PANA ACADEMY

NEPAL ENGINEERING COUNCIL
LICENSE EXAM PREPARATION COURSE

FOR

CIVIL ENGINEERS

Er Dilendra Raj Panta

7. Irrigation and Drainage

7.1 Design of canals

Er Dilendra Raj Panta

Sub topics

PANA ACADEMY

Canal types, network and alignment;
Tractive force approach of canal design;
Design of stable canals, alluvial canals (Kennedy’s and Lacey’s theory),
Design of lined canals

Canal (open channel flow)

Canal is defined as an artificial waterway constructed to carry water from source for different purposes like irrigation, water supply, hydropower etc.

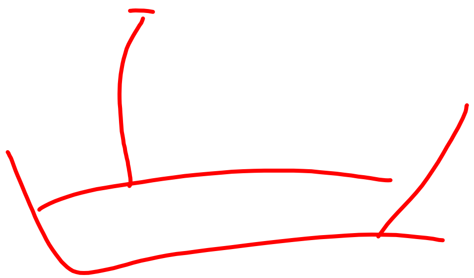
Canal losses

Water loss either by **evaporation** from the surface or by **seepage** through the peripheries of the channels.

While determining the designed channel capacity, a provision for these losses must be made.

The losses are sometimes as high as 20% to 50% water diverted.

Canal losses



Evaporation

- The water lost by evaporation depends on temperature, wind velocity, humidity etc.
- Generally, the water lost by evaporation is 1% to 2% of total canal discharge and about 2% to 3% of total loss.
- In worst case evaporation loss can be up to 7%

Canal losses

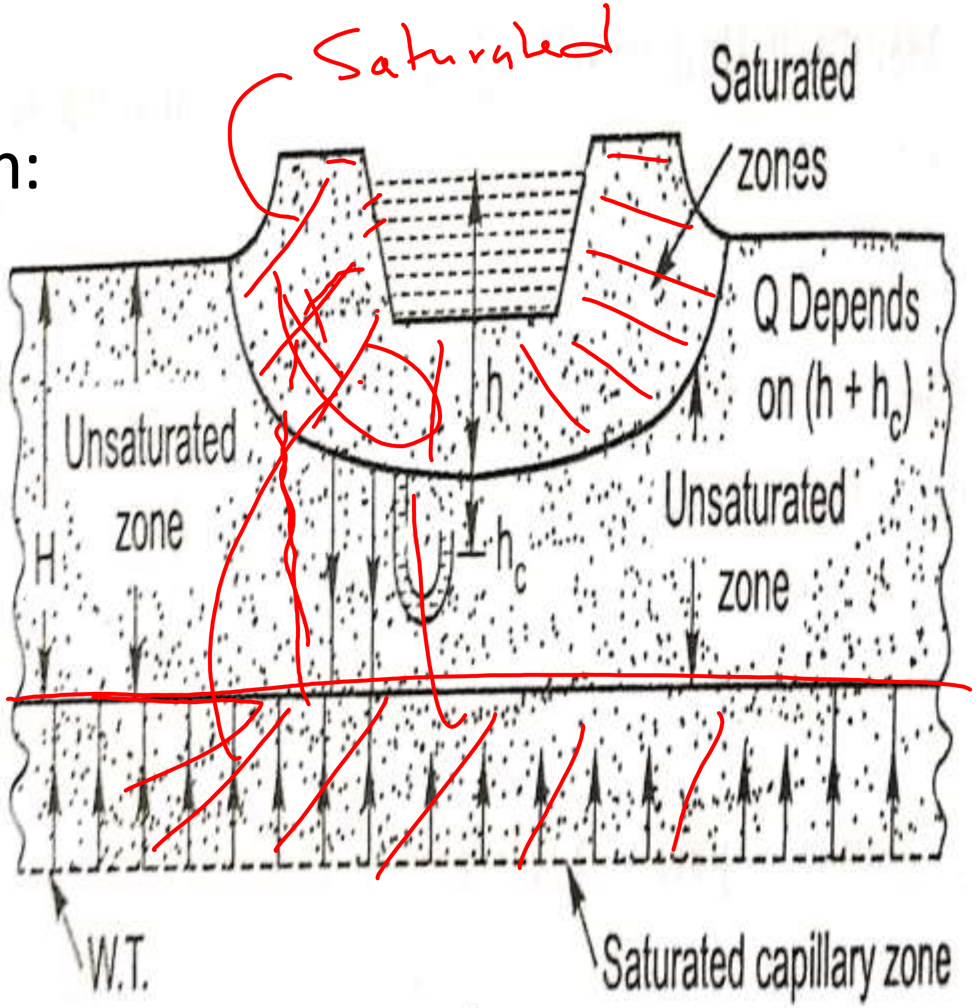
Seepage

Seepage loss occurs by two mechanism: **percolation** and **absorption**.

Can be upto 40%

Absorption loss

- Absorption loss occurs just below canal bed.
- Unsaturated zone exists between the two saturated zones.

