TRAINING PROGRAMME ON

MODERNISATION OF IRRIGATION CANAL SYSTEM

DESIGN, OPERATION AND MAINTENACE OF CANALS

AND DISTRIBUTION SYSTEMS INCLUDING CROSS MASONRY AND CROSS

DRAINAGE WORKS,

BY

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PART I

PLANNING, INVESTIGATION AND & LAYOUT OF CANAL SYSTEM FOR IRRIGATION

I. INTRODUCTION:

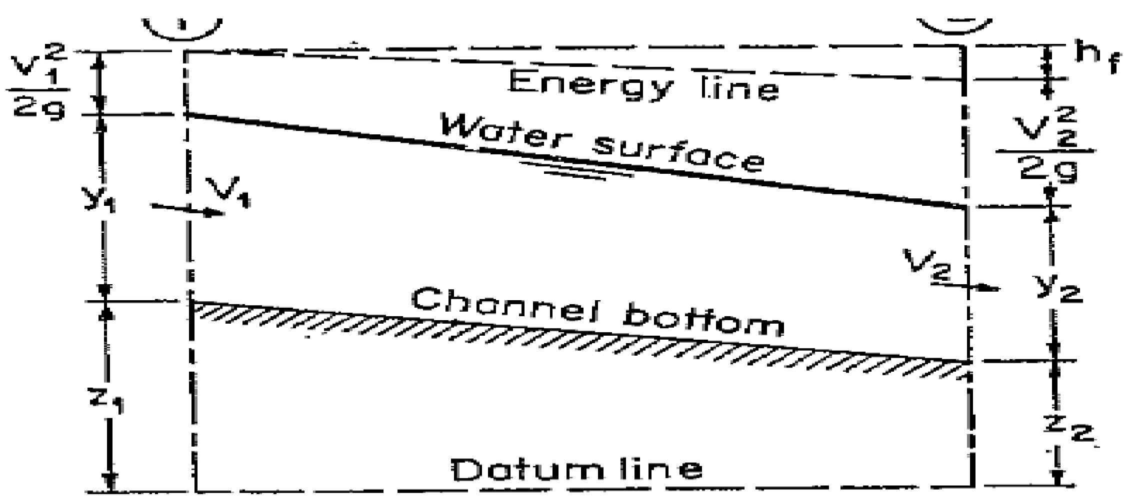
Irrigation is the process of artificially supplying water to soil for raising crops. It is a science of planning and designing an efficient, low cost, economic irrigation system tailored to fit natural conditions. It includes the study and design of works about river control, drainage, and hydraulic power generation.

The source of water for irrigation is precipitation. Artificial irrigation is divided into flow or gravity irrigation and lift irrigation.

Irrigation schemes consist of storage or diversion structures and canal distribution system.

II. CANALS:

Canal is an artificial channel, generally trapezoidal in shape to carry water by gravity to the field either from a river, a reservoir or a tank.
The layout of the canal distribution system is to secure the most economical way effective water distribution combined with adequate command with little interference with natural drainage. The theory in canals is derived from "open channel flow", and the surface is atmospheric. It is assumed that the flow is Uniform Steady flow, and the velocity is distributed Uniformly. The discharge, the depth of flow, the slope of the channel, and the free surface are interdependent. Therefore the selection of coefficient roughness attains greater importance.



Open-channel flow

A. CLASSIFICATION:

Canals are classified as follows:

1. Based on Canal excavation in Soils:

    1. Alluvial Canals
    2. Non- alluvial Canals

2. Shape of the channel:

    1. Circular,
    2. Rectangular,
    3. Trapezoidal,
    4. Triangular,
    5. Parabolic

3. Nature of the Canal:

    1. Un-lined canal-
    2. Lined canal

4. Based on the function:

    1. Irrigation canal.
    2. Carrier canal.
    3. Feeder canal.
    4. Navigation canal.
    5. Power canal

    6. Based on the discharge and its relative importance.

    1. Main canal.
    2. Branch canal.
    3. Major distributaries.
    4. Minor distributaries.
    5. Watercourse or Field channel.

6. Based on canal alignment.
    1. Contour canal.
    2. Ridge canal or watershed canal.
    3. Side slope canal. etc.

B. PLANNING:

1. In case of canals taking off from reservoirs the canal is to be designed for a discharge depending upon live storage of the reservoir.
2. In case it takes off from a diversion work, it should be designed for a discharge 75% dependability available from flow duration curves.
3. After deciding the head discharge of the canal, the area to be irrigated by the canal has to be worked out.
4. Prepare land use maps on a scale of 1:15000, show the area already on cultivation, soil types, habitations, roads, drainage and the contours of the area.
5. The important crops of the area and the water requirements shall be decided in consultation with the Agriculture department.
6. Knowing the duty for various crops, the area under cultivation under various crops, the intensity of irrigation, the culturable command area shall be worked out and marked on the plan.

C. DATA REQUIRED:

1. Topographical map of the area. A canal system operates essentially by gravity flow. It shall be a map of the area to be irrigated by the canal system to a scale of 1:15000 showing the area under cultivation, and area to be newly irrigated, and soil types, habitations, roads, drainages, and other features, with contour intervals of 30 CMS in plains and 2m, in hilly areas.
2. Soil characteristics, texture and salt composition of the command.
3. Sub-surface characters of soils along the canal alignment, such as mechanical and engineering properties, permeability of soils in relation to seepage losses. Trail pits or Auger holes at intervals of 500m or suitable intervals.
4. Crops and crop calendar. Existing cultivated area, both under wells/tube wells and ponds/tanks, the crops, the crop pattern, and the proposed crop pattern, anticipated change in crop pattern, and water required for each crop, crop duration etc.;
5. Water availability both surface and the ground water.

6. Drainage facilities, subsoil water levels, possibility of water logging and salination etc.;
7. Existing communication facilities and transportation.
8. Availability of suitable construction materials.
9. Socio-economic studies, etc.;

D. CAPACITY:

Capacity of the canal shall be fixed based on, the cultivable command area, water allowance, i.e. the outlet capacity in cumecs/s per thousand hectares considering the duty, intensity, proposed crop ratio, rotation period, water availability, etc; and transmission losses due to seepage and evaporation from canals water courses and irrigated area. Refer typical Performa enclosed as appendix.1

Continuous flow system of distribution is in practice for paddy cultivation in Andhra Pradesh and incase of Irrigated Dry (ID) crops the water regulation is effected by turns. In such cases the carrying capacity of canals are to be increased taking into account the full supply duty during canal closure period.

The carrying capacities of the canals and distributaries have to be worked out from head to tail.

The canal and the distributaries shall be designed not only to carry the supplies at peak demand but also to carry the normal supplies at all times, with water levels sufficient to irrigate the command.

The design of canals and distributaries to be carried out such that the command of all lands is attained even when half of full supplies are carried.

E. DUTY OR DUTY OF WATER:

Duty can be defined as the area irrigated per unit discharge. Duty is to be stated with reference to a base period. Duty excludes all losses in the canals system. It may be expressed as:

1. Number of hectares/acres irrigated by one cumecs/cusec of water for a specific number of days called the base period.

2. Number of hectares/acres irrigated by one million cubic meters/ TMCs of water for a base period.

F. CROPS AND CROP CALANDER:

After deciding the cropping pattern water requirement of each crop shall be worked out considering the soil conditions and the climatic conditions by a suitable method like modified penman's method.

G. FULL SUPPOY LEVELS (FSL):

The levels of water required in a channel are the levels that command the land in full, or the maximum water level available at the source. The FSLs shall be decided beginning without lets, minors, distributaries, branch canals, and then main canal.

The working heads to be usually allowed (as per Para 2.80 of CBIP Publication No. 171. Manual on Irrigation and Power channels by CWC)

S.No.	Channel	Minimum Working Head required in MM
1	Head over field	75
2	Major distributaries to minor	300
3	At outlets	150
4	Branch to Branch or Major distributaries	500
5	From Main canal	600
	Slope of Water course	1 in 5000

G. ALIGNMENT:

The canal network system shall be economical from consideration of cost and annual maintenance, and adequate to command the entire area indicated. The following steps are indicated.

1. Survey maps to a scale 1:15000 showing the contours at 0.5m intervals, spot Levels and important land features, roads, railways etc.;
2. Alignment of the main canal, branch canals, and distributaries shall be marked on the map.

3. The main canal generally aligned as contour canal and the branches and distributaries as ridge canals or side slope canals.
4. Deep cuts or high embankments shall be avoided as far as possible and number of alternatives may be tried for economy.
5. No drainage line shall be blocked.
6. Block command plans to a scale 1: 8000 showing the contours at 0.3m intervals, the boundaries and the survey number of each field proposed to be localized, location of cultivable area at higher levels and barren lands, gardens, tanks, roads, inhabitations drains and other important features.
7. The area of the irrigated area is to be marked. The canals, the drains are to be marked.
8. A longitudinal section (L – section) of the canal with longitudinal scale 1: 10000 to 20000 and vertical scale 1: 100. The L- section of the canal shall show all the salient features observed in the field such as the chainage (distances), natural ground levels, designed discharge of the canal, canal bed levels, full supply levels, water surface slopes, free board, top of bund levels, depth of cutting, depth of embankment, Manning's rugosity coefficient 'n' broad details of hydraulic data of out lets/ off takes regulators, bridges, drainage crossings etc. and their locations etc.,
9. Cross sections of the ground at an interval not more than 300m for a uniform terrain and closure intervals for undulating terrain. The cross sections hold extends at least 10m beyond the limits of canal section.
10. Data to be incorporated on the L-section
    a. Test pits/Auger holes at intervals of 500 meters or suitable intervals or at depths Where soils strata vary along canal alignment taken up to 1.0m below canal bed Level.
    b. Locations of off-take (OT) channels/ Outlets with full particulars
    c. Locations and type of Cross-Drainage (CD) works along with full hydraulic data, such as catchment area HFL, designed flood discharge, foundation data and the loss of head provided if any.
    d. Location of Cross Masonry (CM) works, such as road bridges, cross regulator, escapes, fall/drops with full particulars.

H. CURVES:

Radii of curves usually are 3 to 7 times the water surface width subject to minimum given below.

RADII OF CURVES FOR CANALS
(As per table 1. of IS: 5968 – 1968 Reaffirmed 2003)

Un-lined Canal		Lined Canal	
Discharge in Cumecs	Radius in M	Discharge in Cumecs	Radius in M
80 and above	1500	280 and above	900
80 to 30	1000	280 to 200	750
30 to 15	600	200 to 140	600
15 to 3	300	140 to 70	450
3.0 to0.3	150	70 to 40	300
< 0.3	90	40 to 10	200
		10 to 3.0	150
		3.0 to 0.3	100
		Less than 0.3	50

Note 1. The above radii are not applicable to un-lined canals located in hilly reaches and highly permeable soils.
2. On lined canals where the above radii may not be provided proper super elevation shall be provided.

