway

- HFL u/s of weir rises due to construction of weir across river, this rise is afflux
  Afflux = u/s TEL - d/s TEL
- initially, the afflux is confined to a short reach u/s of weir but, gradually extends very far u/s in case of alluvial rivers - due to continued deposition
- afflux governs top levels of guide banks & marginal bunds & length of bunds
- waterway & afflux are interdependent
  larger afflux results in lesser waterway
  increases the discharge intensity q which, in turn,
  increases the scour &, hence, cost of protection works d/s
  higher afflux also increases the risk of failure of river training works
- For alluvial rivers:
  afflux = 1m in upper and middle reaches of river
  = 0.3m in lower reaches with flat gradients
  waterway = 1.1 to 1.2 times Lacey's regime perimeter for the design discharge
  = 0.8 to 0.9 times regime perimeter in rivers with coarser bed material
- lesser waterway increases afflux & cost of protection & river training works
- larger waterway is uneconomical & causes oblique flow and silting in part of waterways

**Loosenes factor:**

- overall length of weir /min. stable width from regime criterion

**Pond level:**

- water level which must be maintained in the under sluice pocket (i.e. u/s of the canal head regulator) so as to maintain FSL in the canal when full supply discharge is fed into it

- = FSL + ( 1.0 to 1.2 m) so that sufficient working head is available even when head reach of canal has silted up or when canal is to be fed excess water
- limit on pond level : FSL = pond level - working head (1.0 to 1.2 m)
- maintained by keeping the weir crest at the pond level or by keeping the weir crest at lower level and provide shutters/gates

**Retrogression:**

- d/s of weir due to degradation; d/s HFL lowered; exit gradient increases during high floods : 0.3 to 0.5 m due to large qty. of sediment; during low floods : 1.25 to 2.25m due to relatively clear water for design flood retrogression is assumed 0.3 to 0.5 m

  d/s TEL = u/s TEL - head loss ( = afflux + retrogression )

## 1.10 Divide Wall

- parallel to canal head regulator
- separates main weir bays ( and floor) from undersluice bays (and floor)
- extends on both sides of weir upto the end of the floor or loose apron
- on d/s it avoids cross flow causing scour near the structure
- isolates canal head regulator from main river flow
  - creates still pond in front of the regulator
  - helps in deposition of sediment and relatively clear water in canal
  - improves scouring of undersluices by ensuring straight approach
- additional divide walls if possibility of cross currents exist
- generally of strong masonry with top width of about 1.5 to 2.25m and nose end sloping at 3(V):1(H); slight divergence of 1 in 10 advisable; extending upto about the u/s end of the canal or half to 2/3rd the length of the regulator

## 1.10 Fish ladder

- fish of various kinds
- migrate to d/s in the beginning of winter in search of warmth
- return u/s before the monsoon for clear water
- a narrow opening (Fish ladder) between the divide wall and the undersluices where water is always present
- baffles to reduce the velocity to less than 3.0 m/s
- these openings are called as fish ladder or fishways or fish pass
- should take into account the requirements of the fish of the river

## 1.11 DESIGN OF WEIR

**Data required:**

1. L-section & x-section of river at the weir site
2. stage - Q relationship
3. sediment characteristics
4. data concerning the offtaking canal (FSL, Q, L- & X-sections)

**Determination of weir crest level**

1. Determine HFL for the design flood (50 to 100 yr. Frequency) from stage-Q curve.
2. d/s TEL = HFL + regime velocity head
3. u/s TEL = d/s TEL + permissible afflux + retrogression, if any
4. q = design flood discharge / width of clear waterway
5. determine k (height of TEL over the weir crest) from

$$q = Ck^{3/2}$$

C is based on model studies, otherwise

= 1.71 for broad-crested weir

= 1.84 for small-crested weir

6. weir crest level = u/s TEL - k

**Length & number of weir bays & height of shutters/gates:**

Calculate total discharge capacity of weir and undersluices taking into account the end contractions

$$Q = C(L - KnH)H^{3/2}$$

K = f(pier shape) may vary from 0.01 to 0.1

L = overall waterway length

n = number of end contractions

H = total head over the weir

Height of shutters/gates = pond level - weir crest level (max. value = 2m for falling shutters)

**Vertical cutoffs**

- Vertical cutoffs at both u/s & d/s ends of the weir and also at intermediate location (ends of slopes) guards against scouring at u/s & d/s and piping at d/s
- Intermediate cutoffs hold the main structure in case of failure of u/s & d/s cutoffs bottom of cutoff is lower than the level of possible scour
- d/s cutoff should also reduce exit gradient to safe value the depth of scour below HFL

$$R = 1.35\left(\frac{q}{f}\right)^{1/3}$$

q calculated taking into account the concentration factor by which q is to be multiplied to take into account the non-uniformity of flow along the waterway during the operation of weir bays