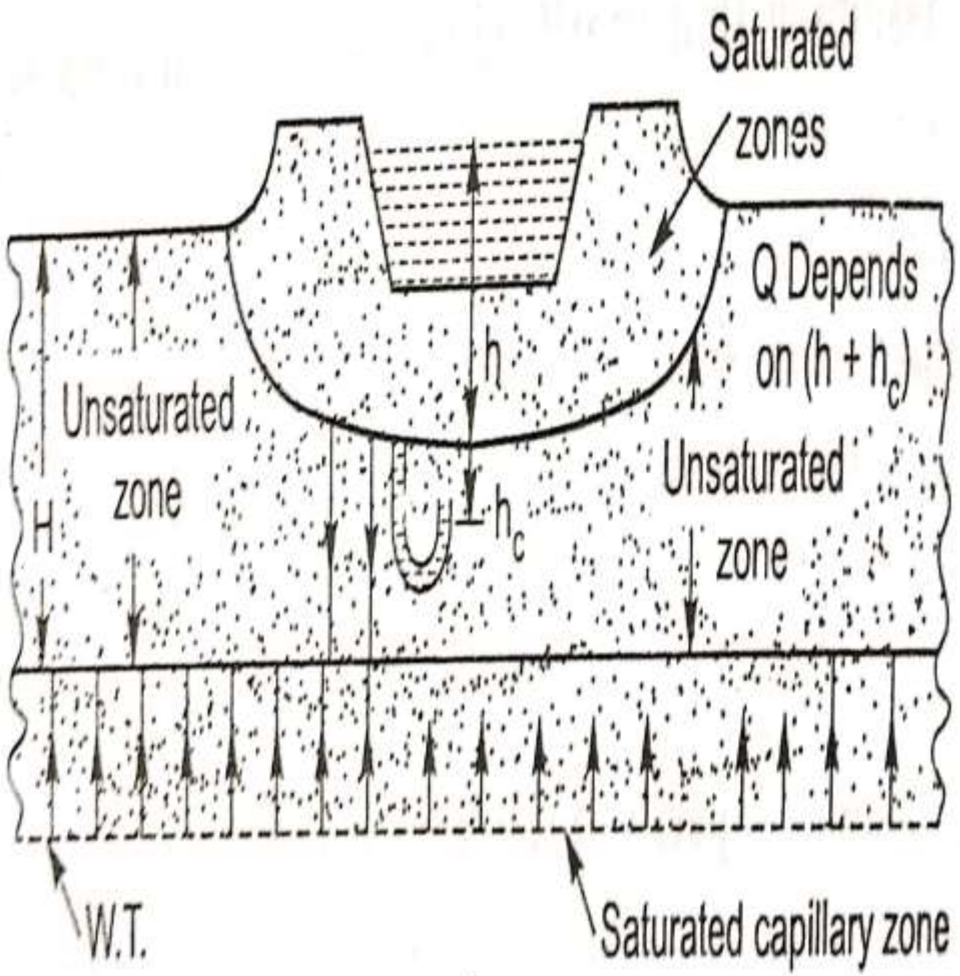


Canal losses

PANA ACADEMY

Percolation loss

- Deep percolation of water from surface to ground water table.
- Percolation loss is very high compared to absorption.



Canal types

1) Based on nature of source of supply

A. Permanent canals (have continuous flow of water)

- ✓ **Perennial canal** : These canal gets continuous supplies from the sources throughout the year. ie generally from the *snow-fed rivers.*
- ✓ **Non-perennial canal**: This canal gets supply only for some part of year

B. Inundation canals (flood water management, flow above certain water level)

No head regulator is provided at the head of flood canal.

PANA ACADEMY

Er Dilendra Raj Panta

Canal types

2) **Based on the function of the canal**

Irrigation canal

used to carry water to the field

Hydropower canal

Used to carry to powerhouse for hydropower generation)

Feeder canal

only feeds other canals

Carrier canals

Carries water for direct irrigation and also to feed another canal

Also called as multipurpose canal.

Canal types

3) **Based on discharge in canal and its importance in canal network**

Main canal: takes supply directly from river

Irrigation can’t be done from main canal

Branch canal (discharge > 5cumec)

Major distributary (0.25 – 5 cumec)

Minor distributary (less than 0.25 cumec)

Water course or field channel

__owned and constructed by the farmers)

Canal types

PANA ACADEMY

4) **Based on canal alignment**

a) Ridge canal/watershed canal

- It is the most desirable alignment
- Canal flows along the ridge line or watershed line.
- It can irrigate the commanded area on its both sides
- Cross drainage can be avoided
- Suitable in plain areas

Canal types

PANA ACADEMY

b) Contour Canal

- Canal aligned parallel to contours
- Irrigates only one side of commanded area so called as single bank canal
- Cross drainage structures needs to be provided
- Suitable in hilly areas

Canal types

PANA ACADEMY

c) Side slope Canal

- Canal aligned perpendicular to contour lines.
- Cross drainage can be avoided
- River and canal flows parallel

Canal types

5) **Based on financial output**

- **<u>Protective canal</u>** (to protect particular area from famine)
- **<u>Productive canal</u>** (to generate revenue to the nation)

Scouring / Silting

6) **Based on the soil through which it is constructed**

- **<u>Alluvial canal</u>** (Canal formed on alluvial soil i.e soft soil)
- **<u>Non-alluvial canal</u>** (Canal formed on Non-alluvial soil i.e hard rock)

Silting

Canal types

7) **Based on the presence of lining**

- **Lined canals**: Canals with their surface lined by impervious materials like concrete, brick etc
- **Unlined canals**: Canals with their surface in natural condition.

8) **Others**

- **Drain canal :** To drain water from water logged areas.
- **Ditch Canal :** Acts as drainage of parent canal.

