CHAPTER 07

CANAL DESIGN

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LECTURE 17

Canal Design Types

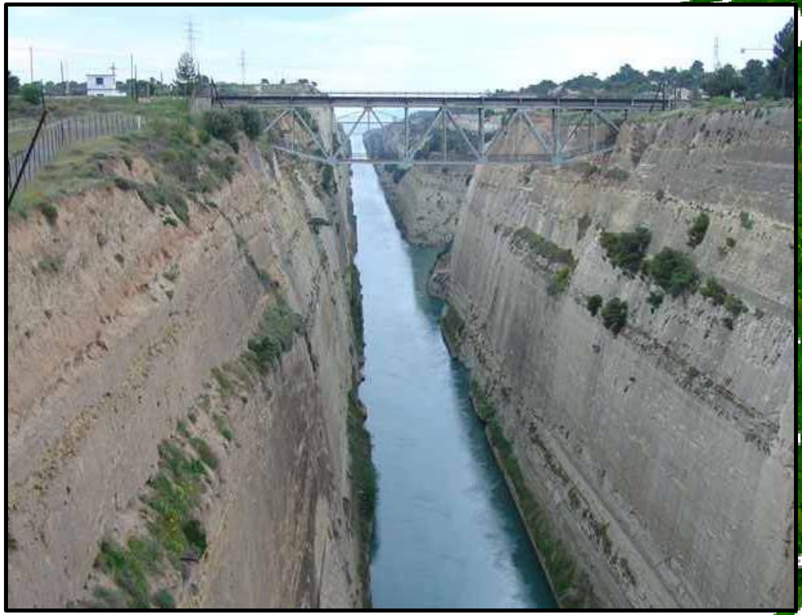
Canal Design

- Drainage Channel Design
- Irrigation Canal Design

Topic will be discussed……. →

Design Parameters

- The design considerations naturally vary according to the type of soil.
- Velocity of flow in the canal should be ***critical***.
- Design of canals which are known as '*Kennedy's theory*' and '*Lacey's theory*' are based on the characteristics of sediment load (i.e. silt) in canal water.



Important Terms Related to Canal Design

- Alluvial soil
- Non-alluvial soil
- Silt factor
- Co-efficient of rugosity
- Mean velocity
- Critical velocity
- Critical velocity ratio (c.v.r), m
- Regime channel
- Hydraulic mean depth
- Full supply discharge
- Economical section

Alluvial Soil

The soil which is formed by the continuous deposition of silt is known as **alluvial soil**. The river carries heavy charge of silt in rainy season. When the river overflows its banks during the flood, the silt particles get deposited on the adjoining areas. This deposition of silt continues year after year. This type of soil is found in deltaic region of a river. This soil is permeable and soft and very fertile. The river passing through this type of soil has a tendency to change its course.

Non-alluvial Soil

The soil which is formed by the disintegration of rock formations is known as **non-alluvial soil**. It is found in the mountainous region of a river. The soil is hard and impermeable in nature. This is not fertile. The river passing through this type of soil has no tendency to change its course.

Silt Factor

During the investigations works in various canals in alluvial soil, *Gerald Lacey* established the effect of silt on the determination of discharge and the canal section. So, Lacey introduced a factor which is known as '**silt factor**'.

It depends on the mean particle size of silt. It is denoted by 'f'. The silt factor is determined by the expression,

$$f = 1.76 \sqrt{d_{mm}}$$

where d_{mm} = mean particle size of silt in mm

Particle	Particle size (mm)	Silt factor (f)
Very fine silt	0.05	0.40
Fine silt	0.12	0.60
Medium silt	0.23	0.85
Coarse silt	0.32	1.00

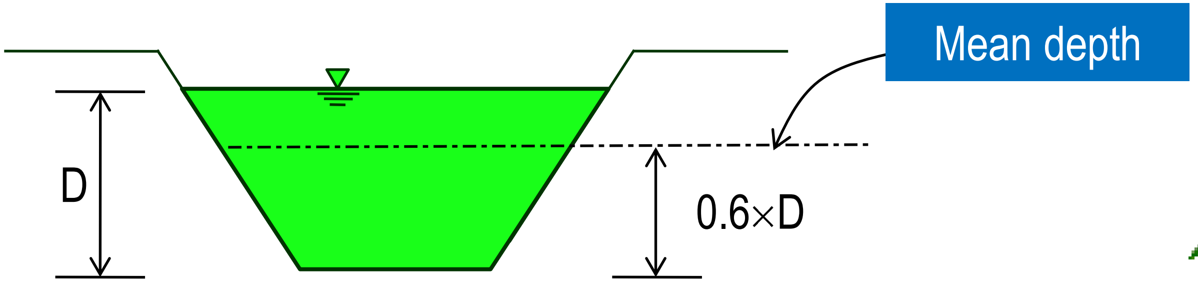
Coefficient of Rugosity (n)

