Design of Irrigation Canals

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Unlined Canal

Introduction

Introduction

A river in alluvium carries huge quantity of sediments alongwith water. This sediment comprises soil particles of various sizes ranging from fine silt to coarse sand. Sediments are either carried in suspension or get deposited on the river bed. A portion of this sediment is also received by the irrigation canals which draw water directly from the river.

In case of unlined alluvial canals, the quantity of silt transported may vary from section to section due to scouring of bed and sides of the canal, as well as silting (deposition of silt) at any section.

If the velocity of flow in a canal is high, then bed and sides of a canal will be scoured. On the other hand, silting may take place on bed and sides if velocity of flow is low. Both silting and scouring changes the cross section of the canal.

Unlined alluvial canals should be designed for such a velocity that no silting and no scouring will occur. This velocity is known as non-silting and non-scouring velocity.

Regime Method

Introduction

Cross section of a stable alluvial canal would depend on the flow rate, sediment transport rate and the sediment size. One method of designing an alluvial canal section is based of the *regime* approach in which a set of empirical equations is used. These equations have been obtained by analyzing the data of stable field channels.

Regime methods for the design of stable channels were first developed by the British engineers working for canal irrigation in India in the nineteenth century. At that time problem of sediment deposition was one of the major problems of canal design in India. In order to find a solution to this problem, some of the British engineers studied the behaviour of such streches of the existing canals where the bed was in a state of *stable equilibrium*.

These stable reaches had not required any sediment clearence for several years of canal operation. Such canals were called *regime canals*. These canals generally carried a sediment load smaller that 500 ppm. Suitable relationships for the velocity of flow in regime canals were evolved. These relationships are known as *regime equations* which find acceptance in other parts of the world as well.

The regime relations do not account for the sediment load and hence, should be considered valid when the sediment load is not large.

Two widely accepted regime method of canal deisgn are *Kennedy's method* and *Lacey's* method.

Kennedy's Method

R. G. Kennedy (Executive Engineer, Irrigation Department, Punjab) collected data from 22 canals of Upper Bari Doab canal system in Punjab. His observations in this canal system led him to conclude that the sediment in a canal is kept in suspension solely by the vertical component of the eddies which are generated on the channel bed. In his opinion, the eddies generating on the sides of the canal had horizontal movements for greater part and therefore did not have sediment transport power.

This means the sediment supporting power of a canal is proportional to its width and not wetted perimeter.

Kennedy's Equation

On plotting the observed data, Kennedy obtained the following relation, known as Kennedy's equation.

$$U_0 = 0.55D^{0.64}$$

Kennedy termed U_0 as the *critical velocity* (in m/s), defined as the mean velocity which do not allow scouring or silting in a canal having depth of flow equal to D (in m). This equation is obviously applicable to such channels which have the same type of sediment as was presented in the Upper Bari Doab canal system.

On recognizing the effect of the sediment size on the critical velocity, Kennedy modified the above equation,

$$U = 0.55mD^{0.64}$$

in which m is the critical velocity ratio, and is equal to U/U_0. Here U is the critical velocity for all sizes of sediment while U_0 is the critical velocity for the Upper Bari Doab sediment.

Kennedy's Method

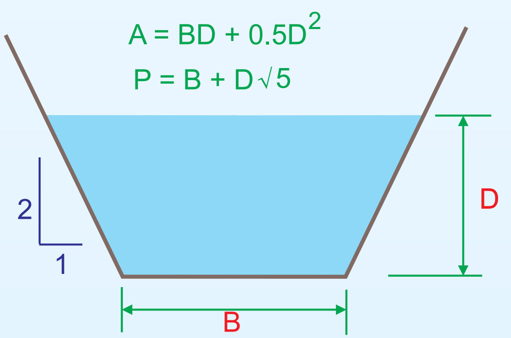
Kennedy did not try to establish any other relationship for the slope of regime canals in terms of either the critical velocity or the depth of flow. He suggested the use of Kutter's equation alongwith Mannig's roughness coefficient. The final result do not differ much if one uses the Manning's equation instead of Kutter's equation. Thus the equations

$$U = 0.55mD^{0.64}$$

$$Q = AU$$

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

enable one to determine the unknowns B, D and U for Given Q, n and m, is the longitudinal slope is specified.