Canal Cross section

PANA ACADEMY

<u>Based on method of earthwork.</u>

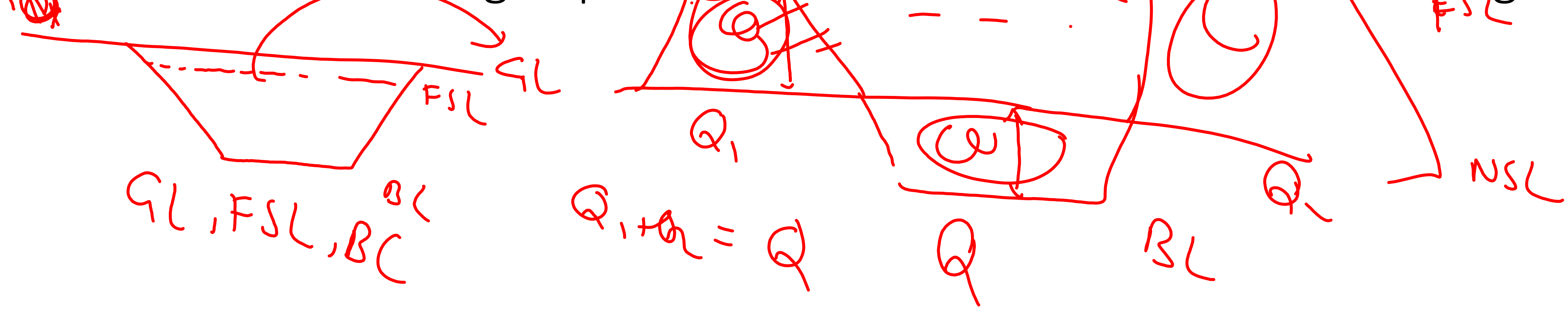
a) Fully cutting

b) fully filling

Higher chances of seepage is seen

c) partly cutting partly filling

Balancing depth is tried to maintain for economic design



Canal Cross section

PANA ACADEMY

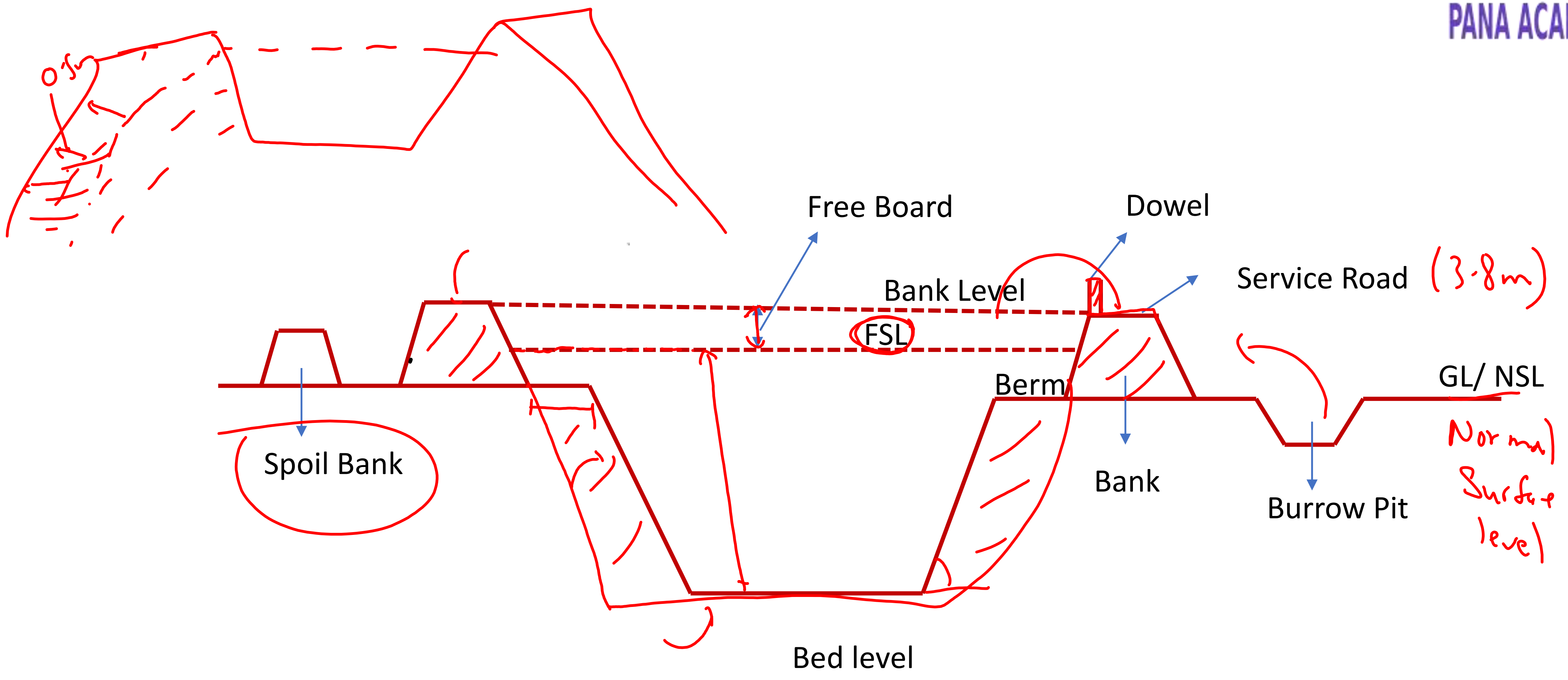
Balancing depth of canal:

The depth of cutting that will result in balance of earthwork i.e. earthwork of excavation equal to that of filling is called balancing depth.

If the balance between cutting and feeling occur, the need of spoil bank and borrow pits are completely eliminated

Canal Cross section

PANA ACADEMY



Er Dilendra Raj Panta

Canal Cross section

PANA ACADEMY

Freeboard(FB)

- Margin between FSL (Full supply level) and bank level
- Depends upon discharge in the canal

0.5 - 1m

Discharge (m3/s)	Free board (m)
Less than 3	0.45
3-30	0.6
30-60	0.75
More than 60	0.9

Canal banks

- Primary purpose is to retain water
- Serves as service road
- Should be wide enough so that at least 0.5 m cover is available above saturation line

Canal Cross section

PANA ACADEMY

Service roads:

- Roads provided on canals for inspection purpose, service and maintenance (about 3.8m width)
- Generally provided 0.4 m to 1.0 m above FSL depending upon canal size.