The roughness of the canal bed affects the velocity of flow. The roughness is caused due to the ripples formed on the bed of the canal. So, a coefficient was introduced by *R.G Kennedy* for calculating the mean velocity of flow. This coefficient is known as coefficient of rugosity and it is denoted by ‘n’. The value of ‘n’ depends on the type of bed materials of the canal.

Materials	Value of n
Earth	0.0225
Masonry	0.02
Concrete	0.013 to 0.018

Mean Velocity

It is found by observations that the velocity at a depth 0.6D represents the mean velocity (V), where 'D' is the depth of water in the canal or river.



(a) Mean Velocity by Chezy's expression:

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

(a) Mean Velocity by Manning's expression:

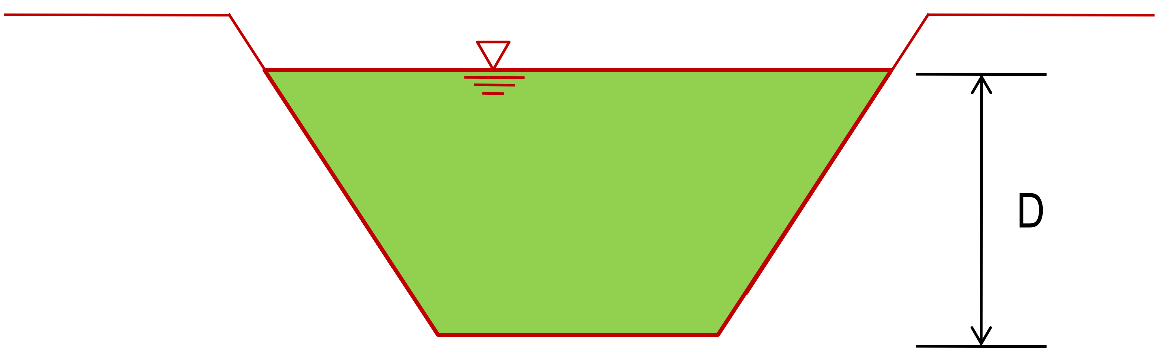
$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Critical velocity

When the velocity of flow is such that there is no silting or scouring action in the canal bed, then that velocity is known as **critical velocity.** It is denoted by 'V_o'. The value of V_o was given by Kennedy according to the following expression,

$$V_o = 0.546 \times D^{0.64}$$

; where, D = Depth of water



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Critical velocity ratio (C.V.R)

The ratio of mean velocity 'V' to the critical velocity 'V_o' is known as critical velocity ratio (CVR). It is denoted by *m* i.e.

$$CVR\ (m) = V/V_o$$

When m = 1, there will be no silting or scouring.
When m > 1, scouring will occur
When m < 1, silting will occur

So, by finding the value of *m*, the condition of the canal can be predicted whether it will have silting or scouring

Regime Channel

When the character of the bed and bank materials of the channel are same as that of the transported materials and when the silt charge and silt grade are constant, then the channel is said to be in its regime and the channel is called regime channel. This ideal condition is not practically possible.

Hydraulic Mean Depth/Ratio

The ratio of the cross-sectional area of flow to the wetted perimeter of the channel is known as hydraulic mean depth or radius. It is generally denoted by R.