G. TRANSMISSION LOSSES:

The losses take place in account of evaporation and seepage. These losses are quite considerable and accounts roughly 25 to 50 percent of canal discharge in unlined canals. The seepage losses are influenced by the nature and porosity of the soils, the depth turbidity and the temperature of the water, the age and the shape no the canal and the ground water table etc;

Seepage losses dependent on nature and permeability of soil, depth of water in the canal and the sub soil water table. Generally, canal reaches having permeability of $1x10^{-5}$cm/s or less need not be lined.

1. SEEPAGE LOSSES IN UNLINED CANALS:
(As per table 2 of Manual on Irrigation and Power Publication no.171 by CWC

S. No.	Character of material	Seepage losses in cumecs Per Million Sq. Mts. of Wetted perimeter.
1	Impervious clay loam	0.90 to 1.20
2	Medium clay loam under laid with hard pan at depth of not over 0.60 to 0.90m below level	1.20 to 1.80
3	Ordinary clay loam silt soil or lavash loam	1.80 to 2.70
4	Gravelly or sandy clay loam, cemented gravel,	2.70 to 3.70
5	Sand and clay, and Sandy loam	3.60 to 5.20
6	Loose sandy soils	5.20 to 6.10
7	Gravelly to sandy soils	7.00 to 8.80
8	Porous gravelly soil	8.80 to 10.70
9	Very gravelly soils	10.70 to 21.30

Note: In the case of lined canals, seepage losses may be assumed as 0.6. Cumecs per million square meters of wetted perimeter.
2.The seepage loss from unlined canals generally varies from 0.30 to 7.00cubicmetres/sec./million sq.m depending on the permeability of the soil (Foreword IF:9447-1980).

H. CANAL SECTION AND SLOPE:

1. The cross section of a canal decreases from head to tail end.
2. A change in hydraulic slope is to be introduced only at control structure.
3. Balancing depth of cutting is to be followed wherever possible. However, a full supply depth of cutting i.e., the canal full supply level always at the natural ground level is preferred for better water regulation and maintenance.
4. The discharge capacity of the section is maximum when the hydraulic mean radius (R) is maximum.

II. DESIGN OF UNLINED CANALS:

(IS: 7112-200 Reaffirmed 2012, and CBIP. 171)

The water flows from higher to lower level by gravity and the motive force for flowing water in open channel is the surface slope of the channel. After deciding the canal capacity, the canal cross section shall be designed, for the different bed to depth ratios.

In case of direct flow irrigation, the velocity in the channel shall not be less than non-silting velocity computed from Kennedy's rule.
In Case of storage system, the occurrence of silt entering into canal need not be considered but the velocity may be limited to non-scouring velocity.

The design procedure commonly adopted is to determine the width and the depth of the canal for given discharge, rugosity coefficient, side slopes of the canal section, the maximum permissible velocity, and the surface fall/bed gradient.

The best discharging channel is that which for the same cross section and slope, passes water with the maximum velocity and the maximum hydraulic mean radius R, and with the smallest absorption losses commensurate with economy.

a. Flow in an open channel:

Q = A x V where Q = discharge in cumecs.
A= cross sectional area in square meters.
V= mean velocity of flow in meters per second.

The mean velocity is given by the Manning's formula

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

Where,
V= Velocity in meters per second,
R= Hydraulic mean radius in meters (A/P)
P= wetted perimeter in meters and
S= Surface slope of water and
n= Coefficient of rugosity.

b. Longitudinal slope:

The longitudinal surface slope of the canal generally depends on the average slope of the countries slope using the Manning's equation.

In general, the slope required to obtain maximum permissible velocity for economy, will normally be steeper. A possible maximum irrigated area would indicate flatter slope and result in minimum permissible velocity. The slope adopted shall be within the two limits.

c. Non-scouring mean velocities:

(As recommended by CBIP publication no.171, Manual on Irrigation and Power published by CWC, at Para 3.6 as follows);

S. No.	Soils	Mean velocity In M/S
1	Very light, loose sand to average sandy soils	0.3 to 0.6
2	Sandy loam, black cotton soil & similar soil	0.6 to 0.9

3	Ordinary soils	0.6 to 0.9
4	Firm loam, clay loam, alluvial soil, soft clay &murum	0.9 to 1.1
5	Hard clay or grit	1.0 to 1.5
6	Gravel and shingle	1.5 to 1.8
7	Cemented gravel conglomerate, hard pan	1.8 to 2.4
8	Soft rock	1.4 to 2.4
9	Hard rock	2.4 to 2.7
10	Very hard rock or cement concrete	4.5 to7.6

d. Maximum permissible Velocities:

(IS: 7784(Part 1): 1993- Design of cross drainage works- code of practice)

S.No.	Type of floor	Max. permissible Velocities in M/S
1	Metal faces (Steel and cast iron)	10
2	Concrete face CC grade M30 and above	6
3	Stone masonry with CC plastering	4
4	Stone masonry with pointing	3
5	Brick masonry with cement plastering	2.5
6	Brick masonry with pointing	2.0
7	Hard Rock	4.0
8	Murum	1.5 to 2.0
9	Soil silt	0.70 to 1.0

Note; when flow carries abrasive materials, the values may be reduced by 25%

e. Side Slopes:

(Cl.4.2 of IS: 7112-2002 and IS: 10430-2000 Edition 2.1 reaffirmed 2004)

The side slopes in banking depend on soil characteristics and designed to with stand the following conditions,

1. Sudden draw down conditions for inner slopes.
2. Canal running full bank saturated due to rainfall.
3. For canal banks of heights more than 5/6 meters, the stability of the slopes of the banks checked using slip circle analysis.
4. For canal banks of heights less 5/6 meters, the hydraulic gradient line shall have a cover not less 600mm. The empirical value for hydraulic gradient line horizontal to vertical may be:

S. No	Type of Soil	Side slopes Horizontal to Vertical
1	Silty soils	4:1
2	Silty sands	5:1
3	Sandy soils	6:1

i. RECOMMENDED SIDE SLOPES (Up to depths 6 meters)
(As per cl. 8.1.1 of IS :10430- 2000 & IS: 4701-1982)

S.No.	Type of soil	Side slopes (Horizontal to Vertical)
1	Very light loose Sand to average Sandy soils	2.0:1.0 to 3.0:1.0
2	Sandy loams	1.5:1.0 to 2.0:1.0(in cutting) 2.0:1.0 (in embankment)
3	Sandy gravel/murum	1.5:1.0 (in cutting) 1.5:1.0 to 2.0:1.0 (in embankment)
4	Black cotton	1.5:1.0 to2.5:1.0 (in cutting) 2.0:1.0 to 3.5:1.0 (in embankment)
5	Clayey soils	1.5:1.0 to 2.0:1.0 (in cutting) 1.5:1.0 to 2.5:1.0 (in embankment)
6	Rock	0.25:1.0 to0.5: 1.0

Note: The above slopes are recommended for depth of cutting/height of embankment up to 6m. For depth/height in excess of the above, special studies for the stability of slopes are recommended.

f. BED WIDTH-DEPTH RATIO (B/D ratio):

For minimizing, the losses due to absorption and evaporation and economical design the value of b/ratio plays a vital role.

Slack velocity will encourage the weed growth and velocity less the optimum will result in increase in uneconomical cross section.

Stipulation of minimum cross section as a percentage of maximum permissible velocity is desirable.

A value between 1.25 and 5 is recommended. A graph showing the canal discharge versus b/d ratio as per CBIP technical report 7.

For a country with steeper slopes and for canals with no command (carrier canals) a lower value between 1.25 and 3.0 is recommended.

For plain country and deltas, a higher value up to 25 is recommended to bring more area under command.

For canals of higher discharges**,** the higher values between 5 and 25 and for smaller canals smaller values between 1.25 and 5 is recommended.

g. CRITICAL VELOCITY RATIO ($V/V^o = m$)

Critical velocity ratio is defined as the ratio between the actual mean velocity (V) to the critical velocity (V^o) given by the Kennedy formula. The criteria ion of V/V^o is needed to prevent deposition or scour of canal bed.

V/Vo = 0.90 to 1.10 where V = RS/n and
$Vo = 0.391\ D^{0.55}$ Godavari delta
$Vo = 0.530\ D^{0.52}$ Krishna delta.

In case of direct flow irrigation, the velocity in the channel shall not be less than non-silting velocity computed from Kennedy's rule.
In Case of storage system, the occurrence of silt entering into canal need not be considered but the velocity may be limited to non-scouring velocity.
In case of canals taking off from reservoir will not carry much sediments and application of V/Vo criterion may not be required for such canals.

h. COEFFICIENT OF RUGOSITY (n):

The flow in the canal should overcome the resistance caused by surface tension, atmospheric pressure at surface, friction on the sides and bottom of the channel. The friction depends on the forming the wetted perimeter, the irregular tiles of the wetted perimeter, the size and shape of the cross section, curves, weeds, and various kinds of vegetation growth, scouring, silting and the suspended loads and the bed loads. The resultant of all these forces expressed by Rugosity coefficient or coefficient of rugosity (n), determined by experiments.

i. RUGOSITY COEFFICIENT (n) FOR UNLINED CANALS.
(Clause. D-1.2 of IS: 7112: 2002)

S.No.	Type of Canal	Minimum	Normal	Maximum
1	Earth, straight and uniform: a. Clean, recently completed b. Clean after weathering c. Gravel, uniform section, clean d. With short grass, few weeds	 0.016 0.018 0.022 0.022	 0.018 0.022 0.025 0.027	 0.020 0.025 0.030 0.033
2	Earth, winding and sluggish: a. No vegetation b. Grass, some weeds c. Dense weeds or aquatic plants in deep channels	 0.023 0.025 0.030 0.030 0.025	 0.025 0.030 0.035 0.035 0.035	 0.030 0.040 0.035 0.040 0.040

	d. Earth bottom and rubble side e. Stony bottom & weedy banks f. Cobble bottom and clean sides	0.030	0.040	0.050
3	Dragline excavated or dredged: a. No vegetation b. Light bush on banks	0.025 0.035	0.028 0.050	0.033 0.060
4	Channels not maintained (weeds and brush uncut) a. Dense weeds, high as flow depth b. Clean bottom, brush on sides c. Same, highest stage of flow d. Dense brush, high stage	0.050 0.040 0.045 0.080	0.080 0.050 0.070 0.100	0.120 0.080 0.110 0.140

Notes:

1. For normal alluvial soils, it is usual in India to assume a value of $n=0.020$ for bigger canals ($Q>15$ cumecs) and $n = 0.0225$ for smaller canals ($Q<15$ cumecs).
2. A suitable value of n should be adopted keeping in view the local conditions and the above values as a guide.

ii. RUGOSITY COEFFICIENT (n) FOR LINED CANALS

(Clauses 4.2.2.1 and 4.1.2.2 of IS: 10430: 2000)

S.No.	Surface characteristics	Value of ‘n’
1	Concrete surface a). Formed, no finish/ PCC tiles or slabs b). Trowel float finish c). Gunited finish	 0.018 to 0.020 0.015 to 0.018 0.018 to0.022
2	Brick/ tile lining	0.018 to 0.020

3	UCR/Random rubble masonry with pointing	0.024 to 0.026
4	Asphalt a). Smooth b). Rough	 0.013 to 0.015 0.016 to 0.018
5	Concrete bed trowel/ float finish & slopes as below a). Hammer dressed stone masonry b). coursed rubble masonry c). Masonry plastered d). Stone pitched lining	 0.010 to 0.020 0.020 to 0.025 0.015 to 0.017 0.020 to 0.030
6	Gravel bed with side slopes as given below a). Formed concrete b). Random rubble in mortar c). Dry rubble (rip-rap)	 0.020 to 0.022 0.017 to 0.023 0.023 to 0.033

Notes:

1. For canals with alignment other straight, a small increase in the value of 'n' may be made or alternatively bend losses may be accounted for. In case of canals of higher discharges in straight reaches, lower value of 'n' may be adopted.
2. The 'n' value shall be decided in view of the age of the lining, surface roughness, weed growth, channel irregularities, canal alignment, silting, suspended material and bed load etc.