Berms

D is depth of flow

Horizontal portion on ground level between toe of bank and top edge of cutting

Berms are provided for following purposes:

- Stability of bank
- Scope for future expansion

Berm	distance
Fully cutting	1.5 D
Filling & cutting	2 D
Fully filling	3 D

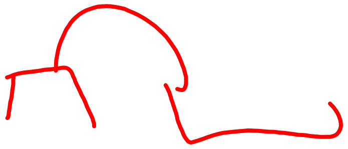
Canal Cross section

PANA ACADEMY

Dowlas/Dowla:

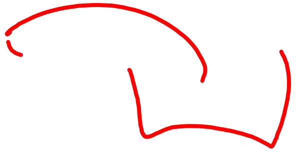
- Dowlas are small embankments by the side of service roads
- Generally height is 0.3 m and width at the top is 0.3 to 0.6 m
- For safety in driving on service roads

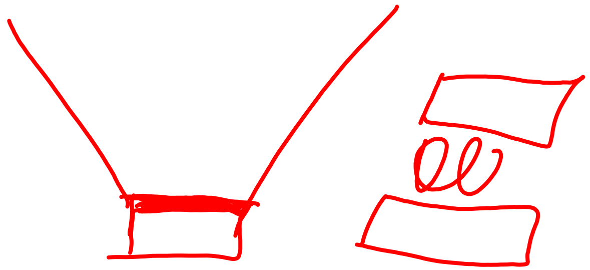
Spoil bank



- Constructed when Volume of cutting is more than filling required.
- Can be provided at left or right side of canal

Canal Cross section





PANA ACADEMY

Borrow pits

- Forms when volume of cutting is less than filling required.
- Borrow pit is preferably provided at center of canal but can be provided at left or right side of canal
- Width is half canal width and maximum depth is 1

Bed Bars

- Concrete or masonry structure constructed at canal bed that shows general behaviour of canal
- It shows whether canal is silting or scouring or to watch the general behavior of canal
- Laid in interval of 200 m to 500 m

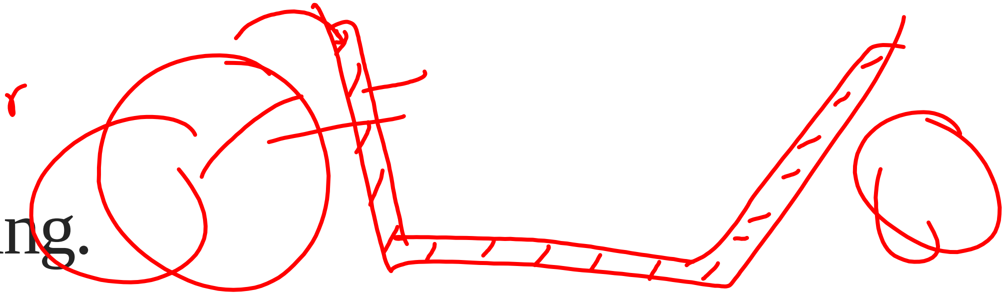
Lined Canal

PANA ACADEMY

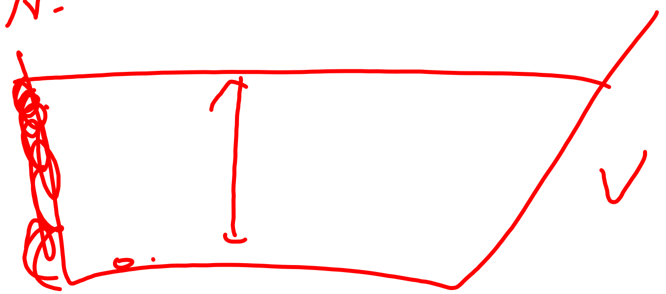
The Process applying an impervious layer on the surface of an unlined canal to make canal impervious and reduce seepage loss is called as canal lining

Advantages of canal lining:

- It helps in seepage control. major
- It helps in preventing water logging.
- Increases discharge capacity of canal.
- Increases duty of irrigation water.
- Reduction in general maintenance and repair cost.



Lined Canal



Type of Lining	Permissible velocity (m/s)	Thickness (cm)
Cement Concrete Lining	2 to 2.5 m/s	10-15 cm
Lime concrete Lining	upto 2 m/s	10-15 cm
Stone Masonry Lining	1 m/s	About 15 cm
Brick Masonry Lining	1.5 m/s	About 15 cm

Er Dilendra Raj Panta

Lined Canal

The Process applying an impervious layer on the surface of an unlined canal to make canal impervious and reduce seepage loss is called as canal lining

Advantages of canal lining:

- It helps in seepage control.
- It helps in preventing water logging.
- Increases discharge capacity of canal.
- Increases duty of irrigation water.
- Reduction in general maintenance and repair cost.

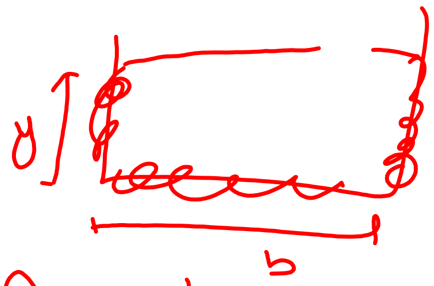
PANA ACADEMY

Lined Canal

$A = \frac{Q}{V}$

$A = b \times y$

$P = b + 2y$



R = Hydraulic Radius = $\frac{A}{P}$

PANA ACADEMY

Designed by manning’s formula

$$v = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Materials	Manning's n
Fine sand	0.02
Fine Gravel	0.02
Coarse Gravel	0.025
Clay	0.025
Silty Clay	0.025
Loam	0.02

