5

Lining of Irrigation Canals and Economics of Lining

5.1. General

Next to China, India has the largest area under irrigation. The irrigated area is constantly and continuously being increased, so as to ensure assured irrigation and to avoid crop failures due to famines and non-availability of water. To secure the benefits of irrigated land, a tremendous amount of capital has been invested in this country in the irrigation projects. So much so, that an expenditure of about Rs. 1,15,000 crores has been incurred in our country on major and medium irrigation projects since independence and up to the end of ninth five-year plan (1997–2002). This data confirms the fact that irrigation water is a costly commodity, and as such, there should be no wastage during its carriage from the reservoirs to the fields. Most of the canals, constructed in India to carry irrigation water, are unlined, and hence, a large part of the costly irrigation water is lost in percolation and absorption as seepage loss. No doubt, there are regions where the soil is such that seepage losses are very small, and there is no justification for lining them, but at the same time, it is also true that there are areas where 25 to 50% of the water is lost in seepage. This is a very serious loss and proportionately reduces the irrigation potential of the supplied water. Such seepage loss of the costly irrigation water must, therefore, be minimised. The seepage can be avoided or minimised by *lining the irrigation canals.*

By lining the canal, we mean that the earthen surface of the channel is lined with a stable (inerodible) lining surface, such as concrete, tiles, asphalt, etc. Depending upon the type of lining adopted, the seepage losses can be reduced to 2%–5% of their original values by lining the canals. Apart from reduction in seepage losses, there are various other advantages of lining the canals. All these advantages are described below in details :

5.2. Advantages of Lining

(1) **Seepage Control.** It has been emphasised above, that the seepage losses are considerably reduced if the channels are lined. A lined canal costs about 2 to $2\frac{1}{2}$ times as much as an unlined canal, but where seepage is heavy, the saving of costly irrigation water may itself be sufficient to fully justify the capital expenditure on lining. It should also be kept in mind that heavy seepage losses in canals would necessitate the construction of larger reservoirs and bigger dams. Prevention of seepage by lining would, therefore, reduce their impounding capacity, and hence, lower the construction costs of these works. The idea of the extent to which seepage takes place in different kinds of channels can be obtained from Table 5.1.

Table 5.1. Seepage Losses in Channels

S. No.	*Type of lining*	*Initial rate of seepage in cumecs per million sq. m. of wetted area before lining*	*Stabilised rate of seepage in cumecs per million sq. m. of wetted area after lining*
1.	Unlined channels.	7.4	3.4
2.	30 cm × 15 cm × 5 cm tiles using cement mortar 1 : 3 (1 cement ; 3 sand in between two layers.	0.17	0.009
3.	10 cm thick cement concrete 1 : 3 ; 6 (1 cement : 3 sand : 6 brick ballast.	0.13	0.007
4.	10 cm thick cement lime concrete 1 : 5 : 12 : 24 (1 cement : 5 lime : 12 surkhi : 24 brick ballast).	0.40	0.13

(2) **Prevention of Water-logging.** Uncontrolled seepage through unlined canals, often raises the water-table in the surrounding fields up to or near to the ground level, as to bring the crop (plant) roots within the capillary fringe. This, in turn, brings up the alkali salts near to the ground surface, which soon renders the land unfit for cultivation. Such a land is usually called *thur*, and the phenomenon of rise of water table is known as water-logging.* It is well-known that large tracts of lands in Punjab (India and Pakistan) have been rendered uncultivable in this manner. Thus, the very canal, built to increase food production, have within a few years, caused the ruin of a large portion of agriculturable land. Lining of canals prevents seepage and, thus, protects cultivable land. Combined with land drainage schemes, lining helps to reclaim water-logged areas.

(3) **Increase in Channel Capacity.** The capacity of a chosen canal section can be considerably increased by lining it. The reason is very simple. The lining presents a smooth surface and, therefore, causes less resistance to the flow of water. The water, therefore, flows faster, and hence, more of it is carried per second than that in an unlined canal. Flow of water in unlined canals, is often, further retarded by the vegetation on the sides and bottom. And since capacity is a function of velocity, the higher the velocity, the greater is the capacity of the channel.

We know that Kutter's formula for channel velocity is

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

where n is the coefficient of roughness. The velocity, therefore, varies inversely with n. For unlined earth channels in good condition, the value of n is about 0.0225 against 0.012 for cement mortar, 0.015 for concrete, and 0.018 for brick lined channels. Table 5.2 gives commonly used n values for different types of linings.

* For details, please see Chapter 6.

Table 5.2. Values of Mannings (*n*) for Lined Channels

Type of Lining	*Values of n for straight alignment**
Cast insitu concrete trowel finish	0.015—0.018**
Cement plastered masonry	0.012—0.015
P.C.C. slabs or tiles	0.018—0.020
Brick lining	0.018—0.020
Split Boulder lining	0.020—0.025
Round Boulder lining	0.025—0.035

Lining, therefore, increases channel capacity and consequently reduces the required channel section. Hence, for a new designed project, a lined channel will require lesser dimensions and hence, lesser earth work. The consequent saving in earth work handling (*i.e.* excavation and filling) and acquisition of land, thus, become possible by canal lining.

(4) **Increase in Commanded Area.** A lined canal can be designed not only smaller in cross-section but also shorter in length. The steeper gradients can be provided because higher velocities are permissible (as the material is less erodible) and a shorter alignment can, therefore, be selected. On the other hand, flatter slopes can be provided without silting on a lined channel compared to these on an unlined channel. It can, therefore, help to bring high areas under command.

(5) **Reduction in Maintenance Costs.** The up-keep of unlined canals involve huge recurring expenditure, generally charged under the head of account : *A.R.* and *M.O.* of the canal system (*i.e.* Annual repair and maintenance of the canal system). This expenditure may be required on :

(*i*) periodical removal of silt deposited on the bed and sides of the canal section ;

(*ii*) minor repairs like plugging of cracks, cuts and uneven settlements of banks ; and

(*iii*) removal of weeds and water plants.

The provision of lining reduces these charges considerably, as the cost of upkeep of a lined canal is comparatively negligible.

The above three heads are discussed below in details :

(*i*) *Removal of silt.* A lined canal is not susceptible to erosion. It is usually designed to carry the sediment load likely to enter at the canal headworks. Moreover, on account of the high velocities in lined channels, the sand blown into it during sand storms, which may occur during summer in areas like Rajasthan deserts, etc. is readily carried away. This eliminates or considerably reduces the annual expenditure required on unlined channels for desilting.

(*ii*) *Minor repairs.* Periodical plugging of holes burrowed by rats, insects, etc., is constantly required in unlined channels, failing which, breaches of channel embankments may occur. The provision of adequate lining, reduces the danger of these breaches, and lesser vigilance is required.