J. FREE BOARD:

Free board is measured from full supply level to the top of the bund or to the top of the lining in case of lined canals. It is governed by the consideration of canal size, location, velocity, storm water in flow, water surface fluctuations due to water regulation, wind action, soil characteristics, hydraulic gradient, service road requirement, and excavated soil availability. Free board requirement as per canal discharge is given below: (Para 8.2 of IS: 10430-2000)

S.No.	Canal discharge	Freeboard in meters
1	More than 10 cumecs	0.75
2	3 cumecs to 10 cumecs	0.60

3	1 cumecs to 3 cumecs	0.50
4	Less than 1 cumecs	0.30
5	Less than 0.10 cumecs (Water course)	0.15

Par 4.3 of IS: 7112-2002 stipulates the free board requirements of un lined canals.
Note: the height of the dowel portion shall not be used for free board purposes.

K. BANK TOP WIDTH:

The width of the bank varies according to the impotence of the and capacity of the canal. In case of main and branch canals service road should be provided on both the banks. In case of distributaries, service road should be provided on one bank only. For distributaries with discharge less than 3.0 cumecs, it is not economical to construct a service road on top of the bank. In such cases, suitable land widths may be provided on natural ground level.

i. Un lined canals:
(Clause 4.4 and table 1 of IS 711-2002)

Discharge in cumecs	Minimum Bank top width	
	Inspection bank in m	Non-inspection bank in m.
0.15 to 7.5	5.0	1.50
7.5 to 10.0	5.0	2.50
10.0 to15.0	6.0	2.50
15.0 to 30.0	7.0	3.50

Notes:

1. Width between and outside of these limits any be used when justified by specific conditions
2. For distributary canals carrying < 1.5 cumecs and minor canals, it is generally not economical to construct a service road on top of bank ad

this usually requires more materials than the excavation provides.
In such cases, service road may be provided on natural ground surface adjacent to the bank, however, the importance of providing adequate service roads where they are needed should always be kept in view.

3. The banks should invariably cover the hydraulic gradient. The width of the non-inspection bank should he checked to see that the cover for hydraulic gradient as given.

ii. Lined Canals: (IS: 10430 – 2000, reaffirmed 2004, Edition .1, 2005-08)

Discharge in cumecs	Minimum Bank top width	
	Inspection bank in m	Non-inspection bank in m.
0.15 to 1.5	4.0	1.50
1.50 to 3.0	40	2.00
3.0 to 10.5	4.0+dowel	2.50
10.0 to30.0	5.0 + dowel	4.00
Above 30.0	6.0 + dowel	5.00

Notes:

1. Bank widths given above may be altered when justified by specific conditions.
2. For distributary canals carrying < 1.5 cumecs and minor canals, it is generally not economical to construct a service road on top of bank ad this usually requires more materials than the excavation provides.
   In such cases, service road suitably lowered below top of lining may be provided on natural ground surface adjacent to the bank, however, the importance of providing adequate service roads where they are needed should always be kept in view. This service road should be above normally encountered high flood level (HFL). with some free board.
3. Where the stability of the embankment is required, wider bank widths can be provided. Turfing should be provided on the other slopes.

4. In hilly terrain where it is not possible to provide above bank widths, the bank widths may be suitably reduced.
5. When the bank widths are reduced on exceptional ground, refuges after every 100m should be provided for passing and sheltering of opposite traffic.

The banks should invariably cover the hydraulic gradient. The non-inspection width of the bank is checked to see that cover for hydraulic gradient, a minimum of 0.3m is provided.

L. Dowel:

Un Lined canals (Para 4.7 of IS: 7112-20020
Dowels may be provided on the canal side of the service road, on one or both sides of the banks. The top width of the dowel may be 0.50m and height 0.50m and side slopes 1.50:1.00 on roadside and same slope of the canal inner slope on canal side.

I. Lined canals:

To check the ingress of rainwater behind the lining of the side slopes of the canals, horizontal cement concrete coping 100m to 150mm, depending upon the size of the canal should be provided at the top of the lining. The width of the coping at the top shall be:

S.No.	Discharge	Width
1	up to 3.00 cumecs	225mm
2	3 to 10 cumecs	350mm
3	Above 10 cumecs	550mm.

A parapet wall may replace a dowel. However, the height of the parapet should not be considered additional free board.

M. **Berms**:

Berms are to be provided in all cuttings when the depths of cutting are more than 5m. It is desirable to provide berms of 3 to5meters at every 5m depth intervals on each slide for stability and maintenance.

P. Falls:

After deciding the canal slopes and canal dimensions, the water surface and bed lines shall be marked in the Longitudinal Section providing the falls wherever the full supply level touching the ground level.

Q. Hydraulic gradient:

Where ever the canal runs in banking the lines of saturation slant downwards from the water surface through the embankment material.

The gradient depends on the permeability of the soil fill. It can be established by Laboratory tests and slope stability analysis for heights more than 5.00 m

For bank heights less than 5.00 m the values of hydraulic gradient (horizontal : vertical) can be used

Silty Soils	4:1
Silty sand	5:1
Sandy soils	6:1

R. **Catch Water Drains:**

Effective system of catch water drains shall be provided to prevent damages due to rains.

III.CANAL LINING:

Lining of canal is an important feature, as it improves the flow characteristics and minimizes the loss of water due to seepage. The water thus saved can be utilized for the extension and improvement of the irrigation. Lining assumes special significance in pumped water supply as the water is relatively costly.

Studies indicate that seepage losses in irrigation channels constitute 25 to 50 percent. Generally, canal reaches having permeability of 1x10* cm/s and more may be lined.

Experiments in south India it is found that cement concrete lining has a rate of seepage of only about 0.50 cusec per million square feet against 8.0 cusecs in an unlined canal.

Canal reaches having permeability of less or I x 10-6 cms/sec need not be lined when the velocity in the canal does not exceed the permissible velocity.

Sometimes the canal transports considerable amount of sediment, which can damage the lining by abrasion. Cement concrete and stone masonry linings provide better abrasion resistance.

Advantages of lining:

1. Seepage control.
2. Prevention of water logging.
3. Increased hydraulic efficiency.
4. Increased resistance to erosion/abrasion.
5. Reduction in cross sectional area.
5. Low operation and maintenance cost.
6. Prevention of weed growth.
7. Elimination of siltation due to permissible higher velocity.
8. Resistance against burrowing animals.

For economic analysis, the life expectancy of concrete, brick/ tile and stone pitched lining may be assumed to be of the **order of 60 years**. (IS:10430-2000)
As far as possible lining should be avoided in expansive clays (Cl. 5 of IS. 7873-1975)

Types of lining:

1. Exposed, hard surface and rigid lining.
2. Buried membrane and Flexible lining.
3. Combination of the two in bed and sides.

1. Exposed, hard surface rigid lining:

1. In situ cement/ lime concrete lining,
2. Cement concrete tile ling,
3. Precast cement concrete/ stone slab lining,
4. Stone- pitched lining.
5. Stone masonry lining,
6. Shot Crete lining,
7. Burnt clay tile or brick lining,
8. Soil cement/ soil cement and fly ash lining,
9. Ferro cement lining,
10. Asphalted cement concrete lining,

A. Thickness of lining: (IS: 3873 – 1993)

The concrete used for lining should be design mix if grade M10 or M15 and should conform to requirements of IS 456-2000.

Hydel Channels require more thickness than irrigation channels. Deeper channels should have greater thickness. Minimum thickness of canal lining based on canal capacity.

Thickness of In-Situ lining

S.No.	Capacity of the canal in cumecs	Depth of water In meters	Thickness lining In MM
1	00 - 005	0.00 – 1.00	50 - 60
2	05 - 50	1.00 – 2.5	60 - 75
3	50 - 200	2.50 – 4.50	75 - 100

4	200 - 300	4.50 - 6.50	90 - 100
5	300 - 700	6.50 – 9.00	120 - 150

Note: If surface deterioration in freezing climate is expected, these thicknesses may be increased. The lining shall not be subjected to external hydrostatic earth pressure or uplift caused by expansive clays or frost heave. Tolerance in concrete thickness, alignment and grade;

a). Departure from established alignment: +or-20mm on straight reaches
+ or-50mm on partial curves or tangents
b). Departure from established grade : + or – 20mm on small canals
c). Variation in lining thickness : + or – 10mm provided average thickness is
not less than specified thickness.

B. Over excavation:

For slopes, more than 1:1 in hard strata, Backfilled with gravel and aggregate and a layer of pea gravel as binding material. The bed may be compacted with road roller and the sides with rammers.

For slopes, less than 1:1 in hard strata, Back fill shall be chip masonry
Alternatively, lean concrete.

C. Sleepers/profiles:

At intervals of 20m in straight reaches and 10m in curves. The size shall be 200mm wide and 150mm deep built in the same grade of lining. Sleeper shall be placed centrally under the joints. (Cl.5.5.1.1.5 of IS 3873-1993)

D. Expansion Joints:

These should not be provided except where a structure intersects is the canal.

E. Construction Joint:

Joints are potential points of seepage. A construction joint is weak link in the lining and deterioration starts from such joints. As such, number of joints shall be kept minimum.

G. **Lining to water Courses and field channels**

Lining of water courses minimizes the seepage losses and also result in achieving economy in land use due to reduction in land use due to reduction of cross section.

IS: 12379-1988- Code of Practice for Lining of Water-Courses and Field Channels may be referred for details.

H. Limiting velocities in different type of lining:

1. Stone pitched lining … 1.5m/s
2. Burnt clay tile or brick lining … 1.8m/s
3. Cement concrete lining … 2.7m/s

2. Buried membrane and flexible lining.

1. Remembrance like HDPE/, PVC/, LDPE, with cover comprising layer of bentonite with adequate earth/ burnt clay tile brick or pulverized fuel ash lime brick or burnt clay flash building brick/precast cement concrete.
2. Bituminous or bituminous/asphaltic felt lining,
3. Fiber reinforced plastic tissue asphalted membrane longing.
4. Composite membrane/ rubber lining.