Designed by Chezy’s formula

$$v = C\sqrt{RS}$$

$$n = \frac{d^{\frac{1}{6}}}{24}, d \ in \ meter$$

Lined Canal

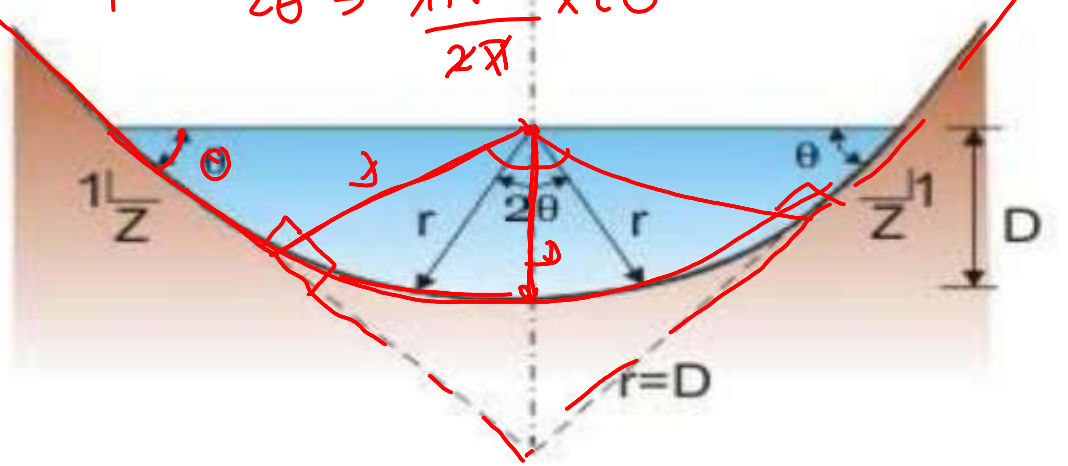
1)Triangular section (for small discharge Q less than 85 cumecs)

$$A = (\pi D^2)(2\theta/2\pi) + 2\left(\frac{1}{2}D^2 \cot\theta\right)$$

$$A = D^2(\theta + \cot\theta)$$

$$P = 2\pi D\,(2\theta/2\pi) + 2D\cot\theta$$

$$P = 2D\,(\theta + \cot\theta)$$



Lined Canal

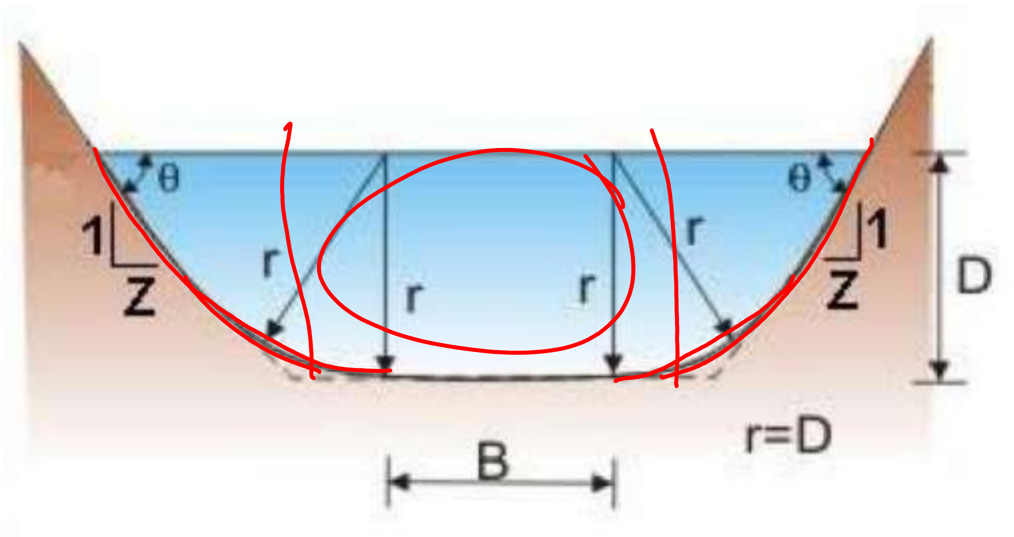
PANA ACADEMY

2) Trapezoidal section(for large discharge more than 85 cumecs)

$$A = BD + (\pi D^2)(2\theta/2\pi) + 2\left(\frac{1}{2}D^2 \cot\theta\right)$$

$$A = BD + D^2(\theta + \cot\theta)$$

$$P = B + 2D(\theta + \cot\theta)$$



Most Economical Canal Section

PANA ACADEMY

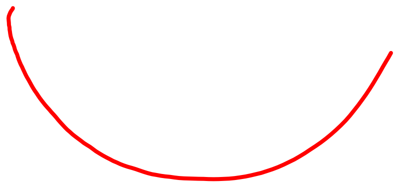
A canal is said to be most economical when its cost of construction is low.

An economic canal section is one which has minimum wetted perimeter.

For a given discharge, canal has minimum cross sectional area.

For a given cross sectional area, canal has maximum discharge.

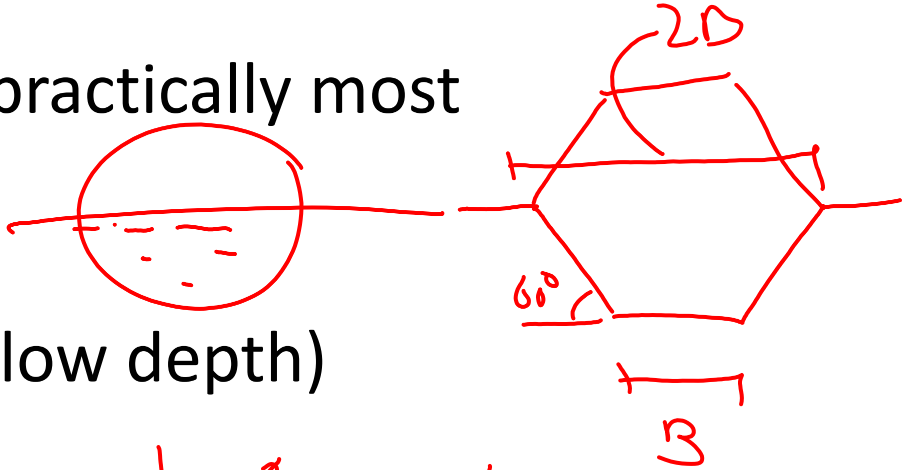
Semicircular $Q/v = 12m^2$



Most Economical Canal Section

PANA ACADEMY

Most economical section is **semicircular**, practically most economical is half hexagon