$$R = A/P$$

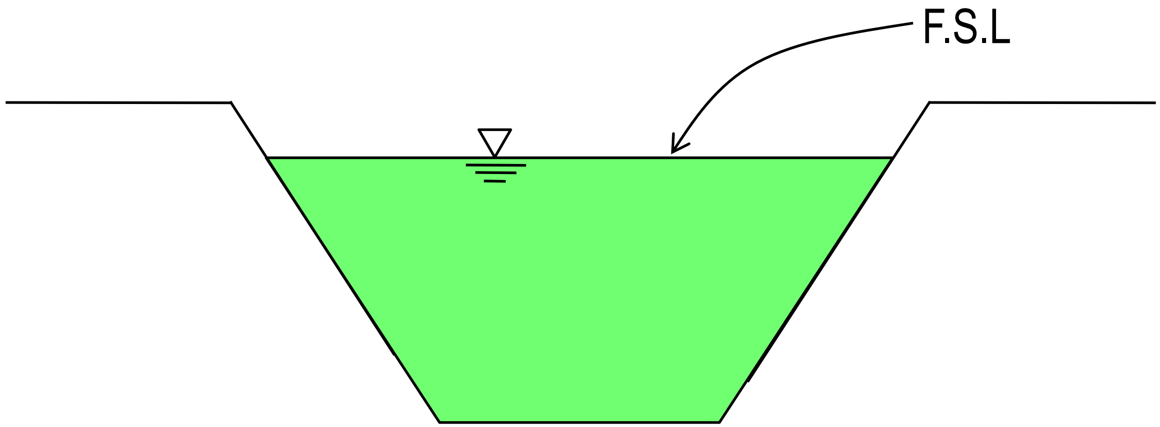
Where,

A = Cross-sectional area

P = Wetted perimeter

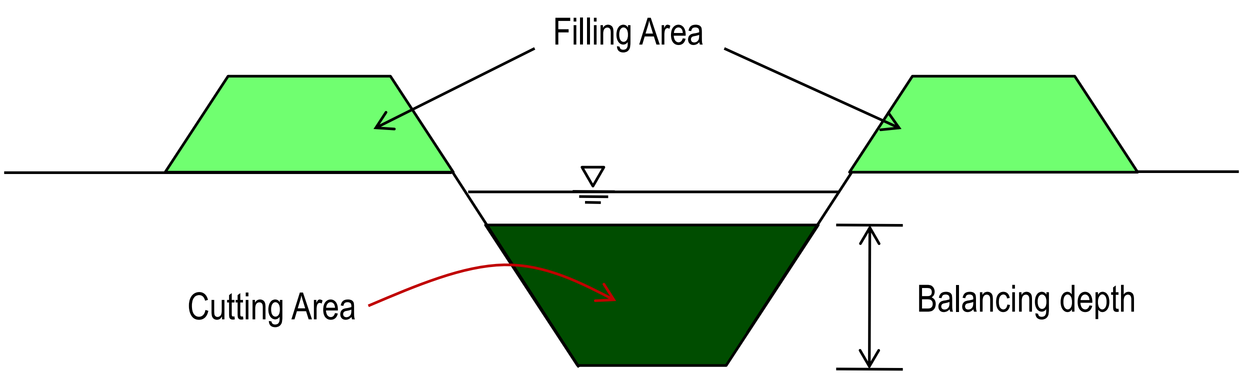
Full Supply Discharge

The maximum capacity of the canal for which it is designed, is known as full supply discharge. The water level of the canal corresponding to the full supply discharge is known as **full supply level (F.S.L).**



Economical Section

If a canal section is such that the earth obtained from cutting (i.e. excavation) can be fully utilized in forming the banks, then that section is known as **economical section**. Again, the discharge will be maximum with minimum cross-section area. Here, no extra earth is required from borrow pit and no earth is in excess to form the spoil bank. This condition can only arise in case of partial cutting and partial banking. Sometimes, this condition is designated as balancing of cutting and banking. Here, the depth of cutting is called **balancing depth**.



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Unlined Canal Design on Non-alluvial soil

The non-alluvial soils are stable and nearly impervious. For the design of canal in this type of soil, the coefficient of rugosity plays an important role, but the other factor like silt factor has no role. Here, the velocity of flow is considered very close to critical velocity. So, the mean velocity given by Chezy's expression or Manning's expression is considered for the design of canal in this soil. The following formulae are adopted for the design.

(1) Mean velocity by Chezy's formula

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

Where,

V = mean velocity in m/sec,

C = Chezy's constant,

R = hydraulic mean depth in m

S = bed slope of canal as 1 in *n*.