Cement concrete lining: Cement concrete in-situ lining is the most conventional type of lining. Higher velocity up to 2.7 m/s can be permitted. It eliminates weed growth, resistance against burrowing animals, and improves flow characteristics and low maintenance costs.
A distinct disadvantage is its lack of extensibility, which result in frequent cracks due to contraction, shrinkage and settlement of sub grade.
Brick/tile, stone pitched lining, and precast slab linings are more easily repairable or repairable than in-situ concrete lining.

4. Shotcrete lining: (IS: 9012- 1978).

Shotcreting is a type of lining, wherein cement motor/ cement concrete is applied to the surface by pneumatic pressure with or without reinforcement. Shotcrete lining can be easily placed over rough sub grade and therefore, better suited for use on deep cut reaches. The thickness of the lining limited to 5.0 CMS mostly.

Stone pitched lining (IS 4515: 2002)
Stone pitched lining will be useful in the following cases.

1. Prevention of erosion
2. Where the ground water level is above the bed of the canal, this type of lining will allow water pressure to be released through the interstices.

A. Types of Shotcreting:

The basic shotcreting process are

1. Dry mix process
   A mixture of cement and moist sand is conveyed though the delivery hose to a nozzle where most of the mixing water is added under pressure.

2. Wet mix process
   In this process, all the ingredients including water is mixed before te entry into the delivery hose.

Shotcret is a structurally adequate and durable material capable of excellent bond with concrete, masonry, steel and other materials. The water cement ratio normally falls within the range of 0.35 to 0.50.

C. Application of shotcreting:

A good base or foundation is necessary for proper and successful application. Where the shotcrete is to be placed against earth surface as in canal linings, such surface shall be first be thoroughly compacted and trimmed to line and grade. The surface shall be kept damp for several hours before applying shotcrete.

In the case of repairs to the existing deteriorated concrete, it shall be cleaned of all loose and foreign materials. If necessary, the surface shall be chiseled or sand blasted to make it rough o receive shotcret.

Depending on the thickness and the nature of the work, reinforcement may either consist of round bars, or weld wire fabric. Small size of bars up to a maximum 16mm bars shall be used.

For repair works, the reinforcement shall be fixed to exiting masonry and concrete by wire nails driven into walls and secured rigidity.

D. Rebound:

Depending on the position of the work the amount of rebound may be

Surface	% of rebound
Floor or slab	5 - 15
Sloping and vertical walls	15 - 30
Overhead works	25 - 50

Rebound shall not be worked back into the construction

Where a layer of shotcrete is to be covered by a succeeding layer, it shall first be allowed to take its initial set. Then all laitance, loose materials and rebound shall be removed by brooming and any laitance has set shall be removed by sand blasting and the surface cleaned air water jet.

It is generally kept continuously wet for 7 days.

5. Steel Fiber Reinforced Shotcrete (SFRS):

The Steel Fiber Reinforced Shotcrete (SFRS) has gradually overtaken the plain shotcrete and gained wide acceptance the world over. Sprayed SFRS provides much better crack resistance than the plain shotcrete with steel mesh.

IV.LINING OF CANALS IN EXPANSIVE SOILS

Canals excavated in expansive soils, such as black cotton soils, pose several problems, involving stability of slopes and shape of section. Cast in situ lining for bed and pre-cost cement concrete slabs for sides are common. The lining material directly placed against expansive soils undergo deformation by heaving, disturbing the lining. This deformation is due to unduly high pressure developed by the expansive soils when they absorb water. By protecting the soil, the heaving of the soil mass is contained mass with a thin layer of muram gravel. To counter the swelling pressure and prevent deformation of the rigid lining material a cohesive Non-swelling (CNS) layer of suitable thickness depending on the swell pressure of the expansive soil is sandwiched between the soils and the rigid lining material.

Treatment of sub-grade:

The soils with swelling pressures of more than 50 kN/m^2 are classified as expansive soils. Expansive soils sub-grade should be covered by a layer of CNS (cohesive non-swelling soil) material of sufficient thickness before laying the canal lining.

Properties of CNS Material:

The CNS soils are to be non-swelling soils with a maximum allowable swelling pressure of 10 KN/m^2 when tested in accordance with IS 2720 (Part 41): 1977

CNS soils should broadly confirm to the following range:

Clay (Less than 2 microns) 15-20%
Silt (0.06 mm - 0.002 mm) 30-40%

Sand (2mm - 0.06 mm) 30-40%
Gravel (of size greater than 2mm) 0-10%
Liquid limit . . . . More than 30 but less than 50%
Plasticity Index . . . . More than 15 but less than 30%

The extent of provision of CNS for the treatment of sub grade, has been determined through testing of soil samples for the swelling pressures.

Treatment of sub-grade

Thickness of CNS layer
The thickness of CNS layer is related to the swelling pressure of the expansive soil and the resultant deformation, the permissible deformation being 2 cm. The thickness of CNS layer required for balancing different swelling pressures of the expansive soils shall be as per the following table:

Canal carrying capacity less than 2 cumecs

Min. thickness of CNS layer (cm)

S.No.	Discharge in cumecs	Swelling Pressure 50 – 150 KN/M^2	Swelling pressure More than 150KN/M^2
1	1.40 – 2.0	60	75
2	0.70 – 1.40	50	60
3	0.30 – 0.70	40	50
4	0.03 – 0.30	30	40

Canal capacity of 2 cumecs and more

S.No.	**Swelling pressure of soil kN/m^2** (min)	**Thickness of CNS layer cm**
1	50 - 150	75
2	150 - 300	85
3	300 - 500	100

Note: Optimum thickness of CNS materials needs to be determined for different swelling pressures by actual experiments both in field and in laboratory, if necessary.

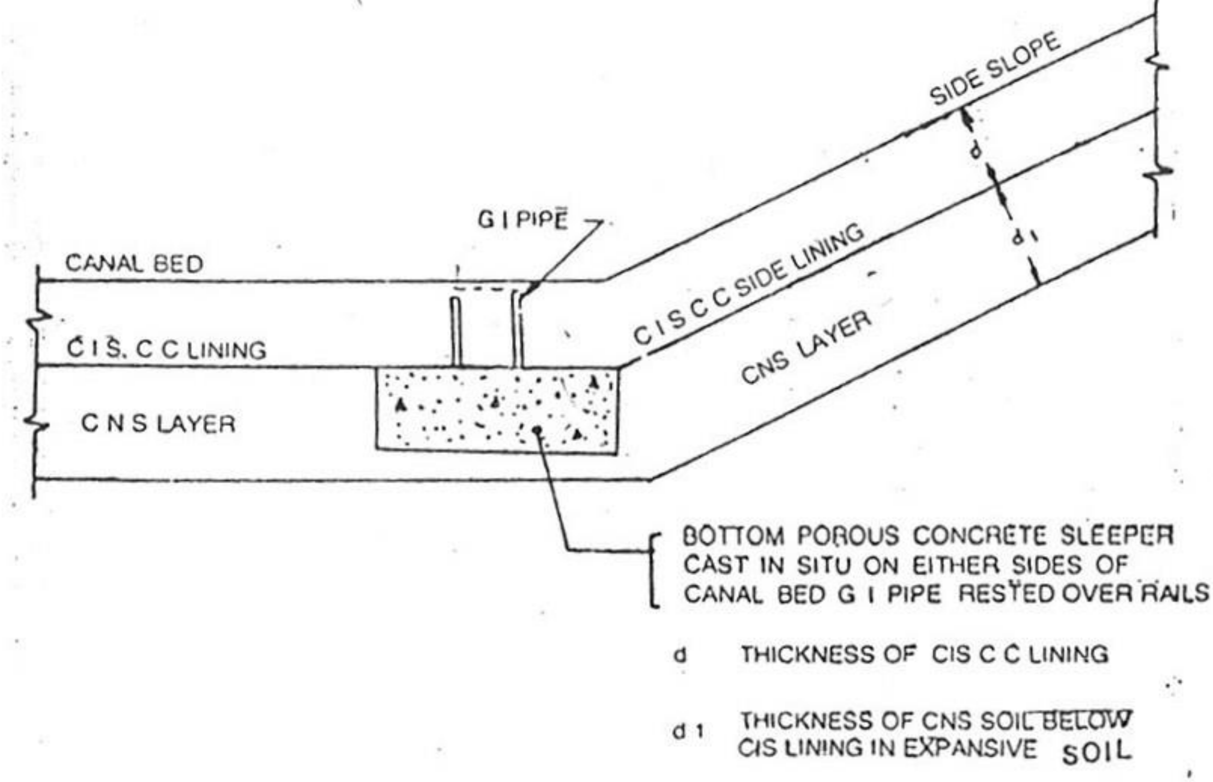


FIG. 2 ILLUSTRATORY DETAIL OF BOTTOM RAILS

Under Drainage:

Cross Section of the Lined Canal:

- As per Cl. 8.8.1 of IS 10430: 2000, The cross section of the lined canal may be trapezoidal with or without rounded corners, and the figure referred there in , shows:
- Bed lining and side lining to be joined with circular curve of radius equal to full supply depth of the canal.
  - The Radius of Curvature (R) adopted in the case of Indira Sagar Polavaram Project, and Sardar Sarovar Project Canals is 1500mm.
    - The Expert Committee on NSP, in a Specific case recommended the radius of curvature (R) equal to 1500mm.

- Suitable under drainage should be provided to protect the lining, where the canal crosses an area subjected to seasonal high ground water.

- Excessive hydrostatic pressure sufficient to damage the lining when the canal is empty or canal is low water level.
- Drainage arrangements provided mainly depend s up on the position of the water table and the type of sub grade.

Water table may be:

- Below canal bed level
- Between canal bed level and full supply level
- Above canal full supply level

The sub grade may be

- Free Drainage
- Poor Drainage

  Practically Impervious

Necessity of Drainage and Filters below lining:

1. Water table below CBL:

A). Sub grade free drainage

- No drainage arrangements required, and no pressure relief arrangements required

B). sub grade poor drainage

- Provide 150 to 200mm filters and pressure relief arrangements with longitudinal and transverse drains with PRVs in the bed, PRVs in the pockets filled with filters in the sides.

C). Sub grade impervious

- Sub grade to a depth of 600mm to be removed and refilled with sand, murram or suitable pervious material and pressure relief arrangements as above required.

Necessity of Drainage and Filters below lining

2. Water table between CBL and FSL:

a). Sub grade free drainage

- Provide 150 to 200mm filters and pressure relief arrangements with Longitudinal and Transverse drains I with PRVs in the bed and PRVs in pockets filled with filters in the sides.

b). Sub grade poor drainage

- Provide 200 to 300mm filters and pressure relief arrangements as above

c). Sub grade impervious

- Sub grade to a depth of 600mm to be remove and refilled with sand, murram, or suitable pervious material. Pressure relief arrangements in bed and sides as above are required.