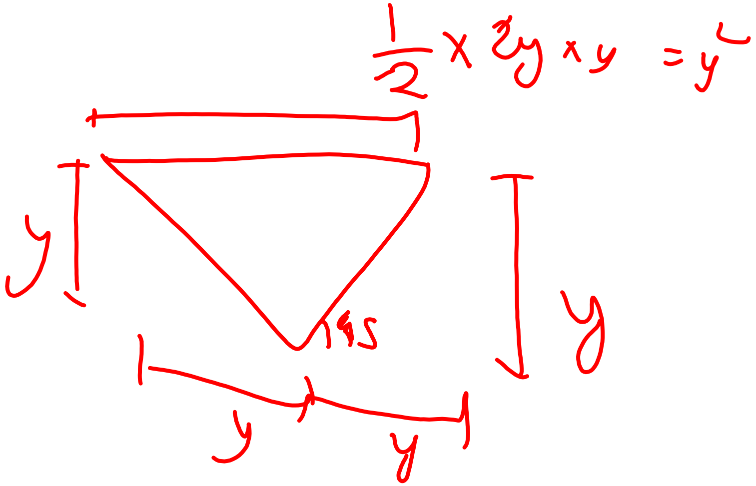
1. **Economic Rectangular section**

B = 2*y (B= canal bed width, y = canal flow depth)

$$R = \frac{y}{2}$$

2. **Econimical triangular section**

Side slope 1:1 or slope angle 45^0



$$R = \frac{y}{2\sqrt{2}}$$

Most Economical Canal Section

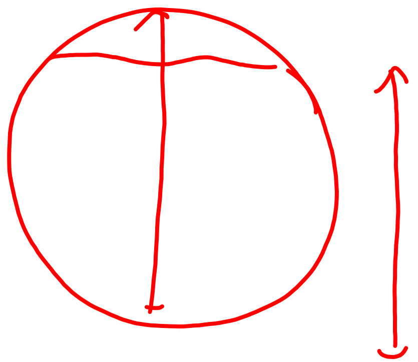
PANA ACADEMY

3. **Economical Trapezoidal section**

Side slope $1:1/\sqrt{3}$ or slope angle 60^0

Top width = 2 * side slope length

Hydraulic mean radius = y / 2



4. **Economical Circular section**

For maximum flow : R=0.29D

d = 0.95*D from chezy and 0.94*D from mannings

For maximum velocity : d = 0.81*D , R=0.3D

D = Diameter of circular canal , d = flow depth

Tractive force Approach

PANA ACADEMY

Mechanism of sediment transport in channels

- The value of average shear stress (τ_o) on bed of alluvial channel at which particle just tend to move is called critical shear stress (τ_c)

$\tau_c > \tau_o$ $\tau_c < \tau_o$

- If the average shear stress is less than critical shear stress, sediments don't move

$\tau_c = \tau_o$

- When the average shear stress just exceeds critical shear, the particles in the bed start to roll
- With further increase in shear stress, the particle goes in suspension and moves downward with the water

Tractive force Approach

Incipient motion condition:

The condition at which the shear force exerted by the flowing water on bed particles just exceeds the force opposing their movement.

Tractive force Approach of canal design

Soil is assumed to be cohesion less.

The force exerted by water in the direction of flow on the channel bed and side is called drag force or tractive force or shear force

At bed

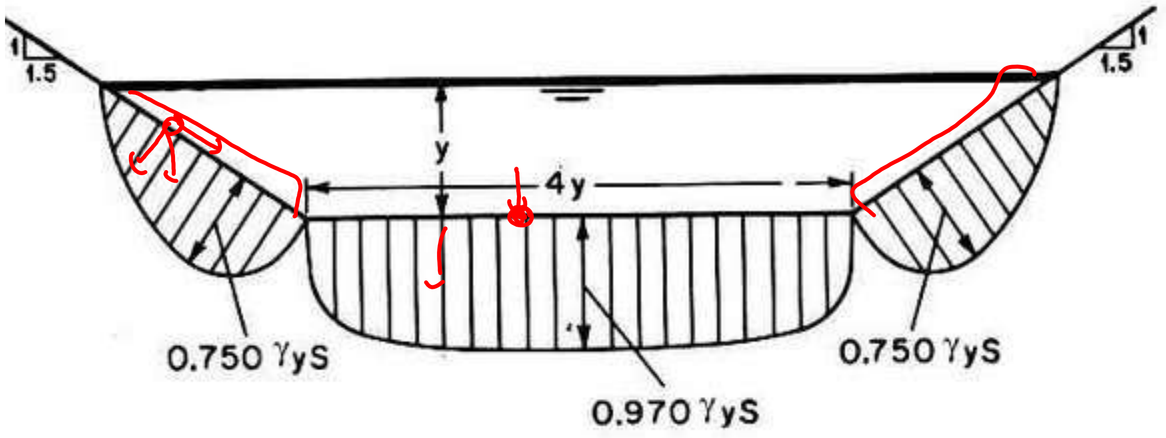
Average tractive force $\tau_o = \gamma_w RS$

Maximum tractive force $\tau_{bm} = 0.97\gamma_w yS$

At side slope

Average tractive force $\tau_o' = 0.75\gamma_w RS$

Maximum tractive force $\tau_{sm} = 0.75\gamma_w yS$



7-6. Distribution of tractive force in a trapezoidal channel section.