The scour depth R (for regime conditions) increased further as follows:

| | |
|---|---|
| u/s of impervious floor | 1.50 R |
| d/s of impervious floor | 2.00 R |
| Nose of guide banks/divide wall | 2.25 R |
| Transition from nose to straight part | 1.50 R |
| Straight reaches of guide banks | 1.25 R |

**Weir crest, glacis and impervious floor:**

- Weir crest at the computed level with a width of about 2m
- For broad-crested weir, width should be greater than 2.5 times H
- u/s slope of weir : 2(H):1(V) to 3(H):1(V)
- d/s slope and horizontal floor (i.e. stilling basin) should cause max. dissipation of energy through hydraulic jump and also be economic
- Slope of d/s glacis : 3(H):1(V)
- Level of the d/s floor so that jump starts at the end of the glacis (or u/s) for all Q's
- Location of the jump is calculated for HFL and pond level discharges
- Level of floor is at lower of the required levels for these two conditions
- length of floor such that the entire jump is on the floor (5 to 6 (h -h ))
- u/s floor at the river bed level and its length so that the resulting exit gradient at the d/s end is less than the safe value for the soil under consideration (1/5 to1/6 for coarse and 1/6 to 1/7 for fine sand, 1/4 to 1/5 for shingles)
- Thickness of the floor from uplift considerations
  *Note: For the estimation of uplift pressures on the Weir floor for deciding the floor thicknesses, as per the Khosla's theory, please consultant any standard book on Irrigation and Hydraulic Structures, like Arora KR Book on Irrigation, Water Power and Water Resources Engineering.*

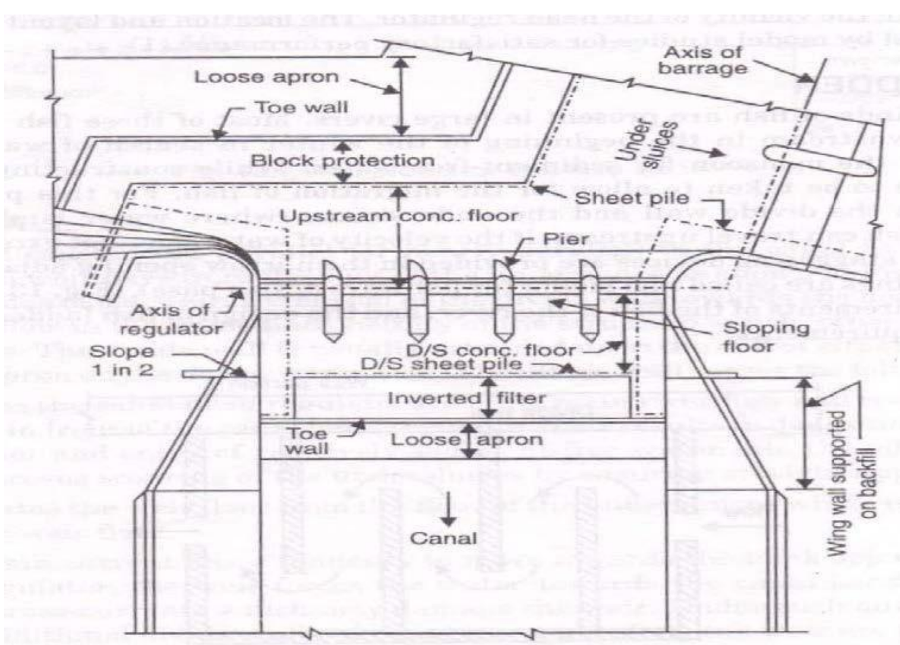
**Upstream and downstream loose protection**

- in the form of concrete blocks and loose stones for protection against scour
- u/s: concrete blocks of size 1500x1500x900 mm laid over loose stones for a distance equal to depth of scour below the floor level
- d/s: concrete blocks on inverted filter; space between blocks filled with gravel; length is 1.5 times the scour depth below the floor level.
- for the boulder reach the size of blocks will be increased
- Inverted filter in two or more layers
- toe wall of masonry/concrete at the end of the filter to a depth of about 500mm
- launching aprons beyond block protection on u/s & d/s ; stones larger than 300mm