* For canals with non-straight alignments, loss of head by resistance to flow shall increase, and hence the given *n* values may be slightly increased.

** Lower values may be attained in canals with relatively higher discharges and in absolutely straight reaches.

(*iii*) *Removal of weeds.* Huge money is spent in removing weeds and water plants like hyaocinth, etc., from the canals. Lining eliminates or reduces this expenditure considerably, as the plants flow down the canal due to higher flow velocites in lined canals.

(6) **Elimination of Flood Dangers.** An unlined canal founded on weaker foundations is always in danger, and a breach may occur at any time. Instances have occurred where small breaches in unlined canals resulted in washing away of considerable length of embankment—leading to flooding of certain areas and causing scarcity of irrigation water in others, as the canal was out of service at a critical time for crops. A strong concrete lining removes all such dangers.

FINANCIAL JUSTIFICATION AND ECONOMICS OF CANAL LINING

In certain cases, the lining of a channel may be required from purely technical considerations. For example, a canal constructed on a high fill or a canal founded partly on rock and partly on permeable strata, may be unsafe, unless it is lined. Sometimes a hard lined surface may be required to withstand the high flow velocities, as in power channels. Apart from these special circumstances, the engineer is required to produce a good economic justification for the capital outlay that is likely to be invested on lining. In considering the economy of canal lining, it is necessary to evaluate the tangible (which can be measured in terms of money) and additional benefits, and then to compare these with the cost of lining. *Benefit cost ratio* can, therefore, be worked out, so as to justify the necessity of lining.

Mathematically speaking, expenditure on a project is justified if the resultant annual benefits exceed the annual costs (including interest on the capital expenditure) *i.e. Benefit cost ratio is more than one.* The justification for lining the existing channels is different from that of constructing new lined channels in a new project. It is because of the fact that a large number of additional advantages ; such as lesser earth-work-handling, lesser land acquisition, lesser impounding reservoir capacities, etc., are obtained in a new project, by adopting lining for new canals.

5.3. Justification for Lining the Existing Canals

(*i*) **Annual Benefits.** Irrigation water is sold to the cultivators at a certain rate. Let this rate be rupees R_1 per cumec. If m cumecs of water is saved by lining the canal, annually, then the money saved by lining $= mR_1$ rupees.

Lining will also reduce maintenance cost. The average cost of annual upkeep of unlined channel can be worked out from previous records. Let it be Rs. R_2. If p is the percentage fraction of the saving achieved in maintenance cost by lining the canal, then the amount saved $= p \cdot R_2$ rupees.

$$\therefore \textit{The total annual benefits} = mR_1 + p \cdot R_2 \qquad ...(5.1)$$

(The value of p is generally taken as 0.4)

(*ii*) **Annual Costs.** If the capital expenditure required on lining is C rupees, and the lining has a life of say Y years, then the annual depreciation charges will be $\frac{C}{Y}$ rupees. If r percent is the rate of annual simple interest, then a locked up capital of C rupees would earn, annually $C\left(\frac{r}{100}\right)$ rupees as interest charges, and since the capital value of the asset decreases from C to zero in Y years, the average annual interest cost may be taken as $\frac{C}{2}\left(\frac{r}{100}\right)$ rupees.

∴ The total *annual costs of lining*

$$= \frac{C}{Y} + \frac{C}{2} \times \frac{r}{100} \quad ...(5.2)$$

Benefit cost ratio $= \frac{\text{Annual Benefits}}{\text{Annual Costs}}$

$$= \left[\frac{m \cdot R_1 + p \cdot R_2}{\frac{C}{Y} + \frac{C}{2} \times \frac{r}{100}}\right] \quad ...(5.3)$$

If p is taken as 0.4, then

$$\text{Benefit cost ratio} = \left\{\frac{m \cdot R_1 + 0.4\, R_2}{\frac{C}{Y} + \frac{C}{2} \times \frac{r}{100}}\right] \quad ...(5.4)$$

For project justification, benefit cost ratio must be greater than unity.

In addition to the benefits grouped above *i.e.* (water saving and reduction in maintenance cost) there may be benefits, like prevention of water–logging, reduced cost of drainage for adjoining lands, reduced risk of breaching, reduced incidence of malaria and other diseases in damp areas. Actual evaluation of these benefits is very difficult and may be approximated, based on experience, and may be taken into account for evaluating the annual benefit cost ratio.

Example 5.1. *An unlined canal giving a seepage loss of 3.3 cumecs per million sq. metres of wetted area is proposed to be lined with 10 cm thick cement concrete lining, which costs Rs. 180.00 per 10 sq. m. Given the following data, work out the economics of lining and benefit cost ratio.*

Annual revenue per cumec of water from all crops	*= Rs. 3.5 lakhs*
Discharge in the channel	*= 83.5 cumecs.*
Area of the channel	*= 40.8 sq. m.*
Wetted perimeter of the channel	*= 18.8 metres*
Wetted perimeter of the lining	*= 18.5 metres*
Annual maintenance cost of unlined channel per 10 sq. m.	*= Re. 1.00*

Assume additional suitable data, if required.

Solution.

Let us consider 1 km reach of canal.

Therefore, the wetted surface per km. = 18.8 × 1,000 = 18,800 sq. m.

(*i*) **Annual Benefits**

(*a*) *Seepage.* Seepage loss in unlined canal @ 3.3 cumecs per million sq m

$$= \frac{3.3}{10^6} \times 18{,}800 \text{ cumecs/km.} = \left(\frac{62{,}040}{10^6}\right) \text{cumecs/km}$$

Assume seepage loss in lined channel at 0.01 cumec per million sq m of wetted perimeter.

∴ Seepage loss in lined canal

$$= \frac{0.01}{10^6} \times 18{,}800 = \frac{188}{10^6} \text{ cumecs/km}$$

Net saving $= \left(\frac{62{,}040}{10^6} - \frac{188}{10^6}\right) = \frac{61{,}852}{10^6} = 0.06185 \text{ cumec/km}$

Annual revenue saved per km of channel

$$= \text{Rs. } \frac{61852}{10^6} \times 3.5 \text{ lakhs} = \text{Rs. } 0.21648 \text{ lakhs} = \textbf{Rs. 21,648}$$

(*b*) *Saving in Maintenance*

Annual maintenance cost of unlined channel for 10 sq. m. = Re. 1.00

Total wetted perimeter per 1 km length = 18,800 sq. m.

∴ Annual maintenance charge for unlined channel per km = Rs. 1,880.00

Assume that 40% of this is saved in lined channel

Annual saving in maintenance charges = Rs. 0.4 × 1,880.00 = Rs. 752.00

∴ Total annual benefits per km = Rs. 21,648.00 + Rs. 752.00 = **Rs. 22,400**

(*ii*) **Annual Costs.** Area of lining per km of channel

$$= 18.5 \times 1{,}000 = 18{,}500 \text{ sq. m.}$$

Cost of lining per km of channel @ Rs. 180.00 per 10 sq. m.

$$= \text{Rs. } \frac{18{,}500 \times 180.00}{10} = \text{Rs. } 3{,}33{,}000$$

Assume life of lining as 40 years

Depreciation cost per year $= \text{Rs. } \frac{3{,}33{,}000}{40} = \text{Rs. } 8325.00$

Assume 5% rate of interest.