Er Dilendra Raj Panta

Tractive force Approach

Hence, for designing non-scouring channels in coarse alluvium

$$\tau_c = \tau_{*c}\gamma_w d(S_c - 1)$$

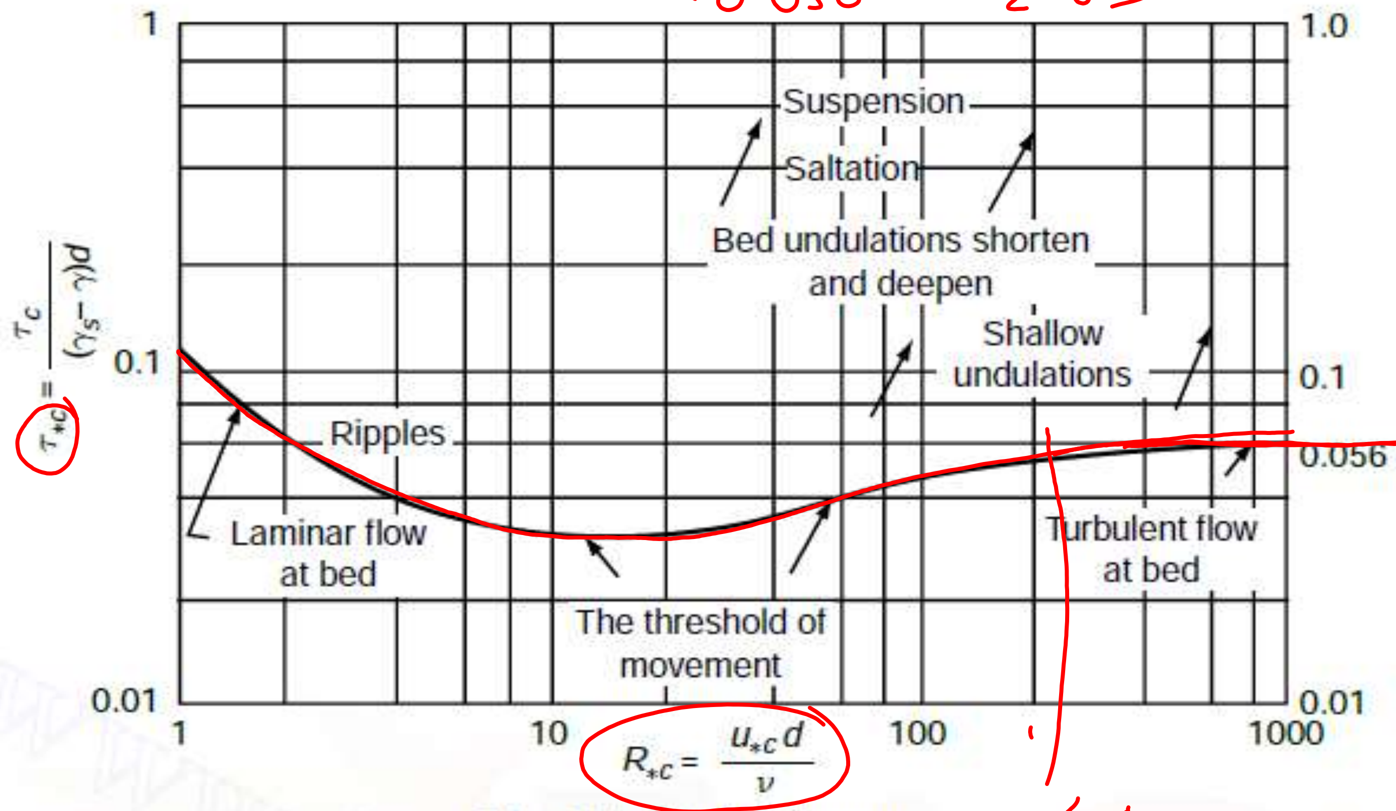


Fig. 11.1 *Shield's diagram*

Er Dilendra Raj Panta

Tractive force Approach

PANA ACADEMY

τ_{*c} = 0.056 for Re>400

For designing alluvium calnal with bed material with diameter

$d_{mm} > 6.0$

Shield's formula $d > 6$ mm

$d \geq 11RS_0$

For stability

$$\tau_c = 0.056\, \gamma_w d(S_c - 1)$$

$$\tau_0 \leq \tau_c$$

$$\gamma_w RS \leq 0.056 * \gamma_w d\ (S_c - 1)$$

(For, $S_c = 2.65$)

$$d \geq 11RS$$

$\tau_0 = 0.97\, \gamma_w y S$

$\tau = \gamma_w R S_0$

(This equation gives the minimum size of the bed material which will remain in rest for given R and S)

Tractive force Approach

PANA ACADEMY

For designing alluvium calnal with bed material with diameter $d_{mm} < 6.0$

$$\tau_c = 0.155 + \frac{0.409 d_{mm}^2}{\left[1 + 0.177 d_{mm}^2\right]^2}$$

$$Tractive\ theory\ ratio\ K = \frac{\tau'_c}{\tau_c} = \sqrt{1 - \frac{\sin^2\theta}{\sin^2\phi}}$$

θ *is inclination of side slope,* ϕ *is internal frictional angle*

The equation shows that the shear stress required to move a particle on the side slope is less than on canal bed.

Design of Unlined alluvial canal Kennedy’s theory

PANA ACADEMY

Kennedy’s Theory

Kennedy carried out research on Upper Bari Doab Canal system in Punjab (Pakistan) having 1:2 (H:V) trapezoidal section.
Side slope is protected

Following are the conslucions drawn from the Kennedy’s theory:

i) Eddies formed due to friction between soil surface and water.
ii) Eddies formed from bed only.
iii) Silt carried by water flowing in a canal is kept in suspension by the vertical component of eddies generated over the full width of the canal.