Necessity of Drainage and Filters below lining

2. Water table above FSL

a). Sub grade free drainage

- provide150 to 200mm filters

b). Sub grade poor drainage

- Provide 200 to 300mm filters

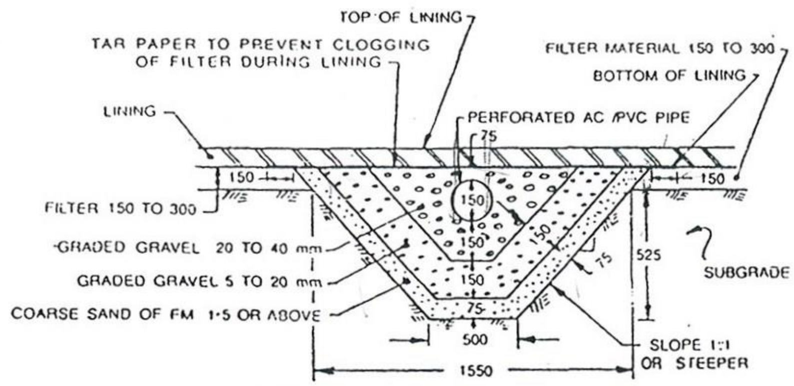
c). Sub Grade impervious

- Remove the sub grade to a depth of 600mm and back filled with sand, murram, or suitable pervious material
- Pressure relief arrangements
    a. Bed – Longitudinal and Transverse drains with PRVS
    b. Sides- Transverse drains with PRVs
    c. Longitudinal drains:
    d. Trapezoidal with bottom width 500mm, and depth 525mm. Number depending on the bed width of the canal usually at least one drain for every 10m width.
- Transverse drains:
    a. Provided in the bed and on the side slopes up to free board level
    b. Provided at 10m intervals
- Pressure Relief Valves (PRV)
    a. Provided on the longitudinal/Transverse drains
    b. Spacing, one row at every 4m on the sides, the first row 50cm above curve line and top row 50

t0100mm below FSL. If the depth of water is less than 1.5m, one row will be adequate.

c. Spacing one PRV for every 100 sq.m in the canal bed and one for every 40 sq.m for sides
d. Porous concrete Plugs:
e. Size 100mm dia. And 400mm long may be provided in place of PRVs

IS 4558 : 1995



All dimensions in millimetres.

FIG. 1 TYPICAL SECTION OF LONGITUDANAL/TRANSVERSE DRAIN
(PRESSURE RELIEF VALVE NOT SHOWN)

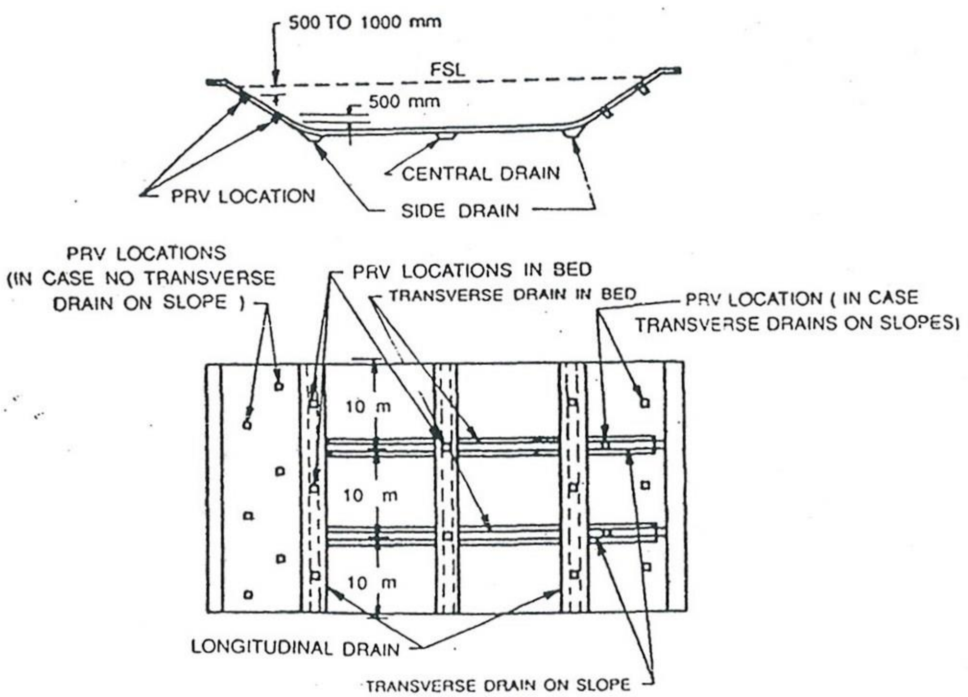
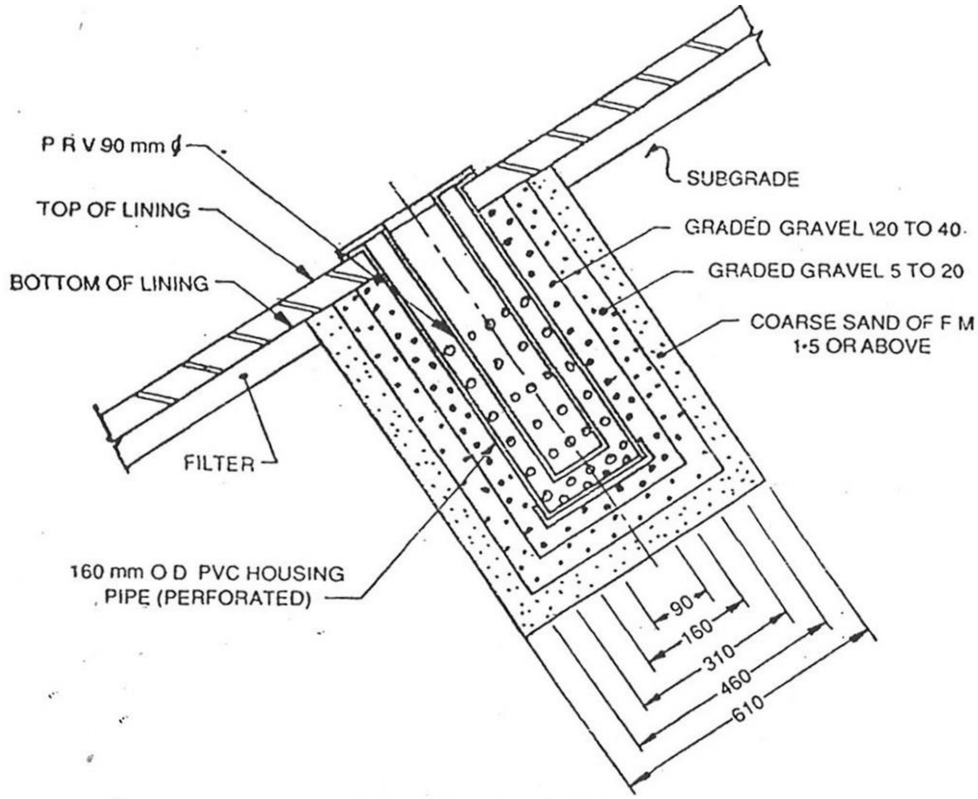


FIG. 2 ARRANGEMENT SHOWING DRAINS AND PRV LOCATIONS



All dimensions in millimetres.
FIG. 3 PRV POCKET ON SLOPE

Over excavation:
For slopes more than 1:1 in hard strata:

- Backfilled with gravel and aggregate and a layer of pea gravel as binding material.
- The bed may be compacted with road roller and the sides with rammers.

For slopes less than 1:1 in hard strata:

- Back fill shall be chip masonry, alternatively, lean concrete.
-

Sleepers/profile walls:
At intervals of 20m/17.5m in straight reaches and 10m /8.75 in curves. The size shall be 250mm wide and 150mm deep built in the same grade of lining, for the main & branch canals and larger distributaries and 200mm X 150mm for other distributaries.

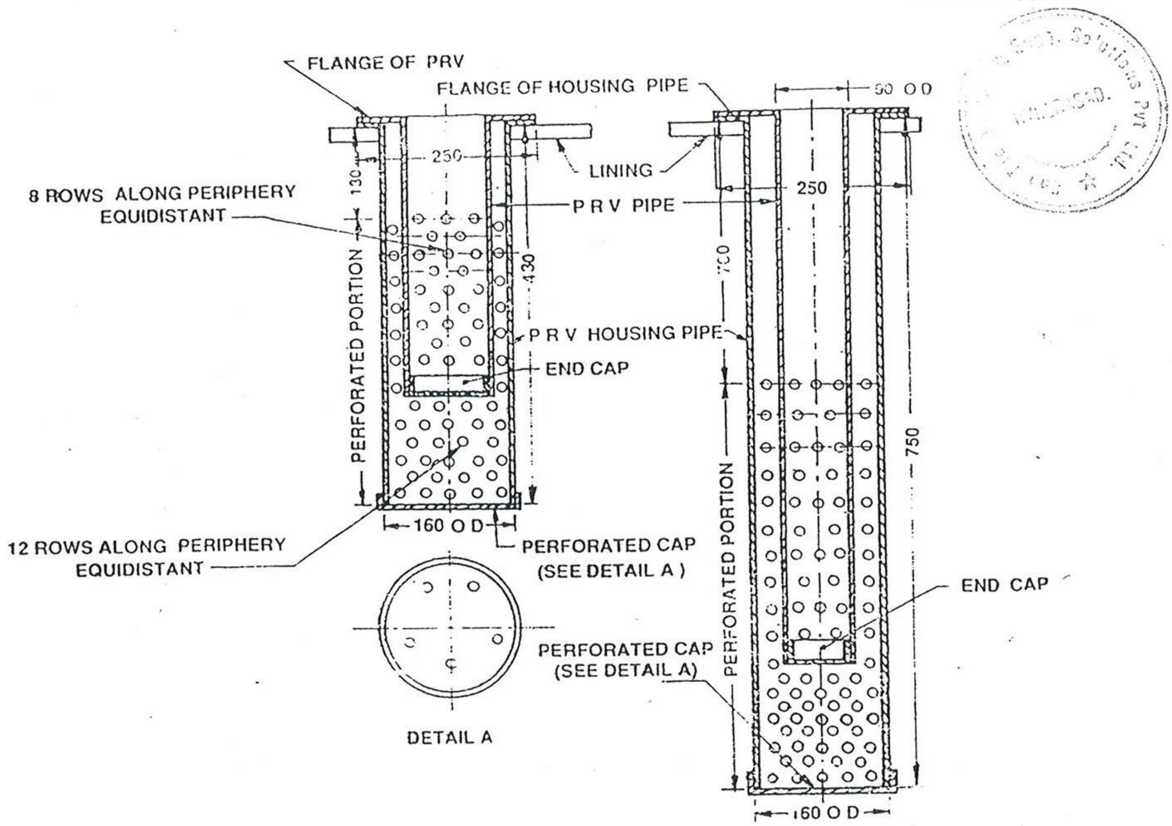
Sleeper shall be placed centrally under the joints. (Cl.5.5.1.1.5 of IS 3873-1993)

Expansion Joints:
These should not be provided except where a structure intersects is the canal.