Again, the Chezy's constant C can be calculated by:

(a) Bazin's Formula:

$$C = \frac{87}{1+\frac{K}{\sqrt{R}}}$$

Where,

K = Bazin's constant,

R = hydraulic mean depth

(b) Kutter's Formula:

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

Where,

n = Co-efficient of rugosity,

S = bed slope,

R = hydraulic mean depth

(2) Mean velocity by Manning's formula

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

(3) Discharge by the following equations:

$$Q = A \times V$$

Where,

Q = discharge in cumec

A = cross-sectional area of water section in m^2

V = mean velocity in m/sec

Note:

- If value of K is not given, then it may be assumed as follows,
  - For unlined channel, K = 1.30 to 1.75.
  - For line channel, K = 0.45 to 0.85
- If the value of N is not given, then it may be assumed as follows,
  - For unlined channel, N = 0.0225
  - For lined channel, N = 0.333

Problem

Design an irrigation channel with the following data:
Discharge of the canal = 24 cumec
Permissible mean velocity = 0.80 m/sec.
Bed slope = 1 in 5000
Side slope = 1:1
Chezy's constant, C = 44

Solution:

We know, $A = 24/0.80 = 30\ m^2$

$$30 = (B + D)D$$

And $P = B + 2.828\ D$

But, $R = 30/(B + 2.828\ D)$

From Chezy's formula, $V = C\sqrt{RS}$

$$\Rightarrow 0.80 = 44 \times \sqrt{R \times 0.0002}$$

$$\therefore R = 1.65\ m$$

Putting the value of R and solving, D = 2.09 m and B = 12.27 m

Exercise Problems

Problem – 1

Design a most economical trapezoidal section of a canal having the following data:
Discharge of the canal = 20 cumec
Permissible mean velocity = 0.85 m/sec.
Bazin's constant, K = 1.30
Side slope = 1.5:1
Find also the allowable bed slope of the canal

Problem – 2

Find the bed width and bed slope of a canal having the following data:
Discharge of the canal = 40 cumec
Permissible mean velocity = 0.95 m/sec.
Coefficient of rugosity, n = 0.0225
Side slope = 1:1
B/D ratio = 6.5

Problem – 3

Find the efficient cross-section of a canal having the discharge 10 cumec. Assume, bed slope 1 in 5000, value of *n* = 0.0025, C.V.R (m) = 1, full supply depth not to exceed 1.60 m and side slope = 1:1

Unlined Canal Design on Alluvial soil by Kennedy's Theory

After long investigations, R.G Kennedy arrived at a theory which states that, the silt carried by flowing water in a channel is kept in suspension by the vertical component of eddy current which is formed over the entire bed width of the channel and the suspended silt rises up gently towards the surface.

The following assumptions are made in support of his theory:

- The eddy current is developed due to the roughness of the bed.
- The quality of the suspended silt is proportional to bed width.
- It is applicable to those channels which are flowing through the bed consisting of sandy silt or same grade of silt.
- It is applicable to those channels which are flowing through the bed consisting of sandy silt or same grade of silt.

Continue…. Kennedy's Theory

He established the idea of critical velocity 'V_o' which will make a channel free from silting or scouring. From, long observations, he established a relation between the critical velocity and the full supply depth as follows,

$$V_o = C \times D^n$$

The values of C and n where found out as 0.546 and 0.64 respectively, thus

$$V_o = 0.546 \times D^{0.64}$$

Again, the realized that the critical velocity was affected by the grade of silt. So, he introduced another factor (m) which is known as critical velocity ratio (C.V.R).

$$V_o = 0.546 \times m \times D^{0.64}$$

Drawbacks of Kennedy's Theory

- The theory is limited to average regime channel only.
- The design of channel is based on the trial and error method.
- The value of m was fixed arbitrarily.
- Silt charge and silt grade are not considered.
- There is no equation for determining the bed slope and it depends on Kutter's equation only.
- The ratio of 'B' to 'D' has no significance in his theory.

Design Procedure

- Critical velocity, $V_o = 0.546 \times m \times D^{0.64}$.
- Mean velocity, $V = C \times (RS)^{1/2}$

Where, m = critical velocity ratio,
D = full supply depth in m,
R = hydraulic mean depth of radius in m,
S = bed slope as 1 in 'n'.

The value of 'C' is calculated by Kutter's formula,

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

Where, n = rugosity coefficient which is taken as unlined earthen channel.

- B/D ratio is assumed between 3.5 to 12.
- Discharge, $Q = A \times V$.

Where, A = Cross-section area in m^2,
V = mean velocity in m/sec

- The full supply depth is fixed by trial to satisfy the value of 'm'. Generally, the trial depth is assumed between 1 m to 2 m. If the condition is not satisfied within this limit, then it may be assumed accordingly.