Average annual interest $= \frac{1}{2} C \cdot \frac{r}{100} = \frac{1}{2} \text{ Rs. } 3{,}33{,}000 \times \frac{5}{100} = \text{Rs. } 8325$

Total annual cost = Rs. 8,325 + 8,325 = **Rs. 16,650**

Benefit cost ratio $= \frac{\text{Annual benefits}}{\text{Annual costs}} = \frac{22{,}400}{16{,}650} = \mathbf{1.35.}$

B.C. Ratio is more than unity, and hence, the lining is justified.

Example 5.2. *An existing unlined channel is having the following dimensions :*

Width of the bottom	*= 1.52 m.*
Side slopes	$= 1\frac{1}{2} : 1$
Depth of flow	*= 0.91 metre*
Bed-slope	*= 0.0006.*

It is proposed to line this channel for the same discharging capacity. Find out the dimensions of the lined channel and work out the economics of the concrete lining, if following data are given :

Length of irrigation season	= *150 days*
Saving in seepage loss by lining the canal	= *1.5 per cent per km*
Cost of water	= *Rs. 150.00 per hectare metre*
Cost of concrete lining	= *Rs. 16.00 per sq. m.*
Cost of reshaping and trimming canal	= *Rs. 4.00 per sq. m.*
Life of lining	= *40 years.*
Interest rate	= *7 per cent.*
Annual maintenance and operational cost (per km per year)	
for unlined canals in earth	= *Rs. 1000.00*
and for concrete lined canals	= *Rs. 200.00*
Other additional benefits	= *Rs. 350.00*

Assume any other necessary data, if not given.

Solution. Let us first of all work out the lined channel section which is required to pass the same discharge as is being passed by the given unlined channel.

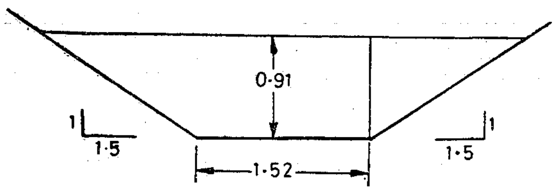

Fig. 5.1. Existing unlined canal section.

Discharge capacity of the existing unlined channel

If y is the water depth in channel, then

$$\text{Sloping side} = y\cdot\sqrt{\left(\frac{3}{2}\right)^2+(1)^2} = \frac{\sqrt{13}}{2}\,y = 1.8y = 1.8\times 0.91 = 1.64\text{ m}$$

$$\text{Wetted perimeter} = 1.52 + 2\times 1.8y = 1.52 + 3.6y = 1.52 + 3.6\times 0.91 = \mathbf{4.8\text{ m}}$$

$$\text{Area}\quad (A) = \left[\frac{1.52+(3y+1.52)}{2}\right] y = (1.52+1.5y)\,y = (1.52+1.5\times 0.91)\,0.91$$

$$= 0.91\,(1.52+1.36) = 0.91\times 2.88 = \mathbf{2.62\text{ sq. m.}}$$

$$R = \frac{A}{P} = \frac{2.62}{4.8}\text{ m} = 0.546\text{ m.}$$

By Manning's Formula

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

Assume n for unlined channel = 0.025

Velocity through unlined channel is given as :

$$V = \frac{1}{0.025}(0.546)^{2/3}\times(0.0006)^{1/2} = \mathbf{0.654\text{ m/sec.}}$$

$$Q = A.V. = 2.62\times 0.654 = \mathbf{1.715\text{ cumecs.}}$$

In a lined channel, the water will flow more rapidly and the depth of flow will be less for the same discharge. Assume n for lined channel = 0.014.

Discharge through lined channel is given by :

$$Q = \frac{1}{n}\cdot A\cdot R^{2/3}\cdot S^{1/2} = \frac{1}{n}\cdot A\left(\frac{A}{P}\right)^{2/3}\cdot S^{1/2}$$

or $$1.715 = \frac{1}{0.014} \frac{(1.52y + 1.5y^2)^{5/3}}{(1.52 + 2 \times 1.8y)^{2/3}} \times (0.0006)^{1/2}$$

or $$1.715 = \frac{1}{0.014} \times \frac{2.45}{100} \left[\frac{(1.52y + 1.5y^2)^{5/3}}{(1.52 + 3.6y)^{2/3}} \right]$$

or $$\frac{1.715 \times 1.4}{2.45} = \frac{(1.52y + 1.5y^2)^{5/3}}{(1.52 + 3.6y)^{2/3}}$$

or $$0.98 = \frac{(1.52y + 1.5y^2)^{5/3}}{(1.52 + 3.6y)^{2/3}}.$$

Solving the above equation by hit and trial, we get

$$y = 0.67 \text{ m}.$$

If we use 0.15 m as free-board, then perimeter of lining is

$$P = 1.52 + 2 \times 1.8 \times 0.82 = 1.52 + 2.95 = \mathbf{4.47\ m}$$

Perimeter per km of lined channel $= 4.47 \times 1000 =$ **4,470 sq. m.**

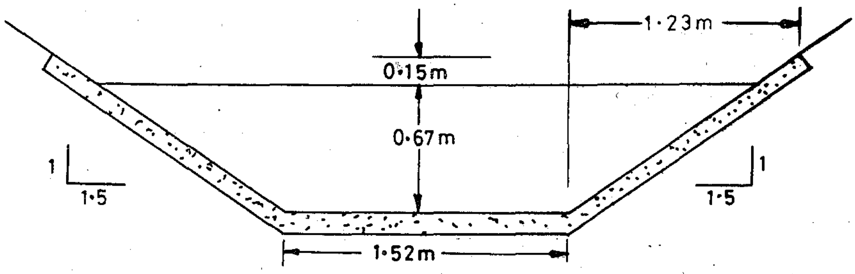

Fig. 5.2. Designed lined canal section.