Construction Joint:
Joints are potential points of seepage. A construction joint is weak link in the lining and deterioration starts from such joints.
As such, number of joints shall be kept minimum.

Dowel Banks:
Main canal & branch canal: 500mm top width, 500mm high with side slopes 1.5:1
Distributaries’: 300m top width, 300mm high with side slopes 1’5:1

IS 4558 : 1995



All dimensions in millimetres.

FIG. 4 DETAIL OF PERFORATIONS IN PRV HOUSING PIPE (DETAIL OF PRV NOT SHOWN)

Contraction joints

Contraction joints should be provided in canal lining at interval of not more than 36 times the thickness of lining, in both longitudinal and transverse directions. The following spacing is adopted for different thicknesses of lining.

S.No.	Thickness of lining in MM	Spacing of contraction joint I MM
1	60	2000
2	75	2500
3	100	3500
4	120	4000

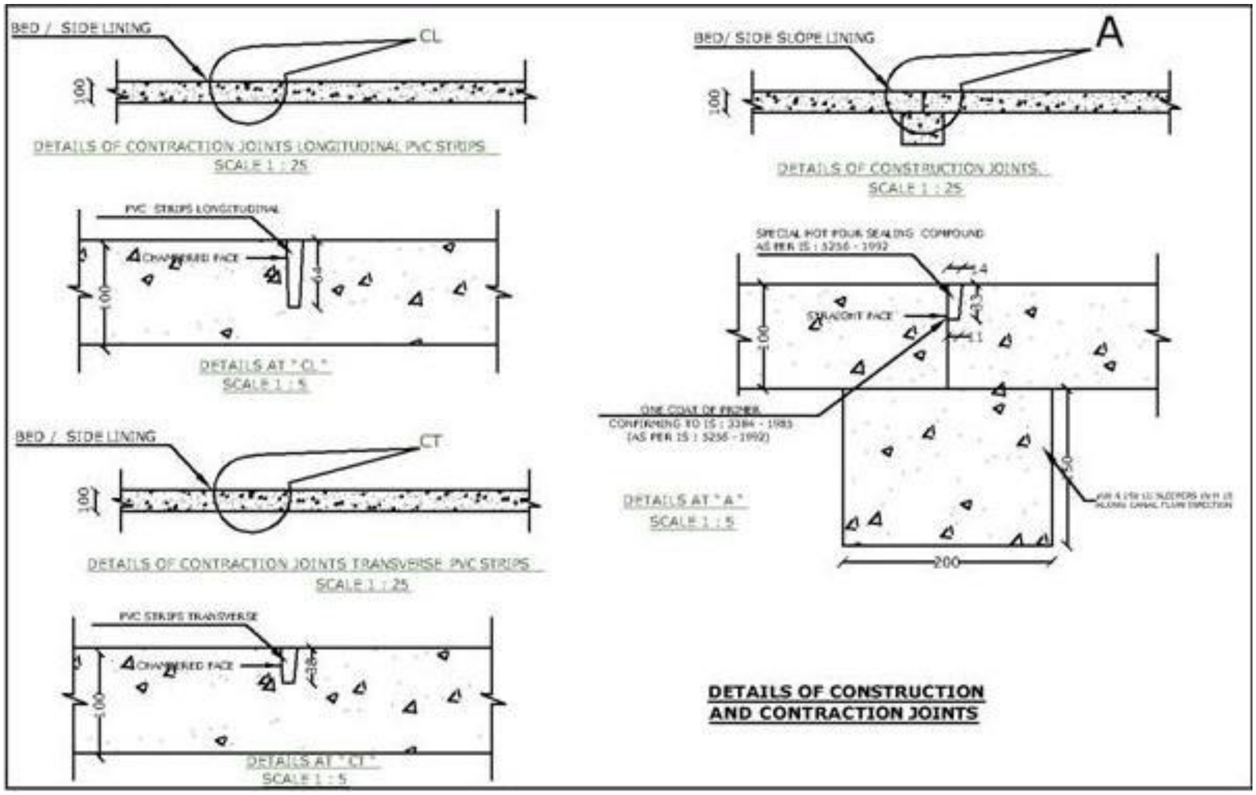
Where in-situ CC lining is laid with mechanical pavers, PVC strips should be provided in the contraction joints. The size of the PVC strips for the longitudinal and transverse contractions joints are shown.
Where alternate method of contraction joints is adopted by cutting the groove in the lining concrete and filling with sealing compound, the dimensions of the groove should be as per the figure shown.

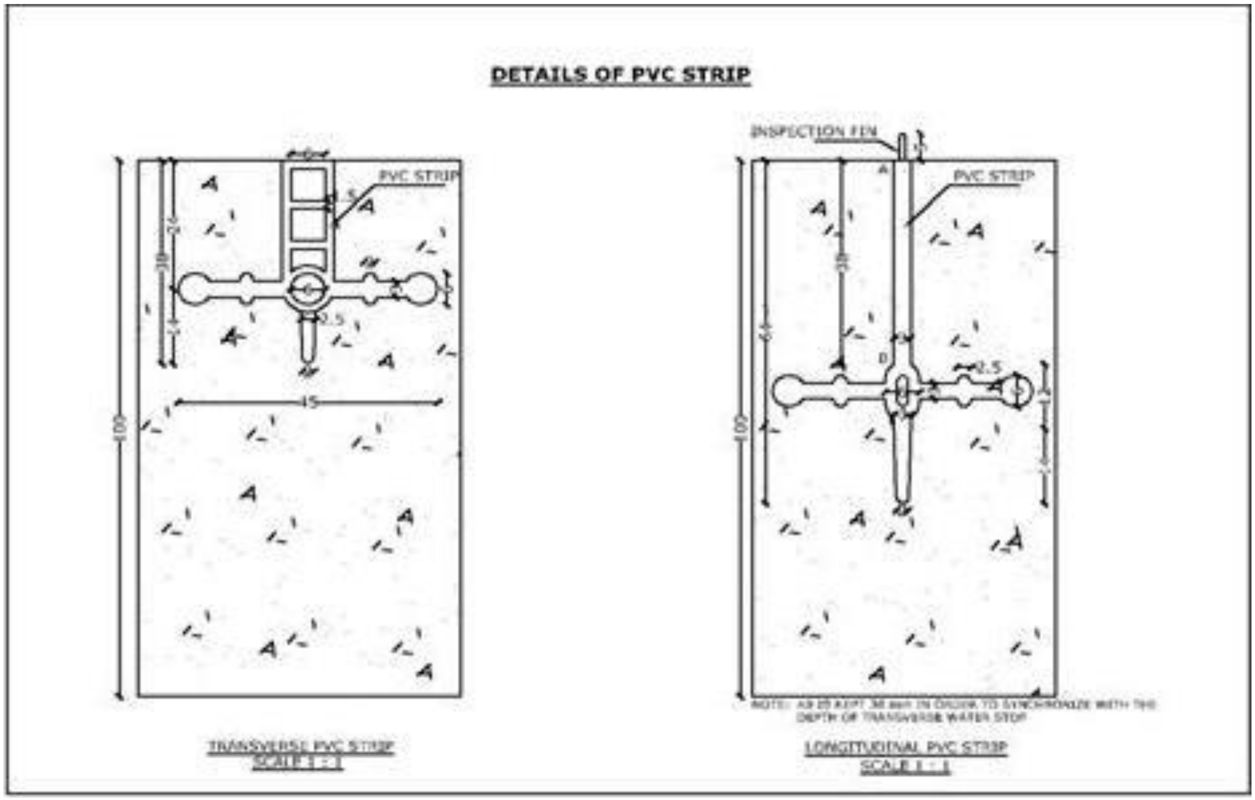
Construction joints:

- The construction joints are provided in the canal lining, wherever there is discontinuity of concrete work for a period of time leading to creation of cold joint. Generally, bed lining is executed in advance of the laying side lining. As such construction joints are required on either side of canal bed at the junction of bed and side lining. Normally longitudinal construction joints are provided at about 500 to 1000 mm from the tangent point of the curve at the junction of canal bed and the side slope on either side of the bed. In the case of small channels, where bed and side lining are laid simultaneously, longitudinal construction joints are not provided. Transverse construction joints should be provided, where discontinuity of work for considerable time is expected. 200 mm x 150 mm size CC M15 grade sleepers are provided under the construction joints. The joint should be filled with hot pour sealing compound as per specifications in IS: 5256 – 1992.

Steps:
1500mm wide (minimum) steps in CC M15 grade should be provided at 300 m C/C staggered on either side of the canal as stipulated in IS: 3873 – 1993. 3000 mm wide steps are to be provided at the villages and structure

locations. In the case of smaller distributaries, steps are to be provided arbitrarily as per the certificate of the Executive Engineer.





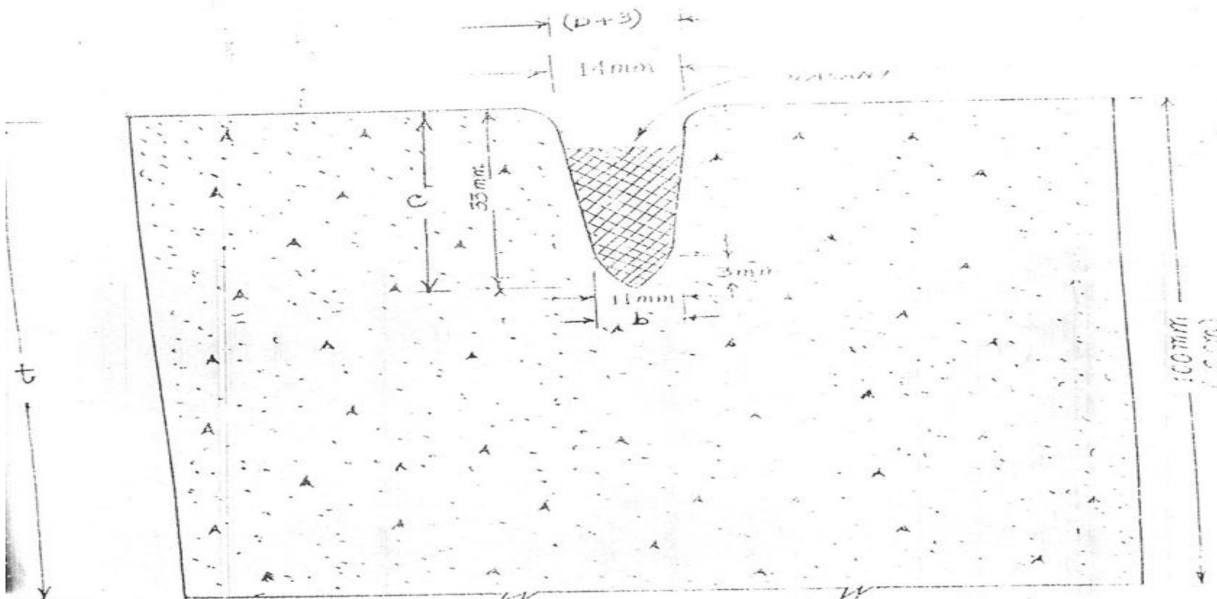
SPECIFICATIONS OF SEALING COMPOUND FOR FILLING LONGITUDINAL AND TRANSVERSE CONTRACTION JOINT GROOVES:

The sealant is prepared from the materials as under:

(i) Bitumen 85/25 . . . . 55%
(ii) Sand (fineness modulus 1.0 to 1.5)…………….. 43%
(iii) Asbestos powder 2%

Bitumen: The Bitumen 85/25 shall be tested as per IS code 702-1961 prior to its use.