Typical Canal Section

Design Procedure

Case 1: Given: Design discharge Q, Manning's roughness coefficient n, critical velocity ratio (CVR) m and bed slope S

Steps

1. Assume a trial value of D (m)
2. Calculate the critical velocity from Kennedy's equation: $U = 0.55mD^{0.64}$(m/s)
3. Calculate cross sectional area, $A = Q/V$ (m^2)
4. Assume side slopes as 1H:2V and calculate B from $A = BD + (D^2/2)$. That is, $B = (A/D) - 0.5D$
5. Calculate wetted perimeter, $P = B + D\sqrt{5}$
6. Calculate mean hydraulic radius, $R = A/P$
7. Calculate average velocity $U = \frac{1}{n} R^{2/3} S^{1/2}$
8. U from step 2 and U from step 7 should be almost equal. If not, change D and repeat the calculations from steps 2 to 7.

Design Procedure

Case 2: Given: Design discharge Q, Manning's roughness coefficient n, critical velocity ratio (CVR) m and B/D ratio

Let us assume $B/D = c$. (c is given)

Then $B = cD$. So, $A = BD + D^2/2 = cD^2 + D^2/2 = (c + 0.5)D^2$

Now from Kennedy's equation, $U = 0.55mD^{0.64}$

So, $Q = AV = (c + 0.5)D^2 \times 0.55mD^{0.64} = 0.55m(c + 0.5)D^{2.64}$

Then, calculate

1. Depth, $D = \left[\frac{Q}{0.55\, m\, (c+0.5)}\right]^{1/2.64}$
2. Bed width, $B = c.D$
3. Mean hydraulic radius, $R = \frac{BD+0.5D^2}{B+D\sqrt{5}}$
4. Critical velocity, $U = 0.55mD^{0.64}$
5. Bed slope, $S = \frac{n^2U^2}{R^{4/3}}$

Example

Design an irrigation canal carrying a discharge of 30 m^3/s with critical velocity ratio m and Manning's n equal to 1.0 and 0.0225 respectively. Assume bed slope as 1 in 5000 and side slopes as 1H:2V.

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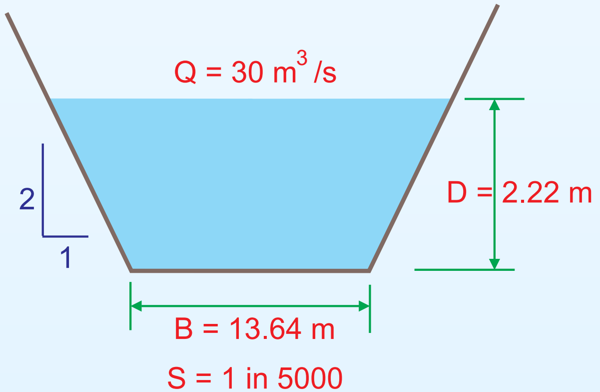
Solution

D (m)	U (m/s)	A (m^2)	B (m)	P (m)	R (m)	U (m/s)	Remarks
2.000	0.8571	35.003	16.501	20.973	1.669	0.8843	Increase D
2.500	0.9887	30.344	10.888	16.478	1.842	0.9443	Decrease D
2.250	0.9242	32.461	13.302	18.333	1.771	0.9199	Decrease D
2.150	0.8977	33.419	14.469	19.276	1.734	0.9071	Increase D
2.200	0.9110	32.931	13.869	18.788	1.753	0.9137	Increase D
2.220	0.9163	32.741	13.638	18.602	1.760	0.9163	OK



Design Canal Section

Question

Design an irrigation channel to carry a discharge of 5 m^3/s. Assume Manning's n = 0.0225 and critical velocity ratio m = 1. The channel has a bed slope of 0.2 m per km.