(*i*) **Annual Benefits**

Seasonal flow. Discharge in the channel = 1.715 cumecs

1 cumec flowing for 150 days

$$= (1 \times 60 \times 60 \times 24 \times 150) \text{ m}^3$$

1.715 cumecs flowing for 150 days

$$= (1.715 \times 3600 \times 24 \times 150) \text{ m}^3$$

$$= \frac{1.715 \times 3600 \times 3600}{10^4} \text{ hectare–metre} = 2220 \text{ ha. m.}$$

∴ Seasonal flow = **2,220 hectare metres.**

Saving in seasonal seepage loss per km = 1.5% of flow

$$= \frac{1.5 \times 2220}{100} = \mathbf{33.3\ hectare\ metres.}$$

Money saved in seepage loss per km

$$= 33.3 \times \text{Rs. } 150 = \text{Rs. } 4995$$

Saving in maintenance charges

$$= \text{Rs. } 1000 - \text{Rs. } 200 = \text{Rs. } 800$$

Other benefits = Rs. 350

Total annual benefits = 4995 + 800 + 350 = **Rs. 6145**

(*ii*) **Annual Costs**

Perimeter of lining = 4,470 sq. m.

The cost of lining per km of channel @ Rs. 16 per sq. m.

$$= \text{Rs. } 16 \times 4{,}470 = \text{Rs. } 71{,}520$$

Life of lining = 40 years

Annual depreciation charges $= \text{Rs. } \dfrac{71{,}520}{40} = \text{Rs. } 1788$

Annual interest charges

$$= \frac{1}{2}\left(C \cdot \frac{r}{100}\right) = \frac{1}{2} \times 71{,}520 \times \frac{7}{100} = \text{Rs. } 2503$$

Total annual costs per km

$$= 1788 + 2{,}503 = \textbf{Rs. 4291} \quad \text{...}(ii)$$

Benefit-cost ratio $= \dfrac{\text{Annual benefits}}{\text{Annual costs}} = \dfrac{\text{Rs. } 6145}{\text{Rs. } 4291} = \mathbf{1.43.}$

Benefit-cost ratio is sufficiently greater than unity, and hence, the lining is justified.

5.4. Justification for Lining Canals on New Projects

It has been stated earlier that the benefits obtained by lining canals in a new project are many more than what are obtained by lining the existing canals. The smaller canal sections, smaller earth work, smaller land acquisition, smaller and possibly fewer canal structures, reduced storage and diversion capacity, etc. are the additional benefits that are obtained in a new project.

These benefits may also be added in finding out the annual benefits for a new project.

DESIGN OF LINED IRRIGATION CHANNELS

Irrigation canals should be aligned and laid out, so that the velocity of flow is uniform under all conditions, and so that the water reaches the irrigated area at an elevation sufficient to ensure even and economical distribution. High velocities of flow can be permitted by taking the advantage of hard wearing surface, so as to ensure a hydraulically efficient channel.

Very high flow velocities, even if not damaging to lining, do entail extra expenditure at turnouts, and require higher walls to take care of pulsations or wave action. While aligning the channel, sharp curves should also be avoided, as they not only reduce the velocity of flow, but also require higher walls on the outside to retain the water as it rounds the curve.

5.5. Channel Cross-sections

Generally, two types of channel sections are adopted, *i.e.*

(*i*) Triangular channel section for smaller discharges, (*ii*) Trapezoidal channel section for larger discharges. In order to increase A/P ratio, the corners are rounded and attempts are made to use deeper sections by limiting depth, etc. The sections and their properties, most commonly used, are shown in Figs. 5.3 and 5.4.

(*i*) **Triangular Section (Fig. 5.3)**

Let central depth = radius of circle = y

$$\text{Area} = \pi \cdot y^2 \cdot \frac{\theta}{\pi} + 2 \times \tfrac{1}{2} y \cdot y \cot \theta$$

$$= \frac{\pi \cdot y^2 \cdot \theta}{\pi} + y^2 \cot \theta$$

$$= y^2 [\theta + \cot \theta]$$

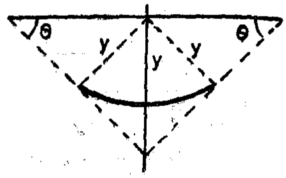

Fig. 5.3. Triangular section.

$$\text{Perimeter} = 2\pi \cdot y \times \frac{\theta}{\pi} + 2 \cdot y \cot \theta$$

$$= 2y \cdot \theta + 2y \cdot \cot \theta = 2y (\theta + \cot \theta)$$

Hence, Area for Fig. 5.3 $= y^2 (\theta + \cot \theta)$ ...(5.5)

Perimeter for Fig. 5.3 $= 2y (\theta + \cot \theta)$ ...(5.6)

Hydraulic mean depth for Fig. 5.3

$$= \frac{y^2 (\theta + \cot \theta)}{2y (\theta + \cot \theta)} = \frac{y}{2} \quad ...(5.7)$$

(*ii*) **Trapezoidal Section (Fig. 5.4)**

$$\text{Area} = B \cdot y + 2 \cdot \left(\pi \cdot y^2 \frac{\theta}{2\pi} \right) + 2 \left(\tfrac{1}{2} y \cdot y \cot \theta \right)$$

or
$$A = B \cdot y + y^2 \theta + y^2 \cot \theta$$

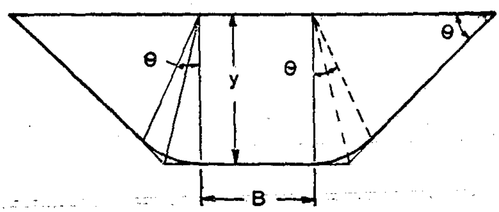

Fig. 5.4. Trapezoidal section.

Hence, area for Fig. 5.4

$$= \boxed{y (B + y\theta + y \cot \theta)} \quad ...(5.8)$$

$$\text{Perimeter } (P) = B + 2 \left(2\pi \cdot y \cdot \frac{\theta}{2\pi} \right) + 2 \ (y \cot \theta)$$

Hence, perimeter for Fig. 5.4 = $\boxed{B + 2y\theta + 2y \cot \theta}$ ...(5.9)

The channel is, then designed, according to Manning's formula. The value of rugosity coefficient (n) depends upon the roughness of the channel boundary, and is different for different kinds of linings. Different values of n for different types of lining materials have already been tabulated in Table 5.2. The velocity or depth may be limited for designing a trapezoidal channel section.

5.6. Permissible Velocities in Lined Channels

Higher velocities can be safely used in lined channels. Though maximum permissible velocities for concrete linings have not been established, velocities up to 2.5 m/sec. (8 ft./sec) are permitted when the lining is not reinforced. The concrete lined Nangal Hydel Channel with a capacity of 355 cumecs is designed for a permissible average velocity of 1.8 m/sec. (6 ft./sec.). If still higher velocities are desired, the lining can be reinforced accordingly. Asphaltic concrete, which has less resistance to abrasion, can withstand maximum velocity up to 1.5 m/sec. (5 ft./sec.). Values of limiting velocities in different kinds of linings, as per Indian Standards, are tabulated in Table 5.3.

Table 5.3. Max. Permissible Velocities in different types of Linings

Type of Lining	*Permissible Velocity*
Cement concrete lining (Unreinforced)	2.0 to 2.5 m/sec.
Burnt clay tile lining	1.8 m/sec.
Boulder lining	1.5 m/sec.