## 1.12 Canal Head Regulator

- regulates the discharge into the canal
- controls the entry of sediment into the canal
- usually aligned at an angle of 90 - 110 degrees to the barrage axis minimises entry of sediment into the canal, prevents backflow and stagnation zones in the undersluice pocket
- discharge controlled by steel gates of 6 - 8 m spans usually; larger spans also used - electric winches required for operation
- pond level = FSL + 1.0 to 1.2 m of working head
- waterway width - so that the canal can be fed its full supply with 50% of working head if more than the canal width, provide a converging transition d/s of regulator
- The required head over the crest H for passing a discharge Q with an overall waterway L is worked out using

$$Q = C(L - KnH)H^{3/2}$$




. Figure 2. Typical Plan of a Head Regulator

- crest level = pond level - head over the crest required to pass the full supply Q kept higher than the cill of the undersluices  to prevent sediment, entry should also take into account sediment excluder, working head waterway width
- Height of gates = pond level - crest level
- RCC breast wall between HFL and pond level

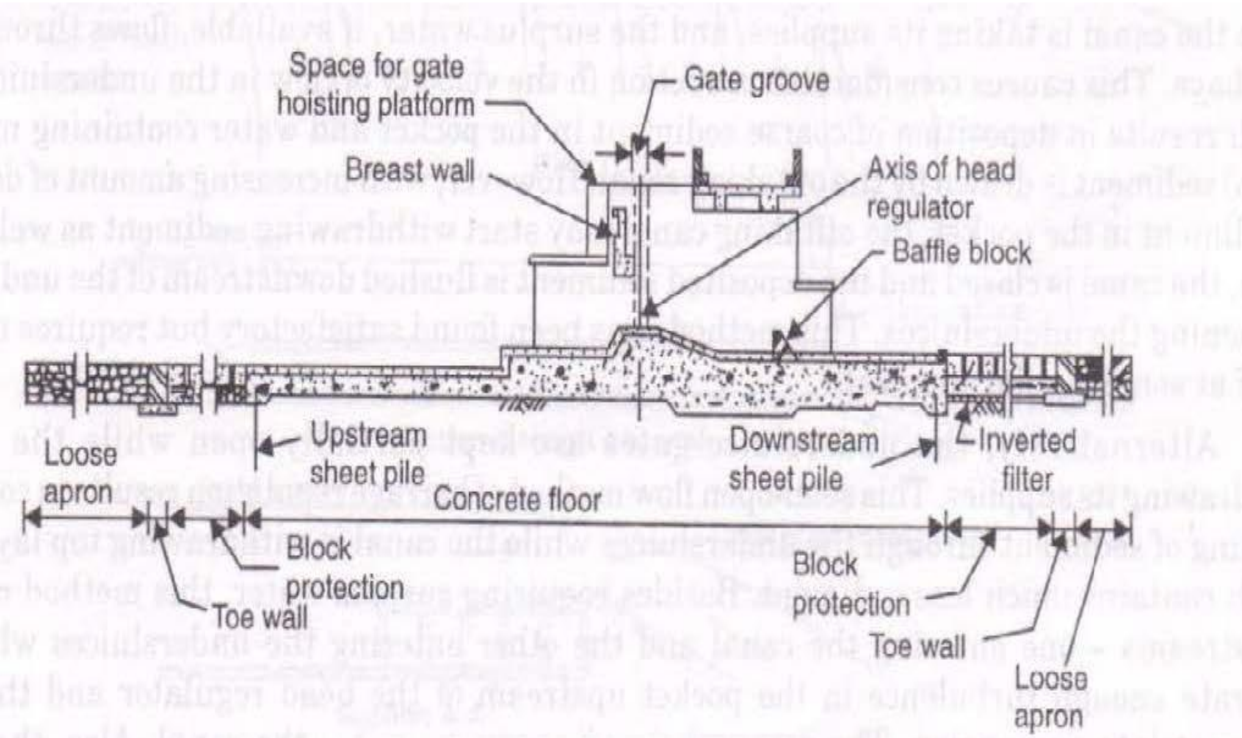



Figure 3. Typical Section of a Head Regulator

- Canal head regulator is designed as weir
- Canal kept closed during highest flood passing through the river, this is the worst static condition and the floor should resist this uplift
- jump trough region - worst condition may occur when some discharge passes safety of this part checked for different discharges including the maximum one
- a bridge and a working platform (for operation of gates) across the regulator

## 1.13 Sediment control in canals

Eexcess sediment entering the canal reduces its capacity, therefore, adequate preventive or curative measures for sediment control entry of sediment can be partly controlled by barrage regulation methods.