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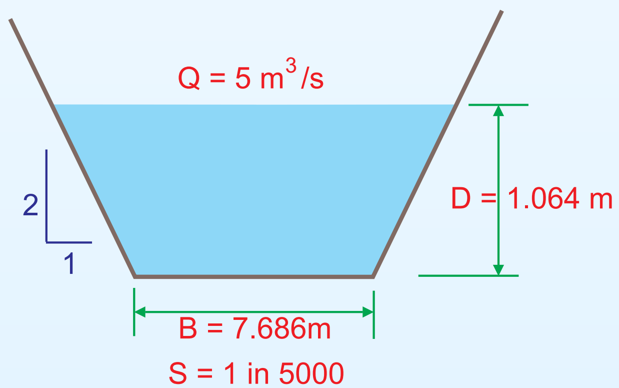
D (m)	U (m/s)	A (m2)	B (m)	P (m)	R (m)	U (m/s)	Remarks
1.0000	0.5500	9.091	8.591	10.827	0.840	0.5594	Increase D
1.1000	0.5846	8.553	7.225	9.685	0.883	0.5785	Decrease D
1.0500	0.5674	8.811	7.867	10.215	0.863	0.5696	Increase D
1.0600	0.5709	8.758	7.732	10.103	0.867	0.5715	Increase D
1.0650	0.5726	8.732	7.666	10.048	0.869	0.5724	Decrease D
1.0635	0.5721	8.740	7.686	10.064	0.868	0.5721	OK



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Solution

Assuming side slopes as 1H:2V, Area $A = BD + 0.5D^2$.

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Hence, $D = \left[\frac{Q}{0.55m\,[0.5+(B/D)]}\right]^{1/2.64} = \left[\frac{5}{0.55\times 1\,[0.5+3.24]}\right]^{1/2.64} =$ 1.4 m

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Mean hydraulic radius, $R = \frac{BD+0.5D^2}{B+D\sqrt{5}} = \frac{1.4\times 4.536+0.5\times 1.4^2}{4.536+1.4\sqrt{5}} =$ = 0.956 m

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Design an irrigation canal to carry a discharge of 5 m^3/s. Assume Manning's n = 0.0225, critical velocity ratio m =1 and B/D = 3.24.

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Assuming side slopes as 1H:2V, Area $A = BD + 0.5D^2$.

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Critical velocity, $U = 0.55mD^{0.64} = 0.55 \times 1 \times 1.4^{0.64} =$ 0.682 m/s

Example

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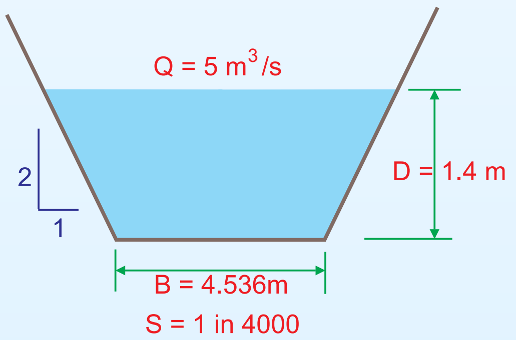
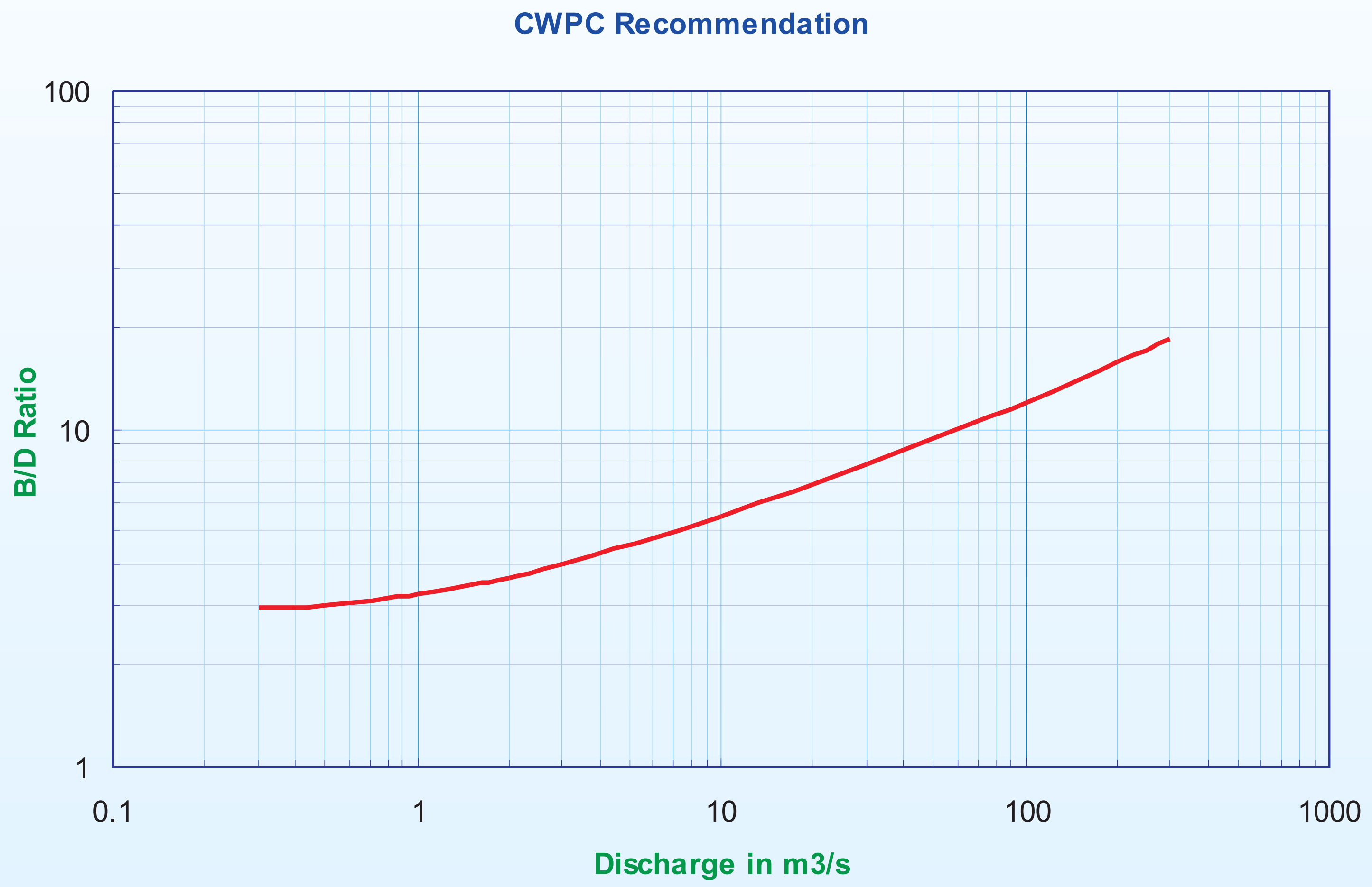