Problem

Design an irrigation channel with the following data:
Full supply discharge = 6 cumec
Rugosity coefficient (n) = 0.0225
C.V.R (m) = 1
Bed slope = 1 in 5000
Assume other reasonable data for the design

Solution:

First Trial:

Assume, Full supply depth, D = 1.5 m

Critical velocity, $V_o = 0.546 \times 1 \times 1.5^{0.64} = 0.707$ [Assume, m = 1]

As m = 1, $V = V_o$

$\therefore A = 6/0.707 = 8.49$ m

$A = (2B + 3)/2 \times 1.5 = 1.5B + 2.25 \Rightarrow B = 4.16$ m

$P = B + 2\sqrt{2} \times 1.5 = B + 4.24 = 8.40$ m

$R = 4.16/8.40 = 1.0$ m

By Kutter's formula, $C = \left[\dfrac{\dfrac{1}{0.0225} + \left(23 + \dfrac{0.00155}{0.0002}\right)}{1 + \left(23 + \dfrac{0.00155}{0.0002}\right)\dfrac{0.0225}{\sqrt{1.0}}} \right] = 44.49$

By Chezy's formula, $V = 44.49 \times \sqrt{(1 \times 0.0002)} = 0.629$ m/sec

C.V.R = 0.629/0.707 = 0.889 < 1

As the C.V.R is much less than 1, the channel will be in silting. So, the design is not satisfactory. Here, the full supply depth is to be assumed by trials to get the satisfactory result.

Second Trial:

Assume, Full supply depth, D = 1.25 m

Critical velocity, $V_o = 0.546 \times 1 \times 1.25^{0.64} = 0.629$ [Assume, m = 1]

As m = 1, $V = V_o$

$\therefore A = 6/0.629 = 9.53$ m

$A = 1.25B + 1.56 \Rightarrow B = 6.38$ m

$P = B + 2\sqrt{2} \times 1.25 = 9.92$ m

R = 0.96 m

By Kutter's formula, $C = \left[\dfrac{\dfrac{1}{0.0225} + \left(23 + \dfrac{0.00155}{0.0002}\right)}{1 + \left(23 + \dfrac{0.00155}{0.0002}\right)\dfrac{0.0225}{\sqrt{0.96}}} \right] = 44.23$

By Chezy's formula, $V = 44.23 \times \sqrt{(1 \times 0.0002)} = 0.613$ m/sec

C.V.R = 0.613/0.629 = 0.97 < 1

In this case, the CVR is very close to 1. So, the design may be accepted. So, finally,

D = 1.25 m and B = 6.28 m

Exercise Problems

Problem – 1

Find the maximum discharge through an irrigation channel having the bed width 4 m and fully supply depth is 1.50 m. Given that n = 0.02, S = 0.0002, side slope = 1:1

Assume reasonable data, if necessary. Comment whether the channel will be in scouring or silting.

Problem – 2

Design an irrigation channel with the following data:

Full supply discharge = 10 cumec

Bazin's constant, K = 1.3

C.V.R (m) = 1

B/D ratio = 4

Side slope = 1:1

Assume other reasonable data for the design

LECTURE 19

Unlined Canal Design on Alluvial soil by Lacey's Theory

Lacey's theory is based on the concept of regime condition of the channel. The regime condition will be satisfied if,

- ❑ The channel flows uniformly in unlimited incoherent alluvium of the same character which is transported by the channel.
- ❑ The silt grade and silt charge remains constant.
- ❑ The discharge remains constant.

In his theory, he states that the silt carried by the flowing water is kept in suspension by the vertical component of eddies. The eddies are generated at all the points on the wetted perimeter of the channel section. Again, he assumed the hydraulic mean radius *R*, as the variable factor and he recognized the importance of silt grade for which in introduced a factor which is known as silt factor '*f*'.