Design of Unlined alluvial canal Kennedy's theory

PANA ACADEMY

By practical observations, he gave an empirical relation for critical velocity

critical velocity $(v_c) = 0.55mD^{0.64}$

$V_c = 0.55mD^{0.64}$

Where, D= flow depth in meter

m = critical velocity ratio (CVR) which depends on size of silt, grade of silt, silt carrying capacity

Er Dilendra Raj Panta

Design of Unlined alluvial canal Kennedy's theory

PANA ACADEMY

CVR (m) = v_a / v_c

v_a is mean velocity which is calculated using kutter's formula

$$v_a = c\sqrt{RS}\,, where,$$

$$c = \frac{\frac{1}{n} + \left(23 + \frac{0.00155}{S}\right)}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{n}{\sqrt{R}}}$$

R= hydraulic mean depth

S= bed slope of canal

n=rugosity coefficient of canal bed.

property

roughness

n = 0.0225

Design of Unlined alluvial canal Kennedy's theory

PANA ACADEMY

Cases:

1. If CVR = 1, $v_a = v_c$,No silting and No scouring
2. If CVR > 1, $v_a > v_c$, Scouring occurs
3. If CVR < 1, $v_a < v_c$, Silting occurs

Drawbacks of Kennedy's theory

- Eddies formed from bed only.
- Design procedure involves trial and error method
- Kennedy uses kutter's formula. So, all the defects of Kutter's formula are associated with Kennedy's formula.

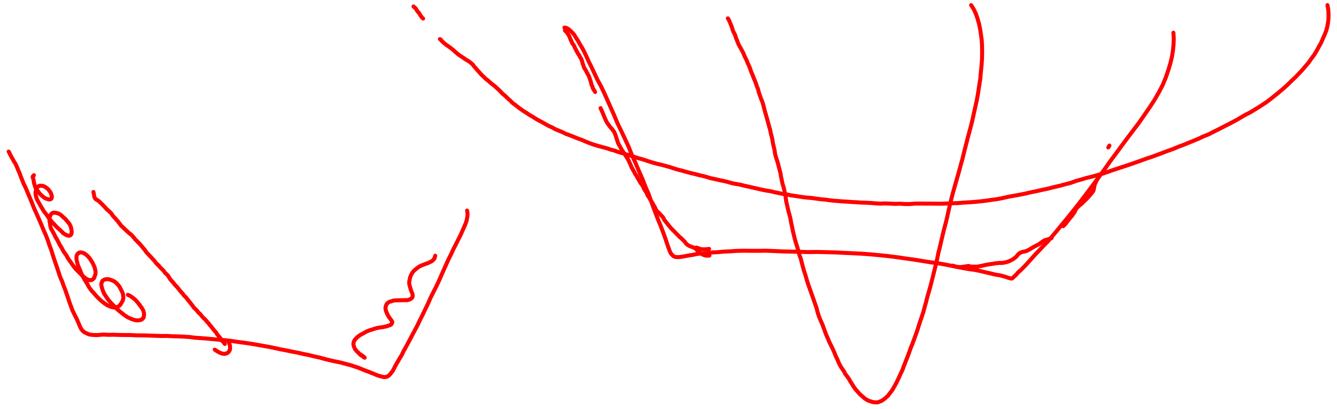
Design of Unlined alluvial canal Lacey's theory

PANA ACADEMY

- Based on the concept of regime theory.
- Eddies generate from whole wetted perimeter i.e. bed and sides.
- Kennedy stated that a channel showing no silting and no scouring is regime channel but lacey came out with the conclusion that even a channel showing no silting and no scouring may not be in regime.

Three regime conditions:

1. True regime
2. Initial regime
3. Final regime



Design of Unlined alluvial canal Lacey's theory

PANA ACADEMY

a) True regime

For the channel to be in true regime following conditions must be satisfied.

- Discharge is constant
- Flow is uniform
- Silt charge is constant
- Silt grade is constant
- Flow takes place in incoherent alluvium.

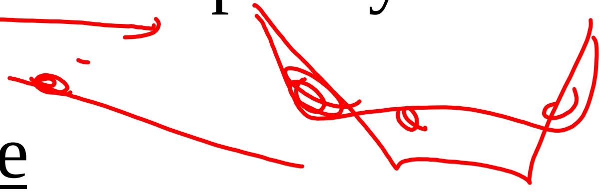
Although lacey theory is applicable in true regime but canal can't practically be in true regime. It means the canal will either be in initial regime or final regime

Design of Unlined alluvial canal Lacey's theory

PANA ACADEMY

b) Initial regime

- When only bed slope and depth varies due to silting and its slope, wetted perimeter remains unaffected then a canal may show no silting and no scouring condition called as Initial Regime.
- This regime is temporary and lacey theory is not applicable.



c) Final regime

- When all parameters such as wetted perimeter, side slope, bed slope vary and finally get adjusted to achieve permanent stability then this condition is called as final regime condition.
- Lacey theory is applicable to final regime condition.

Design of Unlined alluvial canal Lacey's theory

PANA ACADEMY

Relations derived from Lacey's fundamental formulas

Silt factor

$$f = 1.76\sqrt{d_{50}}, d_{50} \text{ in mm}$$

Flow velocity, discharge and silt factor relation

$$v = \left(\frac{Qf^2}{140}\right)^{\frac{1}{6}}$$

Perimeter discharge relation

$$P = 4.75\sqrt{Q}$$

Hydraulic Radius

$$R = \frac{5}{2}\left(\frac{v^2}{f}\right)$$

Design of Unlined alluvial canal Lacey's theory

PANA ACADEMY

Regime slope

$$S = \frac{f^{\frac{5}{3}}}{3340Q^{\frac{1}{6}}} = \frac{f^{\frac{3}{2}}}{49800R^{\frac{1}{6}}}$$

For very wide canal regime width = wetted perimeter for such canal

Scour depth (R)

$$R = 0.473\left(\frac{Q}{f}\right)^{\frac{1}{3}}$$

For all other Scour depth (R)

$$R = 1.35\left(\frac{q^2}{f}\right)^{\frac{1}{3}}$$

Design of Unlined alluvial canal Lacey's theory

For regime flow, velocity is

$$v = 10.8R^{\frac{2}{3}}S^{\frac{2}{3}}$$

For non regime flow, velocity $v \propto R^{\frac{3}{4}}$