SKETCH 5



t	b	c
65 – 70 mm	9 mm	27 mm
75 – 100 mm	11 mm	33 mm
> 100 mm	11 mm	t/3

Note : C should not be more than 1/2 (-); C should be minimum t/3

CONVENTIONAL GROOVES

LONGITUDINAL / TRANSVERSE

CONTRACTION JOINTS

References:

1. IS 7112-2002 Criteria for design of cross sections for unlined canals in alluvial soils.
2. IS 5968-1987 (reaffirmed 2012 Guide for planning and layout of canal system for irrigation.
3. IS 10430:2000 Criteria for Design of lined canals?
4. IS 3873 – 1993 Laying cement concrete / stone slab lining on canals – code of practice.
5. IS 7873 – 1975 (reaffirmed 1995) Code of practice for lime concrete lining for canals.
6. 10. 4515- 2002 Code of practice Stone pitched lining for canals.
7. IS: 9012 - 1978Recommonded practice for shotcreting
8. IS 9451 – 1994 Guidelines for lining of canals on expansive soils.
9. IS 4558 – 1995 Under drainage of lined canals – code of practice
10. IS 12379 – 1988 Code of practice for lining watercourses and field channels.
11. IS:6062-1971 Method pf measurement of flow of water in open channels using
    Standing wave flume.
12. IS 6063-1971 Method pf measurement of flow of water in open channels using Standing wave flume.
13. IS: 4839 (Part I)-1992 Maintenance of canals – code of practice- un lined canals
14. IS: 4839 (Part II)-1992 Maintenance of canals – code of practice- lined canals
15. IS: 15087:2001 Planning and design of drainage in Irrigation Projects-Guidelines
16. IS: 13143- 1991 Joints in Concrete lining of Canals-Sealing Compounds-Specification
17. IS: 9698-1995 – Lining of canals with Polyethylene Film- Code of Practice.
18. IS: 4701-1982- Code of Practice for earth work on canals.
19. IS:11385-1985- code of practice for sub-surface exploration for canals.
20. IS: 4839(Part-1)-1982-Maitenancce of canals Code of Practice.
21. IS: 4839(Part-2)-Maintenance of canals, Code of practice for lined canals.
22. IS: 9452(Part-1)-1993-Measurement of seepage losses from canals-Code of practice.

Manuals:

1. Manual on irrigation and power cannels, CBIP Publication No. 171
2. Design practices for unlined incised canals Technical report .7, May, 1970.by central board of irrigation and power.

PART II

CROSS MASONRY AND CROSS DRAINAGE WORKS,

STRUCTURES ON CANALS:

Main types of structures on a canal.

1. Cross drainage works.
2. Regulating structures.
3. Communication structures.

1. Cross drainage works:

These structures are provided when the canal crosses a valley or a drainage. There is three ways of crossing the drainage and classified as.

1. To pass the drainage over the canal. The bed and water levels of the drain will be higher than the canal.
   This type are super passages and canal syphons.

2. To pass the drainage water in to the canal. The drainage and the canal waters mix up.
   This type of structures are In-lets with or without escapes.
   In lets normally harm to the canal bed and side slopes and drainage or the canal therefore be siphoned.

3. To pass the drainage under the canal.

This type of cross drainage works are relatively more convenient and above ground:

1. Aqueducts.
2. Syphon aqueducts
3. Drainage siphons or under tunnel. And
4. Culverts

2. Regulating structures:

Regulating structures are to maintain the levels and the discharge in the canal. The types of structures are:

1. Canal falls.
2. Cross regulators.
3. Head regulators of the distributaries.
4. Escapes.
5. Outlets of watercourses.
6. Silt ejectors.

3. Communication works:

These are road bridges and to be provided for all existing and future anticipated roads. Road bridges are provided generally at 2 to 3 km. intervals, and at all crossings of metal roads.

Selection of cross drainage works depends on:

1. FSL and functions of canal vis-à-vis high flood level of the drainage cannel
2. Topography of the terrain
3. Regime of the steam
4. Foundation strata
5. Dewatering requirements
6. Ratio of designed flood in drainage channel to the discharge in the canal and
7. Envisaged head loss.

Data required:

Canal;

1. Full supply discharge
2. Bed width

3. FS depth
4. Surface slope
5. Bed level
6. FS level
7. TBL
8. CS of canal showing ground levels
9. Value of ‘n’
10. Subsoil water level

Drainage:

1. Catchment area
2. Maximum annual rainfall and the period
3. Maximum intensity of rainfall
4. Maximum observed flood discharge
5. Maximum observed level
6. water surface slope
7. Site plan with contours
8. Trial pit particulars or log of bore holes
9. Longitudinal section of drainage for a distance of 300m U/S and D/S

11.Cross section at 10 to 20m intervals
12.. Silt factor

Design flood values:

(As per table 1 Design flood values clauses 7.2 and 7.4 of IS; 7784 (part I): 1993)

Category of structure	Canal discharge In m^3 / sec	Estimated drainage Discharge in m^3 / sec	Frequency of design flood
A	0 – 0.50	All discharges	1 in 25 years
B	0.50 – 1.50	0 – 150 Above 150	1 in 50 years 1 in 100 years
C	15 - 30	0 – 100 Above 100	1 in 50 years 1 in 100 years
D	Above 30	0 – 150 Above 150	1 in 100 years As per note 2

Notes:

1. The design flood to be adopted as mentioned in this table should in no case, be less than the observed flood.
2.In case of very large cross drainage structures where estimated drainage discharge is above 150 cumecs and the canal design discharge is more than 30 cumecs, the hydrology should be examined in detail and appropriate design flood adopted which should in no case be less than 1 in 100 years.

Free Board:

In case of cross drainage structures, the free board is reckoned from the HFL (including afflux) and in case of canals from FSL to the formation level of the guide bund or TBL of the canal. It should not be less than 900mm.

Vertical Clearance:

(Taking into account the afflux)

Table 3. Minimum Vertical clearances for Rectangular openings

S.No	Designed flood in cumecs /sec	Minimum Vertical Clearance in mm
1	Below 3	450
2	3 and above but below 30	600
3	30 and above but below 300	900
4	300 and above but below 3 000	1 200
5	3 000 and above	1 500

Afflux:

1. Afflux correspond to the design flood
2. It should be restricted to a value that the resulting velocity does not cause serious bed scour in the drainage or does not create submergence, which cannot be permitted.
3. The afflux may be calculated by using
1. Rational formulae and
2. Empirical formula

Scour Calculations:

Mean depth of Scour below highest flood level (HFL) for natural channels flowing over scourable bed can be calculated from the following equations

$$D = 1.34 (q2 / k_f)^{1/3}$$

Where q is the designed discharge per meter width at effective linear water ay

k_f is the silt factor for a representative sample of bed material obtained up to the level of anticipated depth of scour.

k_f is given by the expression $1.76 (d_m)^{1/2}$

d_m being the weighted mean diameter in millimeters.

The Value of kf for various grades of bed materials normally encountered is given below for general guidance only (Clause 110.1.2 0f IRC:5-1998 and 703.2.2.1 of IRC: 78-2000)

S.No.	Type of bed material	weighted mean diameter of particle in mm, d_m	value of silt factor K_f
1	Fine silt	0.081	0.500
2	Fine silt	0.120	0.600
3	Fine silt	0.158	0.700
4	Medium silt	0.233	0.850
5	Standard silt	0.323	1.000
6	Medium sand	0.505	1.250
7	Coarse sand	0.725	1.500
8	Fine bajri and sand	0.988	1.750
0	Heavy sand	1.290 to 2.000	2.000 to 2.42

Minimum scour depth for design of foundations:

For design of piers and abutments located in a straight reach and having individual foundation without any floor protections and it is below HFL

1. In the vicinity of pier; $2.00d_m$
2. Near abutments: $1.27d_{m\ approach}$ retained
   $2.00\ d_m$ scour all-round

For floor protection works:

For floor protection works, for raft foundations or shallow foundations

1. In straight reach $1.27\ d_m$
2. At a moderate bend $1.50\ d_m$
3. At severe bend $1.75\ d_m$
4. At a straight angle bend $2.00\ d_m$

Loss of head (Energy loss):

When water flows through any structure, there are head losses. The total losses will be sum of the losses represented as

$H = h1 + h2 + h3 = h4$

Where

h1 = Losses at the inlet and outlet (for syphons)

h2 = Losses at the elbow or bends (for barrel)

h3 = Losses due to transitions and

h4 = Losses due to skin friction (from barrels & troughs)

Linear waterway:

For non-meandering channels in alluvial beds but with well-defined banks for all natural channels with rigid ineradicable boundaries, the linear waterway is the distance between the banks at the water surface level, t which the designed discharge can be passed without any harmful afflux.

Effective Linear waterway:

For artificial channels (irrigation, navigation, drainage), the effective linear waterway should be adequate to pass the full discharge at designed velocity. For natural rivers in alluvium beds and having undefined banks, the effective linear waterway for regime condition

$W = C(Q)^{1/2}$

Where W = regime width in meters

C = a constant usually taken as 4.80 for regime channels, but it may vary from 4.5 to 6.3

Q = Designed discharge in cumecs.

Fluming Ratio:

1. A fluming ratio less than 70% may not be adopted
2. For the purpose of fluming ratio of canal the width at mid depth be taken as 100%
3. In drainage channel w the course is hen undefined, a fluming ratio from 75% to 90% of the Lacey's waterway may be adopted.

Abrasion Resistance:

Depending on the velocity of flow and abrasion causing debris (Stone, gravel, sand, silt etc} it may hold, the structural member in the bed should be hard enough and sufficiently hard enough of sufficient strength.

Water seals:
The water stops are used in and across all joints where leakages are detrimental to structural safety or the or water needs are conserved.

Weep Holes:

These are to facilitate the drainage of back fill and to avoid built up pressure. Provided above flow nets. Provided with filters of graded materials to avoid piping of back fill.

Bearings:

Suitable bearings are to be provided between the super structure and the sub-structure like abutments and piers to cater the movements and the load transfer under different load combinations.

Foundations:

To be designed to satisfy the requirements of allowable bearing capacity of the foundation strata under critical loads including positive pressure conditions, seismic effects, anticipated scour and settlement.