Example 5.3. *Design a lined channel to carry a discharge of 15 cumecs. The available and accepted country slope is 1 in 9000. Assume suitable values of side slopes and good brick work in lining.*

Solution. Let us first of all assume that the side slopes of the channel be $1\frac{1}{4} : 1$ (*i.e.* $1\frac{1}{4} H : 1 V$) and the value of Manning's rugosity coefficient be 0.015 for good brick work. The channel section may be designed as triangular (as given in Fig. 5.3) because the discharge is small.

Considering Fig. 5.3, we have

$$\tan\theta = \frac{1}{1\frac{1}{4}} = \frac{1}{1.25}$$

or $$\cot\theta = 1.25$$

$\therefore$ $$\theta = 0.675 \text{ radians}$$

Using $$A = y^2 (\theta + \cot\theta) \quad ...(5.5)$$

and $$P = 2y (\theta + \cot\theta) \quad ...(5.6)$$

We get $$A = y^2 (0.675 + 1.25) = 1.925\, y^2$$

$$P = 2y (0.675 + 1.25) = 3.85\, y$$

$$R = \frac{y}{2} = 0.5\, y \quad ...(5.7)$$

Now, using Manning's formula

$$Q = \frac{1}{n} \cdot A \cdot R^{2/3} \cdot S^{1/2}$$

Q is given to be 15 cumecs.

$\therefore$ $$15 = \frac{1}{0.015} \times (1.925y^2) \cdot (0.5y)^{2/3} \frac{1}{\sqrt{9000}}$$

or $$15 = \frac{1.925}{0.015 \times 94.8} y^2 (0.63y^{2/3})$$

$$= 0.852\, y^{8/3}$$

$\therefore$ $$y^{8/3} = 17.6$$

or $$y = (17.6)^{3/8} = \mathbf{2.93.\ metres.}$$

Hence, use the section shown in Fig. 5.3 with 2.93 m depth and $1\frac{1}{4} : 1$ side slopes.

Example 5.4. *Design a concrete lined channel to carry a discharge of 350 cumecs at a slope of 1 in 5,000. The side slopes of the channel may be taken as $1\frac{1}{2}$: 1. The value of n for lining is 0.014. Assume limiting velocity in the channel as 2m/sec.*

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

$\therefore$
$$2 = \frac{1}{0.014} R^{2/3} \cdot \frac{1}{\sqrt{5000}}$$

or
$$(2 \times 0.014 \times 70.8) = R^{2/3}$$

or
$$R = (1.98)^{3/2} = \mathbf{2.79\ m.} \qquad ...(i)$$

The channel section is assumed to be trapezoidal as shown in Fig. 5.4. For $1\frac{1}{2}$: 1 slopes ; we have, $\cot\theta = 1.5$ or $\theta = 34.1° = 0.59$ radians.

Using
$$A = y\,(B + y\theta + y\cot\theta) \qquad ...(5.8)$$
$$P = B + 2y\theta + 2y\cot\theta \qquad ...(5.9)$$

we get
$$A = y\,(B + 0.59\,y + 1.5\,y) = y\,(B + 2.09\,y)$$
$$P = B + 1.18\,y + 3y \qquad = B + 4.18\,y$$

But
$$A = \frac{Q}{V} = \frac{350}{2} = 175 \text{ sq.m.}$$

$\therefore$
$$175 = y\,(B + 2.09\,y)$$

or
$$\frac{175}{y} = B + 2.09\,y$$

or
$$\left(B = \frac{175}{y} - 2.09\,y\right) \qquad ...(ii)$$

From (*i*), we get
$$2.79 = R = \frac{A}{P} = \frac{175}{B + 4.18\,y}$$

or
$$2.79 = \frac{175}{\left(\frac{175}{y} - 2.09y\right) + 4.18\,y}$$

or
$$\left(\frac{175}{y} - 2.09\,y\right) + 4.18\,y = \frac{175}{2.79} = 62.7$$

or
$$175 - 2.09y^2 + 4.18y^2 = 62.7y$$

or
$$2.09\,y^2 - 62.7\,y + 175 = 0$$

or
$$y^2 - 30\,y + 83.7 = 0$$

or
$$y = \frac{30 \pm \sqrt{900 - 334.8}}{2} = \frac{30 \pm 23.8}{2} = \frac{30 - 23.8}{2}$$

(ignoring unfeasible + ve sign)

$$= \mathbf{3.2\ metres.}$$

But
$$B = \frac{175}{y} - 2.09\,y = \frac{175}{3.2} - 2.09 \times 3.2 = 54.7 - 6.7 = \mathbf{48\ m.}$$

So use, Bed width = **48 m**, Depth = **3.2 m** **Ans.**

Example 5.5. *Design a concrete lined channel to carry a discharge of 350 cumecs at a slope of 1 in 6400. The side slopes of the channel may be taken as $1\frac{1}{2}:1$. The value of n for lining material may be taken as 0.013. Assume limiting depth of the channel as 4.0 m.*

Solution. The channel section is assumed to be trapezoidal as shown in Fig. 5.4. Now, we have

$$A = y\,(B + y\theta + y\cot\theta) \quad \text{...(5.8)}$$

$$P = B + 2y\cdot\theta + 2y\cdot\cot\theta \quad \text{...(5.9)}$$

For $1\frac{1}{2}:1$ slope, $\cot\theta = 1.5$ and $\theta = 0.59$ radian.

$$\therefore \quad A = y\,(B + 0.59\,y + 1.5\,y) = y\,(B + 2.09\,y) \quad \text{...(i)}$$

$$P = B + 1.18\,y + 3y \quad = B + 4.18\,y \quad \text{...(ii)}$$

$$y = 4.0 \text{ m (given)}$$

Therefore, from (*i*)

$$A = 4\,(B + 2.09 \times 4) = 4\,(B + 8.36) = \mathbf{4B + 33.44} \quad \text{...(iii)}$$

From (*ii*) $P = B + 4.18 \times 4 = B + 16.72 \quad \text{...(iv)}$

$$R = \frac{A}{P} = \frac{4B + 33.44}{B + 16.72} \quad \text{...(v)}$$

$$Q = \frac{1}{n}\cdot A\cdot R^{2/3}\cdot S^{1/2}.$$

$$\therefore \quad 350 = \frac{1}{0.013} \times (4B + 33.44)\left(\frac{4B + 33.44}{B + 16.72}\right)^{2/3} \frac{1}{\sqrt{6400}}$$

or $$350 \times 0.013 \times 80 = \frac{(4B + 33.44)^{5/3}}{(B + 16.72)^{2/3}}$$

or $$364 = \frac{(4B + 33.44)^{5/3}}{(B + 16.72)^{2/3}} \quad \text{...(A)}$$

Solving Eq. (A) by Hit and Trial

(*i*) Use $B = 30$ m.