Thus, he deduced the velocity as; $V = \sqrt{(2/5 f R)}$

Where, V = mean velocity in m/sec, f = silt factor,

R = hydraulic mean radius in meter

Then he deduced the relationship between A, V, Q, P, S and f are as follows:

- $f = 1.76 \times \sqrt{d_{mm}}$
- $Af^2 = 140 \times V^5$
- $V = \left(\frac{Q \times f^2}{140}\right)^{1/6}$
- $P = 4.75 \times \sqrt{Q}$
- Regime flow equation, $V = 10.8 \times R^{2/3} S^{1/3}$
- Regime slope equation,

(a) $S = \frac{f^{3/2}}{4980 \times R^{1/3}}$

(b) $S = \frac{f^{5/2}}{3340 \times Q^{1/6}} \Rightarrow Q = \left[\frac{f^{5/3}}{3340 \times S}\right]^6$

- Regime scour depth, $R = 0.47 \times \left(\frac{Q}{f}\right)^{1/3}$

Problem

Design an irrigation channel with the following data:

Full supply discharge = 10 cumec

Mean diameter of silt particles = 0.33 mm

Side slope = ½:1

Find also the bed slope of the channel

Solution:

f = 1.76 $\times\sqrt{0.33}$ = 1.0 and V = $\left(\frac{Q\times 1^2}{140}\right)^{1/6}$ = 0.64 m/sec

A = 10/0.64 = 15.62 m^2

P = 4.75 $\times\sqrt{10}$ = 15.02 m

R = 0.47$\times$(10/1)$^{1/3}$ = 1.02 m

S = $\frac{1^{5/2}}{3340\times 10^{1/6}}$ = 1/4902

But, A = BD + 0.5 D^2

$\Rightarrow$ 15.62 = BD + 0.5 D^2 ------------------- (i)

P = B + $\sqrt{5}$D

15.02 = B + 2.24 D ------------------------- (ii)

Solving equation (i) & (ii) D = 1.21 m and B = 12.30 m

Exercise Problem

Problem – 1

Find the section and maximum discharge of a channel with the following data:

Bed slope = 1 in 5000

Lacey's silt factor = 0.95

Side slope = 1:1

Drawbacks of Lacey's Theory

- The concept of true regime is theoretical and con not be achieved practically.
- The various equations are derived by considering the silt factor f which is not at all constant.
- The concentration of silt is not taken into account.
- Silt grade and silt charge is not taken into account.
- The equations are empirical and based on the available data from a particular type of channel. So, it may not be true for a different type of channel.
- The characteristics of regime channel may not be same for all cases.

Comparison between Kennedy's and Lacey's theory

Kennedy's theory	Lacey's theory
It states that the silt carried by the flowing water is kept in suspension by the vertical component of eddies which are generated from the bed of the channel.	It states that the silt carried by the flowing water is kept in suspension by the vertical component of eddies which are generated from the entire wetted perimeter of the channel.
It gives relation between 'V' and 'D'.	It gives relation between 'V' and 'R'.
In this theory, a factor known as critical velocity ratio 'm' is introduced to make the equation applicable to different channels with different silt grades.	In this theory, a factor known as silt factor 'f' is introduced to make the equation applicable to different channels with different silt grades.
In this theory, Kutter's equation is used for finding the mean velocity.	This theory gives an equation for finding the mean velocity.
This theory gives no equation for bed slope.	This theory gives an equation for bed slope.
In this theory, the design is based on trial and error method.	This theory does not involve trial and error method.

Design of Lined Canal

The lined canals are not designed by the use of Lacey's and Kennedy's theory, because the section of the canal is rigid. Manning's equation is used for designing. The design considerations are,

- The section should be economical (i.e. cross-sectional area should be maximum with minimum wetted perimeter).
- The velocity should be maximum so that the cross-sectional area becomes minimum.
- The capacity of lined section is not reduced by silting.

Section of Lined Canal:
The *following two* lined sections are generally adopted:

❑ Circular section:

The bed is circular with its center at the full supply level and radius equal to full supply depth ‘D’. The sides are tangential to the curve. However, the side slope is generally taken as 1:1.

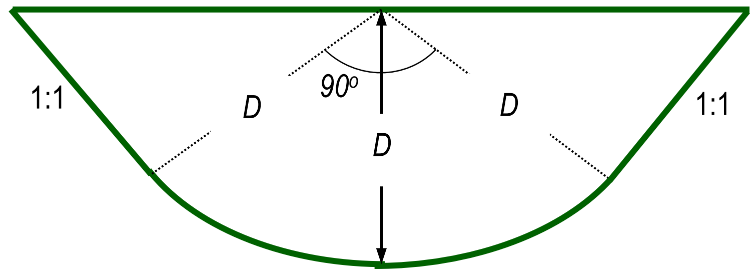

Table – 1:Design parameters for circular section

Design parameter	Side slope		
	1:1	1.5:1	1.25:1
Sectional area (A)	$1.785\times D^2$	$2.088\times D^2$	$1.925\times D^2$
Wetted perimeter (P)	$3.57\times D$	$4.176\times D$	$3.85\times D$
Hydraulic mean depth or radius (R)	$0.5\times D$	$0.5\times D$	$0.5\times D$
Velocity (V)	$V = (1/n)\times R^{2/3}\times S^{1/2}$	–	–
Discharge (Q)	$A\times V$	–	–