1. Aqueducts:

An aqueduct is cross drainage work in which the carrier channel is carried over the drainage channel and bottom of the trough or the covering over the drainage is above HFL in the drainage channel.

Types of aqueducts:

1. Type – 1: The canal continues over the drainage channel in its normal section including its banks and the earthen slopes.

2. Type - 2: The canal continues over the drainage channel in its normal section but the outer slopes of the banks are replaced by retaining walls.

3. Type – 3: The earthen banks of the canal will be discontinuous over the drainage channel and canal water carried in masonry or concrete trough, box, barrel, pipe or any other suitable section.

II. Superpassage:

Superpassage is a cross drainage work to carry the drainage channel or the stream over the canal normally with the FSL of the canal below the bottom of the trough.

Free Board required between the underside of the trough and FSL of the canal

S.No	Discharge of canal in cumecs	Free Board in mm
1	Below 3	200
2	3 and above but below 30	300
3	30 and above but below 300	450
4	300 and above	600

Minimum free board required in the trough

S.No	Drainage discharge in cumecs	Free Board in mm
1	Up to 30	400
2	More than 30 up to 100	500
3	More than 100 up to 300	600
4	More than 300	750

Note: Higher free board may be provided depending upon the drainage characteristics.

III. Canal Syphon:

It is structure with closed conduit designed to run full and usually under pressure to transport canal water under the drainage channel or a road or a railway.

Fluming ratio as above

Loss of head at the entry, exit and in the barrel due to friction are to be calculated and accounted for.

Avoided as far as possible.

IV.Level Crossing:

It is a cross drainage work involving intermixing of irrigation And drainage water and provided they approaches practically at the same bed level and syphoning of the any one of them is economical or not possible.

It essentially comprises of
1. Canal inlet and outlet regulators
2. Drainage inlet and out let regulators.

V. Syphon Aqueduct:

It is cross drainage work where the drainage channel is syphoned and carried under the canal. The shape of the syphon may be circular, square, rectangular, horseshoe, single or multi cell barrels.

Precast RCC pipes may be economical for syphoning small drainage channels.

Types of syphon Aqueducts:

1. Barrel type, using barrel for drainage waterways
2. Trough type using trough section for carrier channel waterways.

VI. Canal Escapes:

Even though the canal regulated by the head regulator, the excess rise in water levels may occur due to entry of storm water, reduction in demand, breakdown in the water lifting arrangements in case of lift irrigation may cause breaches or dangerous leaks through the canal banks. To avoid such events canal escapes are to be provided at suitable locations.

The canal may be required closing for carry out repairs or removal of weed growth the canals can be drained quickly.

Types of Escapes:

1. Weir or Surface Escapes
2. Sluice Escapes

Locations:
1. Determined by the location of the drainage, stream, river or a depression below the bed level of canal.
2. Downstream of canal embankment
3. Upstream of Balancing reservoir and Fore bays
4. Downstream of Canal Inlets etc.

Designed Discharge:

Half the discharge to full discharge of the canal depending on the location, type and the necessity of the structure.

VII. Cross Regulators:

A structure constructed across a canal with arrangements to provided with arrangements to regulate the discharge

1. To supply waters to a feeder canal during low flows
2. To divert supplies to another canal or to regulate supplies in the same canal downstream

3. To regulate the supplies in and out of a reservoir or a lake
4 To regulate flows through the escapes.etc

Cross regulators may be combined with a bridge of a canal fall.

Water way:

1. Headless canal (no fall between FSLs of canal from u/s to d/s) in an unlined canal
   a. equal to bed width for shallow and wide canals and
   b equal to mean width for canals of narrow and deep canals
2. Headless canal (no fall between FSLs of canal from u/s to d/s) in a lined canal
   a. equal to average width of the canal or
   b. equal to width of the canal at FSL
3. Regulators combined with a fall, it depends upon
   a. for submerged falls Drowning ratio (tail water level minus crest level divided by head over the crest) should be > 0.8
   b. for free falls, the discharge per unit width over crest should be equal to greater than that required for the available loss of head and required value of the FS depth downstream

The fluming ratio Bt/B (where Bt is the clear water way, and B is the designed Bed with on the downstream) should not be kept < 0.5.

Number and width of Bays:

May be kept odd from aesthetic reasons and avoid a pier in the center of the canal.

Crest Level:

The crest level be worked using the formula

$$Q = C\ Bt\ H^{3/2}$$

Where
Q= full supply discharge in cumecs
C= coefficient of discharge

Bt= Clear water way in meters
H= Head over crest considering the approach velocity.

VIII. Canal Outlets:

It is device built at the head of a water Couse to control flow of water in it. It connects the watercourse with the distribution channel and may provide a measure of discharge passing through it.

Types of outlets:

1. Modular Outlet:
These are the outlets whose discharge is independent of the water levels in the distributing channel and the watercourse, with or without moving parts.

2. Non-Modular outlets:
A pipe outlet with one end submerged in watercourse is called non- modular and the discharge is computed by

$$Q = CA(2gH)^{1/2}$$

Where
A = Cross sectional area of the pipe in sq.cms
C di coefficient of discharge
H = Difference in water levels between the distributary and the water course.

3. Semi-Modular outlets:

These are independent of water levels in the water course so long as minimum working head is available.

A. Open Flume Outlet:
It is a smooth weir with a throat constructed sufficiently to ensure velocity above the critical and long enough to ensure that the controlling section remain within parallel throat at all discharges up to the maximum. The entire work can be built in brick except the controlling section, which is built by cast iron.
The discharge is calculated by

$$Q = K\ B\ H^{3/2}$$

Where K= a constant
Bt= Throat width
H = Head over the crest in meters.

B. Crump's Adjustable Proportional Modular:

It is most commonly used outlet. It cannot be tampered with and it may be conveniently adjusted at a very small cost.

References:

1. IS: 7784 (Part I)- 1993 Design of Cross Drainage Works-Code of Practice
Part I: General Features.
2. IS: 7784 (Part II section 1)- 1995 Design of Cross Drainage Works-Code of Practice
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3. IS: 7784 (Part II Section2)- 2000 Design of Cross Drainage Works-Code of Practice.
Section 2: Super Passages
4. IS: 7784(Part II Section3) 1996 Design of Cross Drainage Works-Code of Practice
Section 3: Canal Syphons.
5. IS: 7784(Part II Section4):1999 Design of Cross Drainage Works-Code of Practice
Section4: Level Crossings
6. IS: 7784(Part II section 5) Design of Cross Drainage Works-Code of Practice
Section 5: Syphon Aqueducts.
7. IS: 6936:1992 Guidelines for location, Selection and hydraulic Design of Canal
Escapes.
8. IS: 3370 (Part I): 2009 Code of Practice for concrete Structures for storage of liquids
General Requirement
9. IS: 3370 (Part II): 2009 Code of Practice for concrete Structures for storage of liquids Reinforced concrete Structures
10. IS: 3370 (Part III): 2009 Code of Practice for concrete Structures for storage of liquids Prestressed Concrete Structures

11.IS: 12331:1988 General requirements of canal outlets
12.IS: 7114: 1973 Criteria for hydraulic design of Cross Regulators for canals
13.IS:12331:1998 General requirements of canal outlets.
14.IS: 7331: 1981 Code of practice for inspection and maintenance of cross drainage works
15. IS: 9447-1980 – Guidelines for Assessment of Seepage losses from Canals by Analytical method.
16. IS:12379-1988- Code of Practice for lining of Water-courses and Field channels.

Manuals:

3. Manual on irrigation and power cannels, CBIP Publication No. 171
4. Design practices for unlined incised canals Technical report .7, May, 1970.by central board of irrigation and power.

PART III

Inland Waterways - Navigation Canals

Classification of Inland Water Ways – Navigation Channels:

(IWAI Act 1985 – Inland Water Authority of India. Ministry of Shipping, Road Transport & Highways, Government of India – section IV)

Class	Minimum Depth in m	Bottom Width in m	Vertical Clearance in m	Horizontal Clearance in m	Bend Radius In m
Class-I Rivers Canals	 1.2 1.2	 30 20	 4 4	 30 20	 300 300
Class-II Rivers Canals	1.4 1.8	40 30	5 5	40 30	500 500
Class-III Rivers Canals	1.7 2.2	50 40	7 7	40 40	700 700
Class-IV Rivers Canals	2.0 2.5	50 50	10 10	50 50	800 800
Class-V Rivers	 2.0	 80	 10	 80	 800
Class-VI Rivers Canals	2.75 3.5	80 60	10	80 80	900 900

Class-VII Rivers	2.75 & above	100 &above	10	100	900

2. Vertical clearance for power cables or telephone lines or cables for any transmission purpose for all the classes of waterways mentioned at 3(1) shall be as follows:
   i) Low voltage transmission lines including telephone lines - 16.5 metres
   ii) High voltage transmission lines, not exceeding 110 kilo volt - 19.0 metres
   iii) High voltage transmission line, exceeding 110 kilovolt - 19.0 metres +1 centimetres extra for each additional kilovolt
3. In case of underwater pipelines, power cables and other cables, norms to be followed shall be decided as per the site conditions and navigational requirement.

Explanation for the purpose of this regulations, - Reference level for vertical clearance in different types of channel shall be-

(i) for rivers, over Navigational High Flood Level (NHFL), which is the highest flood level at a frequency of 5% in any year over a period of last twenty years.

(ii) for tidal canals, over the highest high-water level.

(iii) for other canals, over designed full supply level.

4**. Inland vessels shall be classified as follows namely**: -

Class I Passenger vessels
Class II Ferry launches and boats
Class III Cargo vessels and vessels other than those falling under Class – I, II, IV & V
Class IV Non-propelled vessels (barges)
Class V Pleasure crafts

Waterways and Types of vessels:

Class	Type of Vessel	Dead weight In ton	Over all Length in m	Moulded Breath in m	Loaded Draft in m
Class-I	Self-Propelled Vessel One tug & Two Barges combination	100 200	32 80	5 5	1.0 1.0
Class-II	Self-Propelled Vessel One tug & Two Barges combination	300 600	45 110	8 8	1.2 1.2
Class-III	Self-Propelled Vessel One tug & Two Barges combination	500 1000	110 58	8 9	1.2 1.5
Class-IV	Self-Propelled Vessel One tug & Two Barges combination	1000 2000	70 170	12 12	1.8 1.8
Class-V	Self-Propelled Vessel One tug & Two Barges combination	1000 4000	70 170	12 24	1.8 1.8
Class-VI	Self-Propelled Vessel One tug & Two	2000 4000	86 210	14 14	2.5 2.5

	Barges combination				
Class-VII	Self-Propelled Vessel One tug & Two Barges combination	2000 8000	86 210	14 28	2.5 2.5

5. All the new structures to be constructed across the national waterways classified under these regulations shall conform to the respective criteria of horizontal and vertical clearances of the appropriate class of waterway as provided.

References:

1. (IWAI Act 1985 – Inland Water Authority of India. Ministry of Shipping, Road Transport & Highways, Government of India)