$$\text{L.H.S.} = 364\ ;\ \text{R.H.S.} = \frac{(120 + 33.44)^{5/3}}{(30 + 16.72)^{2/3}} = \frac{(153.44)^{5/3}}{(46.72)^{2/3}} = \mathbf{339}$$

(*ii*) Use $B = 32$ m.

$$\text{R.H.S.} = \frac{(161.44)^{5/3}}{(48.72)^{2/3}} = \mathbf{359}$$

(*iii*) Use $B = 32.5$ m.

$$\text{R.H.S.} = \frac{(163.44)^{5/3}}{(49.22)^{2/3}} = 364;\ \therefore\ OK$$

Hence, use **$B = 32.5$ m**, **$y = 4.0$ m** **Ans.**

TYPES OF LININGS, THEIR CONSTRUCTION, AND USES

Various types of canal linings, which are commonly adopted are enumerated below:

(*A*) **Hard Surface Linings**

(1) *Cast insitu Cement Concrete lining*
(2) *Shotcrete or Plaster lining*
(3) *Cement Concrete tile lining or Brick lining*
(4) *Asphaltic Concrete lining*
(5) *Boulder lining*

(*B*) **Earth Type Linings**

(1) *Compacted earth lining*
(2) *Soil cement lining*

All the above types of linings are discussed below :

5.7. Hard Surface or Rigid Linings

5.7.1. Cast Insitu Cement Concrete Lining. Cement concrete lining made from M15 cement concrete mix (1:2:4) is considered a *good quality type of lining.* Such linings usually give very satisfactory service, and are widely used owing to their durability, impermeability, hydraulic efficiency, and for providing weed free surface. Despite the fact that the initial cost of C.C. lining is high, yet its long life and minimum maintenance cost usually makes it an economical type of lining over the life span. For this reason, concrete linings have been extensively used in America and other developed nations. India being a developing nation, however, finds it difficult to afford their high initial costs, and as such, their use is restricted only to important projects. Concrete linings have been used in India in the canals of various important projects, such as Bhakra-Nangal Project, Tungabadhra Project, Amaravati Project, Sarda Canal in U.P., etc. About 570 km length of channels have been lined in concrete in Bhakra-Nangal Project.

5.7.1.1. Sub-grade preparations. Cement concrete linings are best suited for main canals which have to carry huge flows and at higher velocities. However, being rigid, its success depends to a great extent upon a stable foundation. Particular care should, therefore, be taken on thorough compaction of side slopes of the canals, on which the lining is to be laid. A firm foundation eliminates the possibility of cracking due to settlement of the subgrade. Natural earth in cutting, is usually, satisfactory ; but embankments in filling must be compacted by some suitable means.

Ordinarily, any rock or earth or predominantly sandy soil, is suitable as a subgrade material for cement concrete canal linings. However, when unusual subgrade conditions are encountered, such as expansive clays, susceptible to volume changes, then proper moisture and density control of the soil should be ensured during placing the lining. If the subgrade becomes too dry, it should be thoroughly wetted several hours before the lining is placed, so that the subgrade will be moist but not muddy at that time. Highly expensive soils like *black cotton soils*, need special treatment in the form of laying a layer of CNS (Cohesive non-swelling soil) material like *murum*, etc. in depth of about 300-1000 mm over the given soil surface before laying the lining.

Occasionally, it may be necessary to construct a concrete lined canal in areas where the ground water is likely to rise above the invert level of lining. In such cases, it may be necessary to lay drains underneath or alongside the canal, so as to relieve the hydrostatic pressure, which might cause uplift pressure on the lining during periods of low flow or no flow.

5.7.1.2. Thickness. A thickness of about 5 to 15 cm of cement concrete is generally used for larger canals, depending upon the canal capacity*, the nature of canal*, and the special requirements of imperviousness and structural strength to resist cracking, on slight movement of subgrade. *Minimum thickness used in India is 7.5 cm.* Stable side slopes of the order of $1\frac{1}{2}$: 1 or $1\frac{1}{4}$: 1 should be adopted. Steeper slopes entail extra earth pressure and consequently require more thickness, and hence are uneconomical.

5.7.1.3. Laying of Concrete The levelled and dressed sub-grade soil surface shall be moistened thoroughly before laying cement concrete, so that the moisture is not withdrawn by the sub grade from the cement concrete. In case an **inverted filter** is laid over the sub grade to take care of the differential hydrostatic pressure and draw-down in canals, it shall be properly designed keeping the coarsest filter material (gravel) layer in immediate contact with C.C. lining. *To make such filter blanket effective and to prevent ingress of concrete into it, a tar paper may be placed over the filter blanket before placing cement concrete.*

Hand placing of cement concrete is usually adopted in India, particularly for smaller canal sections. The cement concrete shall be dumped and spread on the bed and side slopes of the canal, usually in panels of not more than 3 m side, with suitable joints in between. The *construction joints* so formed will also serve the purpose of *contraction joints,* which are basically required for shrinkage of concrete and to take care of temperature stresses caused by the changes of temperature.

In order to prepare uniform panels, *screed guides* shall be laid on the sub grade, and the cement concrete shall be screeded up to the grade to proper thickness. Before laying the cement concrete for lining, precast cement concrete sleepers on side slopes and cast in situ C.C. sleepers on bed shall be placed under the joints, to serve as templates for accurate dressing of subgrade and to reduce the seepage through the joints. The sleepers shall be 20 cm wide and 10 cm deep for canals with capacity more than 15 cumec ; and 15 cm wide and 7.5 cm deep for canals with capacity less than 15 cumec. The sleepers shall be placed centrally below the joints. The C.C. used for sleepers shall

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* *Hydel canals* oten require greater thickness of lining than the *irrigation canals,* because of the drawdown effects and non-possibility of closure of hydel canals for repairs. Similarly, deeper canals will have greater thickness than shallow depth canals. Minimum thickness of canal lining, based on canal capacity, is shown in table 5.4 below :

Table 5.4. Suggested Thickness of C.C. Lining for Irrigation Canals

S. No.	*Capacity of canal in cumec*	*Depth of water in m*	*Thickness of C.C. lining in cm*
1	0—5	0—1	5—6
2	5—50	1—2.5	6—7.5
3	50—200	2.5—4.5	7.5—10
4	200—300	4.5—6.5	9—10
5	300—700	6.5—9.0	12—15

be of the same grade as for lining. Mechanical Vibration of cement concrete is always preferred, for which, screed vibrators should be used.

Mechanical placing of cement concrete for laying C.C. lining is usually adopted on large sized projects in developed countries, by using *slip-form machines* supported on rails placed along both berms of the canal. Concrete for slip form should be *air-entrained* as to provide a more workable and slippable mix. The percentage of air recommended in shown in table 5.5.