1. Still pond method:

- undersluices kept closed when canal takes its supplies
- excess water flows through weir bays
- causes still pond condition
- sediment deposited at the bed; canal draws clear water
- when considerable sediment deposited, canal is closed and sediment is flushed d/s of the undersluices though satisfactory, requires frequent closing of the canal

2. Semi-open flow method:

- undersluices gates are kept partially open while canal is taking its supplies
- results in continuous flushing of sediment
- requires surplus water
- the two streams - to river & to canal generates turbulence, bring sediment into suspension and may enter canal; not suitable except during floods when water is surplus

3. Wedge-flow method:

- undersluices near the divide wall are opened more
- the undersluices near the regulator are opened less
- results in wedge-like flow resulting in favourable flow curvature in the undersluice pocket and, thus, reduces sediment entry into canal

Some important points:

- When the stream carries high sediment load, close the canal itself
- Barrage regulation methods have their limitations requiring either closure of canal or surplus water. Therefore, sediment excluder/ejector and stilling basins are constructed.
- Sediment excluders/ejectors take advantage of the fact that the bed load part of the transported sediment in a stream moves near bed and the suspended load part is distributed non-uniformly in the vertical with heavier concentrations near the bed.
- Settling basins reduce the sediment transport capacity of the canal flow by enlarging the flow cross-section over the length of the basin. The deposited sediment is suitably removed.

**Sediment excluder (or silt excluder)**

- most commonly used preventive measure
- constructed in river bed in front of the canal regulator
- flow u/s of regulator divided by a platform below which excluder tunnels
- only upper layer water enters the canal; carries much less sediment

- lower layer water passes d/s of weir/barrage through the excluder tunnels
- tunnels are parallel to the axis of the regulator and are of different lengths
- all tunnels terminate at the end of the undersluice bays
- tunnels accommodated in the space between regulator crest and undersluice floor
- design procedure based on thumb rules evolved from past experiences

1.min. discharge through excluder tunnels: about 20% of canal discharge
2. self-flushing velocity in tunnels depend on sediment size: 1.8 to 4.0 m/s
3. usually, 2 to 6 tunnels: usually rectangular x-section and bell-mouthed
4. tunnels accommodated in the space between regulator crest floor and undersluice floor - determines height of the tunnels keeping in mind the self-flushing velocity and convenience for inspection & repair
5. estimate the waterway width required for tunnels
6. divide the width into a suitable number (whole number for one sluice bay) of one sluice bay) of tunnels
7. length of the tunnel nearest the regulator equals the length of the regulator
8. other tunnels are successively shorter - mouth of longer is in the suction zone of the shorter one - so that no dead zone between adjacent tunnels
9. water and sediment discharge of all the tunnels should be the same this requires width of shorter tunnel to be smaller to satisfy resistance condition
10. designed excluder is model-tested