Design Canal Section

B/D Ratio

Central Water and Power Commission (CWPC), New Delhi has recommended B/D ratio for canals carrying discharges ranging from 0.3 to 300 m^3/s through a graph of discharge vs B/D ratio.



Lacey’s Method

Lacey’s Regime Equations

According to Lacey’s theory, silt carried by the water in a canal is kept in suspension by the vertical component of eddies generated generated on the bed as well as on the sides of the canal. Accordingly, he selected mean hydraulic radius R as the more appropriate variable than the depth of flow D. Based on his observations of field data, Lacey’s proposed a number of basic equations, from which another set of useful equations can be derived.

Basic Relations

1. Silt Factor
2. Mean Velocity of Flow
3. Cross-sectional Area
4. Regime Flow

Basic Relation 1

Silt Factor, f

As a measure of the silt grade, Lacey introduced the parameter *Silt Factor*, f. It depends on the mean particle size, d_m of the boundary material in the canal and the relationship is

$$f = 1.76\sqrt{d_m} = 1.76\sqrt{d_{50}} \tag{1}$$

where $d_m = d_{50}$ = mean particle size in mm.

Basic Relation 2

Velocity of Flow, V

Lacey collected Kennedy's data and data from canal systems in Madras. After plotting these data with f and R, he obtained the following relation

$$V = \sqrt{\frac{2}{5} f\, R} \tag{2}$$

where V = mean velocity in m/s, f = silt factor and R = mean hydraulic radius in m.

Basic Relation 3

Cross-sectional Area

To determine the channel dimensions, Lacey proposed the following equation

$$Af^2 = 140V^5 \tag{3}$$

where A = cross sectional area in m^2.

Basic Relation 4

Regime Flow Equation

After plotting the data of mean velocity V, mean hydraulic radius R and canal bed slope S, Lacey obtained the following relation

$$V = 10.8R^{2/3}S^{1/3} \tag{4}$$

This equation is also known as the General Regime Equation. It does not involve the roughness coefficient as it is considered that the coefficient is implicit in R and S. This equation is of considerable practical importance in evaluating flood discharge of rivers. During floods the river temporarily remains in regime and the above equation may be applied.

Derived Relation 1

From equations 1, 2, 3 and 4, a number of useful equations may be derived.