Table 5.5. Percentage of air for Air-entrained cement concrete for C.C. lining to be placed by slip form machines

S. No.	*Maximum Aggregate size in mm*	*Air percent by volume*
1	10	8.0
2	12.5	7.0
3	20	6.0
4	25	5.0
5	40	4.5

For lining small to moderate sized canals, *sub grade guided slip forms* are used. The slip form is supported directly on the sub grade and operated longitudinally along it. Concrete is screeded on the bed along the canal length and on sides from bottom to top.

For larger canals of considerable length, *rail guided slip-forms* are used. Slip-forms supported on rails are placed along both berms of the canal and are operated longitudinally and on the side slopes from bottom to top.

For hand placing with the light machines, where concrete in screeded from bottom to the top of the side slope, the consistency of concrete should be such that it will barely stay on the slope. A slump of 60 to 70 mm is generally allowed. For heavier longitudinally operating slip-form machines, a slump of 50 mm at the laying point is permitted. There should be a close control on the consistency and workability of concrete, and the slumps should not vary more than 20 mm, otherwise there will be interference with the progress and quality of the work.

5.7.1.4. Finishing. The surface of concrete finished against forms shall be smooth and free from projections, honey-coming and other objectionable defects. Immediately on removal of forms, all unsightly ridges or lips shall be removed, and undesireable local bulging on exposed surfaces shall be remedied by tooling and rubbing. Repairs to concrete surfaces and additions where required shall be made by cutting regular openings into the concrete and placing fresh concrete to the required lines. The chipped openings shall be sharp and shall not be less than 70 mm in depth. The fresh concrete shall be reinforced and chipped and trowelled to the surface of the openings. The mortar shall be placed in layers not more than 20 mm in thickness after being compacted, and each layer shall be compacted thoroughly. All exposed concrete surfaces shall be cleaned of impurities, lumps of mortar or grout, and unsightly strains.

5.7.1.5. Curing. Subsequent to laying of concrete lining and after a period of 24-36 hours, the lining shall be cured for at least 28 days.

On bed, this may be done by constructing 150 mm deep earthen bunds across the bed, so that a small depth of water will regularly stand on the bed.

The curing of side slopes may be done by constructing masonry drains with weep holes or perforated pipes on the coping at the top of lining, or by sprinklers.

5.7.1.6. Surface drainage. Concurrently with the curing operation, surface drainage arrangement of the bank such as construction of dowels, bank surface slope away from the lining, and construction of longitudinal drain on the outer wedge shall be completed. This is necessary to prevent surface and subgrade erosion and consequent damage to the lining.

5.7.1.7. Joints in cement concrete lining. Cracks in C.C. lining usually occur due to :

(*i*) *Warping stresses* caused due to the difference in temperature between the atmosphere and the concrete lining, or due to moisture potential between the two faces of the C.C. slab ; and

(*ii*) *Tensile stresses* caused by the differential temperature variation between the upper and lower faces of the C.C. slab.

Cracking caused due to above causes is controlled either by providing reinforcement (as discussed in artile 5.7.1.8), or by providing joints in concrete lining, as discussed below :

The various types of joints which may be provided in C.C. lining are :

(*i*) Expansion joints ;

(*ii*) Construction joints ; and

(*iii*) Contraction joints.

Expansion joints are usually not provided in C.C. lining, except where structures intersect the canal. At the intersecting structure, an expansion joint of 25 mm width, filled with sealing compound, is provided.

Construction joints which are left during casting of cement concrete lining as pointed out earlier, do serve the purpose of **contraction joints**, which are specifically required to take care of shrinkage and temperature stresses. Each *construction joint* will oppose contraction stresses, and hence will be a *contraction joint*. Therefore, practically, there is no difference between the two types of joints. *Theoretically, however, the joints left due to difficulty in laying the cement concrete at a stretch, are called construction joints ; whereas, the joints left intentionally for making provision for shrinkage and temperature stresses, are called contraction joints.*

The most commonly adopted type of construction joint (serving as contraction joint also) provided while placing cement concrete lining in panels on top of C.C. sleepers, is shown in Fig. 5.5 (read in conjunction with Fig. 5.6 and table 5.6). Other types of construction joints, which are in use, are shown in Fig. 5.7.

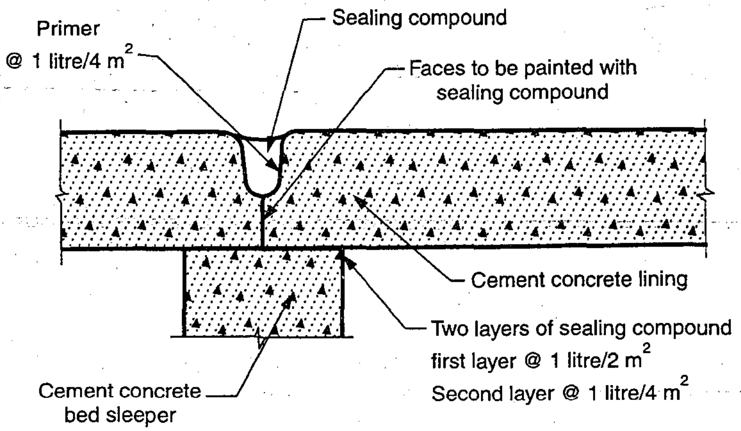


Fig. 5.5. Commonly adopted construction joints in cement concrete lining (IS : 3873-1978).

Table 5.6. Details of Groove to be provided in Expansion joint of Fig. 5.5 ; and lone contraction joints provided when lining is laid at a single stretch without leaving construction joints. (IS 3873-1978)

Values of distances b and c for various values of thickness (t) of lining (Fig. 5.6)			*App. groove spacing (c/c) m*
t (mm)	*b (mm)*	*c (mm)*	
50	8	17	3
65	8	20	3
75 and 80	11	27	4 to 5
90	11	30	4 to 5
100 and more	11	33	4 to 5

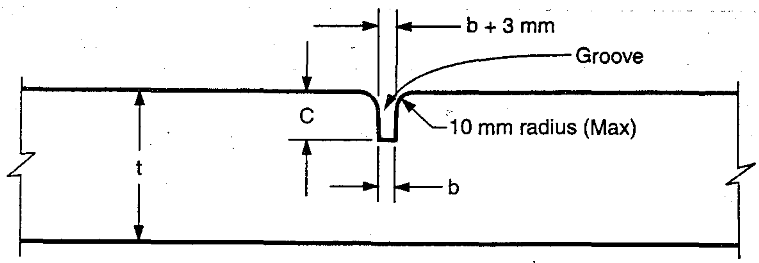
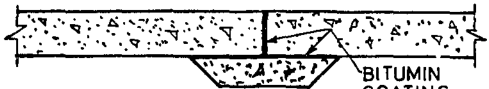


Fig. 5.6. Details of groove to form part of expansion joint of Fig. 5.5, or as an independent contraction joint.