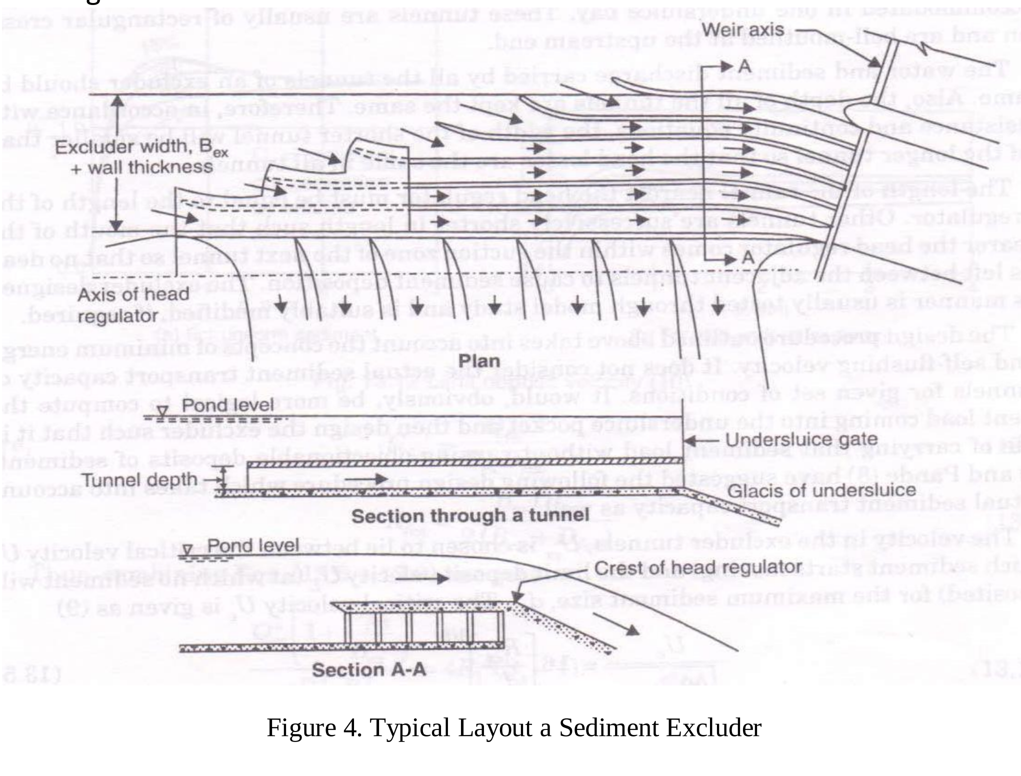



Figure 4. Typical Layout a Sediment Excluder

Above design procedure is based on self-flushing concept and does not take into account the sediment transport capacity of the tunnels. Garde and Pande have suggested an alternative method for this purpose.

**Sediment Ejector /Extractor (Or Silt Ejector/Extractor)**

- curative measure; removes excess sediment load that has entered the canal
- constructed in canal d/s of the canal head regulator
- taking advantage of the concentration distribution, the near-bed water layers ejected
- not too near the regulator - residual turbulence keeps the sediment in suspension
- not too far from regulator - sediment deposits d/s of regulator and reduces canal capacity reach up to the ejector to be wide to carry extra discharge for ejector
- ejector spans the entire width of the canal ; divided into tunnels which, in turn, are subdivided with gradually converging turning vanes to accelerate the escaping flow
- main components - diaphragm, tunnels, control structure and an outfall channel
- diaphragm so shaped as to cause least disturbance to sediment concentration u/s of it
- diaphragm level = f(sediment size to be ejected, size of tunnels and u/s & d/s canal levels)
- lower side of u/s end of diaphragm is bell-mouthed/or made elliptical
- escaping discharge - generally 10 to 20 per cent of full supply discharge
- tunnel dimensions - resulting velocity is adequate to carry the sediment of desired size about 20-25% depth of flow in the canal
- tunnels further converged to increase the velocity further by 10-15%; range 2.5 - 6m/s
- depth of tunnels; 1.8 - 2.2 m to facilitate inspection and repair
- ejector discharge is controlled by regulator gates(near the outfall)
- outflow led to natural drainage through outfall channel design to have self-cleansing velocity
- sufficient drop between FSL of the outfall channel and HFL of the drainage
- proposed design model-tested

The efficiency E of the sediment ejector (or excluder) is given as:

$$= \left[\left(\frac{IU - ID}{IU}\right)\right] 100\%$$

IU and ID are sediment concentration in the canal u/s and d/s of the ejector.

**Settling Basin:**

- removal of sediment from flowing canal by reducing flow velocity through a long expansion
- reduces velocity, shear, turbulence which stops sediment movement and also deposition of suspended sediment
- material from the bed of the basin suitably removed and disposed of

**Design of settling basin:**

- size of sediment particle = d
- fall velocity of the particle = w
- depth of flow in the basin = D
- velocity of flow in the basin = U
- Time required by a particle on the w/s to reach the bed of the basin = D/w
- Horizontal distance travelled by the particle during this time = UD/w (i.e length of basin, L)
- Fall velocity is affected by turbulence, concentration etc.
- Therefore, length of basin L = UD/w is increased by about 20%.

**Garde, Ranga Raju and Sujudi method for design of settling basin:**

- Efficiency of removal of sediment (n) by settling basin:

$$n = \frac{q_{si} - q_{se}}{q_{si}}$$

$q_{si}$ & $q_{se}$ are amounts of sediment of a given size entering and leaving the basin

- Based on dimensional analysis and experimental investigation, they obtained

$$n = n_o\left(1 - e^{\frac{-KL}{D}}\right)$$

$n_o$ & K are related to w/u* (u* is the shear velocity).

## 1.14 River training works for canal headworks

**Purposes:**

- to prevent outflanking of the structure
- to minimise cross flow (through weir) which may endanger the structure
- to prevent flooding of the riverine lands u/s of the weir
- to provide favourable curvature of flow u/s of the head regulator

**Types (usually provided):**

- Guide banks to narrow down & restrict the course of the river so that it flows centrally
- Approach embankments aligned with the weir axis and extend up to a point beyond the range of the anticipated meander loop
- Afflux embankments - earthen embankments extending from both approach embankments connected to the u/s ground above the affluxed highest flood level
- Spurs
- Launching apron, Stone pitching etc.