$V - Q - f$ Relation

Multiplying both sided of Eq. (2) by V, we get $AV f^2 = 140V^6$. But $Q = AV$. So $Q\, f^2 = 140\, V^6$ and hence

$$V = \left[\frac{Q f^2}{140}\right]^{1/6} \tag{5}$$

where Q = discharge im m^3/s.

Derived Relation 2

$P - Q$ Relation

Squaring both sides of Eq. 2 twice, we get

$$V^4 = \frac{4}{25} f^2 R^2$$

Again from Eq. 5

$$f^2 = \frac{140\, V^6}{Q}$$

So,

$$V^4 = \frac{4}{25} \times \frac{140\, V^6}{Q} R^2$$

Or,

$$V^2 R^2 = \frac{25\, Q}{560}$$

Now $R = A/P$ and $Q = AV$. So, $R = (Q/VP)$ and the above equation becomes

$$V^2 \frac{Q^2}{V^2 P^2} = \frac{25\, Q}{560}$$

or

$$P^2 = \frac{560}{25} Q = 22.4\, Q$$

$$P = 4.75 \sqrt{Q} \tag{6}$$

Derived Relation 3

Regime Slope Equations

$S - f - R$ Relation

From Eq. 4,

$$V^3 = (10.8)^3 R^2 S$$

Again from Eq. 2

$$V^3 = (2/5)^{3/2} f^{3/2} R^{3/2}$$

So,

$$(10.8)^3 R^2 S = (2/5)^{3/2} f^{3/2} R^{3/2}$$

or

$$S = \frac{0.0002\, f^{3/2}}{R^{1/2}} \tag{7}$$

Derived Relation 4

$S - f - Q$ Relation

From Eq. 2 and 5 we get,

$$\sqrt{\frac{2}{5} f\, R} = \left[\frac{Q\, f^2}{140}\right]^{1/6}$$

Or

$$R^{1/2} = \left[\frac{5}{2\, f}\right]^{1/2} \left[\frac{Q\, f^2}{140}\right]^{1/6} = \left[\frac{5^3}{2^3 \times 140}\right]^{1/6} \left[\frac{Q}{f}\right]^{1/6} = \left[\frac{Q}{8.96\, f}\right]^{1/6}$$

From Eq. 7

$$S = \frac{0.0002\, f^{3/2}}{R^{1/2}} = \frac{0.0002\, f^{3/2}}{\left[\frac{Q}{8.96\, f}\right]^{1/6}}$$

Or

$$S = \frac{f^{5/3}}{3470\, Q^{1/6}} \tag{8}$$

Design Procedure

Steps to design a canal section using Lacey's method (Known: Q and d_{50} or f)

Step 1: Calculate f from (if d_{50} is given)

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$$S = \frac{f^{5/3}}{3340Q^{1/6}}$$

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$$S = \frac{f^{5/3}}{3340 Q^{1/6}}$$

Step 9: Draw the design section.

Examples

Example 1

Using Lacey's method, design an irrigation canal in alluvial soil with silt factor f = 0.9, to carry a discharge of 10 m^3/s. Assume side slopes as 1H : 2V.

Solution

Step 1: Calculate V from $V = \left[\frac{Qf^2}{140}\right]^{1/6} = \left[\frac{10 \times (0.9)^2}{140}\right]^{1/6} = 0.622$ m/s

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That is, $1.736D^2 - PD + A = 0$. Hence,

$D = \frac{P-\sqrt{P^2-4\times1.736\times A}}{2\times1.736} = 1.251$ m and $B = 12.223$ m

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Step 8: Calculate bed slope S from: $S = \frac{f^{5/3}}{3340Q^{1/6}} = 0.00017 = 1$ in 5850

Questions

Question 1

The slope of a canal in alluvium is 1/4000. Lacey's silt factor is 0.9 and side slopes are 1H : 2V. Find the canal section and the maximum possible discharge through it.

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The slope of a canal in alluvium is 1/4000. Lacey's silt factor is 0.9 and side slopes are 1H : 2V. Find the canal section and the maximum possible discharge through it.

Answer: Q = 1.03 m^3/s

Question 2

Design an irrigation canal to carry a discharge of 5 m^3/s using i) Lacey's method with silt factor 1.0 and ii) Kennedy's method with Assume Manning's n = 0.0225, critical velocity ratio m =1 and B/D = 3.24. Draw the sections and compare the results.