❑ Trapezoidal section:

The horizontal bed is joined to the side slope by a curve of radius equal to full supply depth D. The side slope is generally kept as 1:1

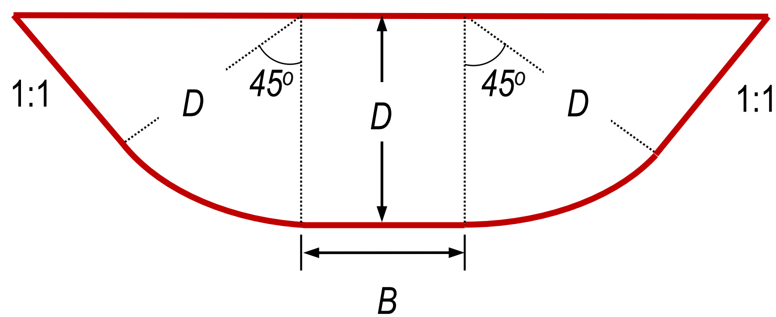

Table – 2:Design parameters for circular section

Design parameter	Side slope		
	1:1	**1.5:1**	**1.25:1**
Sectional area (A)	$BD + 1.785 \times D^2$	$BD + 2.088 \times D^2$	$BD + 1.925 \times D^2$
Wetted perimeter (P)	$B + 3.57 \times D$	$B + 4.176 \times D$	$B + 3.85 \times D$
Hydraulic mean depth or radius (R)	A/P	A/P	A/P
Velocity (V)	$V = (1/n) \times R^{2/3} \times S^{1/2}$	–	–
Discharge (Q)	$A \times V$	–	–

Note: For the discharge up to 50 cumec, the circular section is suitable and for the discharge above 50 cumec trapezoidal section is suitable.

Problem - 1

Design a lined canal to carry a discharge of 40 cumec. Assume bed slope as 1 in 5000, N = 0.0225 and side slope – 1:1

Solution:

Since the discharge is less than 50 cumec, the circular section is suitable slope as 1 in 5000, n = 0.0225 and side slope = 1:1

From table 1, $A = 1.785\ D^2$

$P = 3.57\ D$

$R = 1.785\ D^2/3.57D = 0.5\ D$

Again, $V = (1/0.0225) \times (0.5D)^{2/3} \times (0.0002)^{1/2} = 0.38 \times D^{2/3}$

But, $50 = 1.785\ D^2 \times\ 0.38 \times D^{2/3}$

$\therefore\ D = 4.61$ m

$V = 1.05$ m/s

$A = 37.93\ m^2$

$P = 16.45$ m

Problem - 2

Design a lined canal having the following data:

Full supply discharge = 200 cumec
Side slope = 1.25:1
Bed slope = 1 in 5000
Rugosity coefficient = 0.018
Permissible velocity = 1.75 cumec

Solution:

Since the discharge is more than 50 cumec, the trapezoidal section will be acceptable.

From table – 2,

Sectional area, $A = BD + 1.925\,D^2$ -------------- (i)

Wetted perimeter, $P = B + 3.85\,D$ ------------- (ii)

Now, $A = 200/1.75 = 114.28\ m^2$

Again, $V = (1/n)\times R^{2/3}\times S^{1/2}$

$\Rightarrow 1.75 = (1/0.018)\times R^{2/3}\times(0.0002)^{1/2}$

$\therefore\ R = 3.32$ m

$P = 114.28/3.32 = 34.42$ m

From equation (i) $\Rightarrow 114.28 = BD + 1.925\times D^2$

From equation (ii) $\Rightarrow 34.42 = B + 3.85\times D$

Solving equation (i) & (ii) $\Rightarrow D = 4.4$ m (Full supply depth)

$\therefore\ B = 17.5$ m (Bed width)

END OF CHAPTER – 7