Lined Canal

Advantages

The main advantages of lining of irrigation canals are as follows:

1. The lining of canals reduces seepage losses, resulting in substantial saving of water that can be used for irrigating additional area.
2. Reduction of seepage also reduces waterlogging problems.
3. Lining provides a relatively smooth surface having a lower value of roughness coefficient. Hence a lined canal can have higher velocity of flow.
4. Higher velocity of flow makes it possible to carry more discharge through the same cross section.
5. Problem of silting is reduced due to higher velocity of flow.
6. Lining reduces weed growth and hence helps in maintaining the discharge.
7. Lining makes it possible to provide a smaller cross-sectional area for the same discharge, thus saving in cost of earthwork.
8. Routine operation and maintenance of a lined canal is relatively easier than unlined canal.

Disadvantages

Lining of irrigation canals has certain disadvantages. However, the advantages far outweigh these disadvantages.

1. Lining of irrigation canal require a substantial initial investment.
2. Repairing of damaged lining is difficult.
3. Lining being permanent it is difficult to shift the outlets, if necessary.
4. Lined canal section does not have any berm. Hence additional safety for vehicular and pedestrian traffic is not available.

Economics of Canal Lining

Lining of a canal will be economically justified if the extra cost of lining is less than the value of benefits resulting from it. Let

L = Length of the canal, in m

T = Total perimeter of lining, in m

p and P = Wetted perimeter of the unlined and lined canals respectively, in m

s and S = Seepage losses in unlined and lined canal respectively, in m^3 / m^2 of wetted surface per day

d = number of running days of the canal per year

Y = Life of lining in years

W = Value of water saved in Rs./m^3

M = Annual savings in operation and maintenance due to lining, in Rs.

B = Annual estimated value of other benefits for the length of the canal under consideration, which include reduction in waterlogging and associated drainage, reduced risk of breaching etc.

x = Percent rate of annual interest

C = Cost of lining in Rs./m^2 including the additional cost of dressing the banks

Economics of Canal Lining

Annual Benefit

i) Savings due to reduction seepage loss = $spLdW - SPLdW = LdW(ps - PS)$

ii) Annual savings in operation and maintenance cost = M

iii) Other annual savings = B

Total annual benefit = $LdW(ps - PS) + M + B = a$, say

Cost of Lining

Total cost of construction = TLC

This cost must be recovered from the savings during useful life of lining, Y years. The net present worth (NPW), i.e., the investment needs to be fixed at present for a period of Y years at an annual interest rate $x\%$ to get annual interest of Rs. a. is

$$NPW = a\,\frac{(1+x)^Y - 1}{x(1+x)^Y}$$

For the lining to be economically feasible, $TLC \leq NPW$

Note: Usually the expected life of concrete, brick tile and boulder lining is assumed as 60 years.

Example

Example 1

An unlined canal in alluvial soil has annual seepage loss of 2.5 m^3/s per 10^6 m^2 of wetted perimeter. The canal has a wetted perimeter of 25 m and has annual maintenance cost of Rs. 0.20/m^2 of wetted perimeter.

There is a huge scarcity of water in the area and as such the canal is to be lined with 12mm thick cement concrete lining, so as to reduce the annual seepage loss to 0.02 m^3/s per 10^6 m^2 of wetted perimeter. The lined canal will have a wetted perimeter of 20m. The extra cost of lining works out to be Rs. 20/m^2. If the average annual revenue per m^3/s of water is Rs. 5.00 lakhs, and the percentage reduction in annual maintenance cost is 40%, decide whether it is economically feasible to provide canal lining. Assume the life of canal lining as 50 years and the interest rate is 6% per anum.

Solution

Let us assume L = 1 km =1000 m.

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Area of lining = 20$\times$1000 m^2 = 20000 m^2, cost of lining = Rs. 20/m^2. So, total cost of lining = Rs. 400000

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Annual interest rate, x = 6% = 0.06. So,

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Economics

Annual interest rate, x = 6% = 0.06. So,

$$NPW = a\,\frac{(1+x)^Y - 1}{x(1+x)^Y} = 33050\,\frac{(1+0.06)^{50} - 1}{0.06(1+0.06)^{50}} = 520929.50$$

Therefore, $TLC \leq NPW$. Hence, the lining is economically feasible.

Types of Lining

Various types of lining may be grouped into the following three categories.

1. Exposed and hard surface linings

    - Cement concrete lining
    - Precast concrete lining
    - Shotcrete lining
    - Cement mortar lining
    - Hydraulic lime concrete lining
    - Brick tile lining
    - Stone blocks lining
    - Asphaltic lining

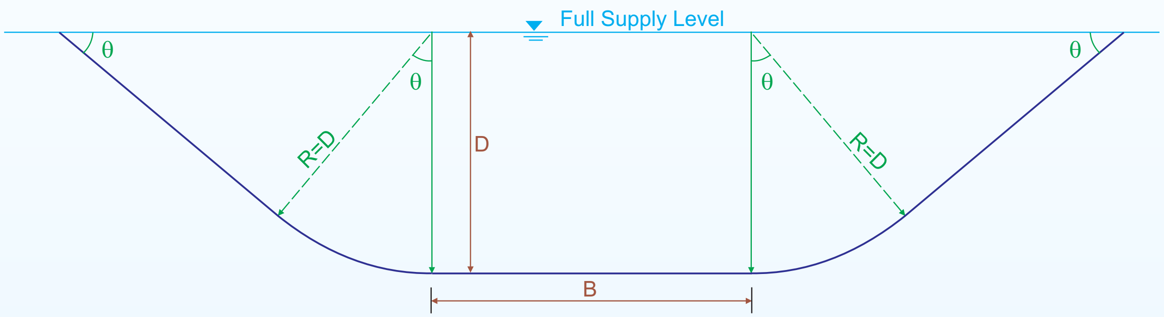
Types of Lining

2. Buried membrane lining
   - Sprayed-in-place asphalt membrane lining
   - Prefabricated asphaltic membrane lining
   - Polyethylene film and synthetic rubber membrane lining
   - Bentonite and clay membrane lining
   - Road oil lining
3. Earth lining
   - Thin compacted earth lining
   - Thick compacted earth lining
   - Loosely placed earth lining
   - Stabilized soil lining
   - Bentonite soil lining
   - Soil-cement lining

Specifications

IS:10430-1982 recommendations

1. Section



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

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

2. Side Slopes

The side slopes should be nearly equal to the angle of repose of the natural soil in the subgrade, so that no earth pressure is exerted over the back of the lining.

Specifications

3. Freeboard

	Type of canal	Discharge (m^3/s)	Freeboard (m)
i)	Main and branch canal	>10	0.75
ii)	Branch canal and Major	5 to 10	0.60
iii)	Major distributaries	1 to 5	0.50
iv)	Minor distributaries	< 1	0.30
v)	Water courses	< 0.06	0.10 to 0.15

4. Limiting Velocities

1. Cement concrete lining: 2.7 m/s
2. Brick or burnt tile tile lining: 1.8 m/s
3. Boulder lining: 1.5 m/s

Specifications

Values of roughness coefficient, n

	Surface characteristics	Value of n
1.	Concrete surface	
	a) Formed, no finish/PCC tiles or slabs	0.018 - 0.020
	b) Trowel float finish	0.015 - 0.018
	c) Gunited finish	0.018 - 0.022
2.	Concrete bed trowel finish and sides as follows	
	a) Hammer dressed stone masonry	0.019 - 0.021
	b) Coursed rubble masonry	0.018 - 0.020
	c) Random rubble masonry	0.020 - 0.025
	d) Masonry plastered	0.015 - 0.017
	e) Dry boulder lining	0.020 - 0.030
3.	Brick tile lining	0.018 - 0.020

Design Procedure

Known parameters

1. Discharge Q
2. Roughness coefficient n
3. Bed slope S
4. Side slopes, θ
5. Limiting velocity V

Equations

Continuity equation:

$$Q = A \times V$$

Manning's equation:

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

Steps

1. Calculate mean hydraulic radius, R from

$$R = \left(\frac{V \times n}{\sqrt{S}}\right)^{3/2}$$

2. Calculate cross sectional area, A from

$$A = Q/V$$

3. Calculate wetted perimeter, P from

$$P = A/R$$

4. Calculate B and D from the following (A and P calculated above, θ known)

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

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

Note: If limiting velocity is not available, then B/D ratio is to be assumed.

Example

Example 1

Design a trapezoidal shaped concrete lined canal to carry a discharge of 200 m^3/s at a slope of 30 cm/km. The side slopes of the channel are 1.5(H):1(V) and. Assume Manning's n as 0.017 and limiting velocity as 2 m/s.

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$$A = Q/V = 200/2 = 100\,\text{m}^2$$

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5. Draw the design section