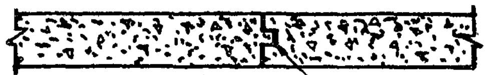
Note 1. Allowable tolerance on *b* and *c* shall be ± 1.5 mm.

Note 2. The groove shall be cleaned and made free from foreign substances, and then filled with hot applied sealing compound, after curing period of cement concrete is over. During the curing period, course sand is filled in the groove which can be easily blown out while filling sealing compound.

(*a*) Lap joint.



(*b*) Lap joint with separate fillet.



(*c*) Tongue and groove joint.

Fig. 5.7. Various types of construction Joints in C.C. Linings.

5.7.1.8. *Reinforcement.* It has now been widely accepted that normal steel reinforcement (0.25 to 0.3% of concrete) adds practically nothing to the structural strength of uncracked lining. But it has been found that reinforcement reduces the width of shrinkage cracks, thereby reducing seepage and prevents possible faulting of the cracked slabs where unstable subgrades are encountered. In long slabs of more than 15 m or so, the intervals between transverse cracks was found to be more in unreinforced slabs as compared to those in reinforced slabs. If transverse joints can be provided at intervals sufficient to control intermediate cracking, the use of reinforcement is of no material advantage and is not justified. However, transverse expansion and contraction joints can be avoided by providing longitudinal steel reinforcement of the order of 0.5 per cent, and transverse steel reinforcement of the order of 0.25 per cent of the cross-sectional area of concrete. Such a lining will involve only the construction joints to be left after days work and longitudinal steel to be taken continuously through these joints.

Advantages of cast in situ cement concrete linings.

(*i*) Longer life than that of any other type.

(*ii*) Least permeable of all types. (*iii*) Most resistant to erosion.

(*iv*) Permits fast construction by mechanical means.

(*v*) Low recurring maintenance charges.

Disadvantages of cast-in-situ cement concrete linings.

(*i*) Higher initial cost. (*ii*) Greater possibility of temperature cracking.

(*iii*) Less flexible and easily affected by adverse subgrade conditions.

(*iv*) Skilled supervision and construction necessary.

Advantages of pre-cast cement concrete tile linings (discussed in article 5.7.3)

(*i*) Higher strength for equivalent thickness.

(*ii*) Avoids plaster finish. (*iii*) No lead of raw materials.

(*iv*) Lesser skilled labour, as campared to that required for cast in situ c.c. lining, is required for pre-cast c.c. tile lining.

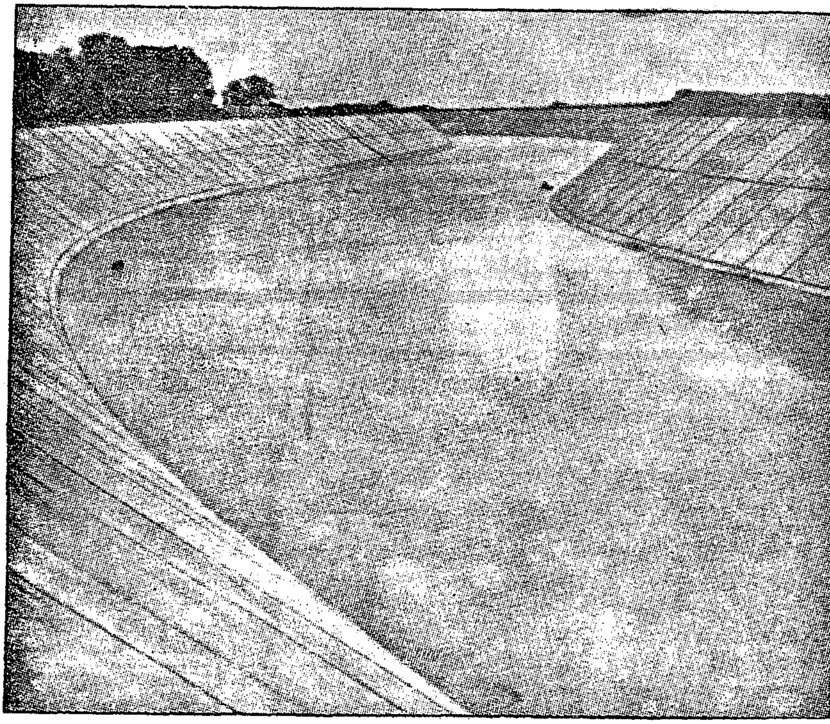


Fig. 5.8. Photographic view of one of the most unique artificial channels in the world, the Nangal power canal–constituting a part of the Bhakra-Nangal project–is lined with concrete throughout its length of 64 km.

(*v*) Easy to repair.

(*vi*) Various types of joints possible.

(*vii*) Lesser formwork than what is reqd for cas insitu c.c. lining, is required here.

Disadvantages of pre-cast cement concrete tile linings (discussed in article 5.7.3.)

(*i*) Slow progress.

(*ii*) Not suitable for curves.

(*iii*) Too light for hydel channels.

5.7.2. Shotcrete Lining. Shotcrete is a technical term used to designate cement mortar applied under pressure through a nozzle on the surface of the channel. It consists of a mixture of cement and sand (generally in the ratio of 1:4). Sand is having a maximum size of 0.5 cm. Larger proportions of cement are required in shotcrete as compared to what is required in cement concrete. Wire mesh reinforcement is generally, although not necessarily, used in shotcrete canal linings.

Shotcrete is of immense use for smaller jobs, because of the lighter equipment and small crew required to carry out the work. It is also useful for repair works and in rehabilitation of old canals. Shotcrete linings can be placed in an irregular canal section, thus eliminating the necessity of trimming the section, as is required for concrete canal linings when placed with a slip-form. Shotcrete lining is generally laid in a thickness of about 3.5 cm.

Excavation, compaction, curing etc. for a shotcrete lining are the same as those required for a cement concrete lining.

5.7.3. Cement Concrete Tile Lining or Brick Lining. Such types of linings are very popular in India, because of certain inherent advantages in their use. These *advantages* are :

(*i*) Bricks or concrete tiles can be laid by ordinary masons, and specially skilled labour, as reqd for cast insitu c.c. lining, is not required.

(*ii*) Rigid quality control is not required.

(*iii*) No expansion joints are required.

(*iv*) Rounded sections can be easily laid without using any formwork.

(*v*) Larger number of labour is required, thus providing greater employment potential.

(*vi*) Isolated damaged portions can be repaired easily.

(*vii*) Bricks can be plastered to increase the carrying capacity of canal with the same section, and also to help increase the life span of lining.

The specifications may provide either a single or a double layer of c.c. tiles or bricks laid in mortar. Sometimes, a layer of tiles is laid over a layer of brick masonry. The top layer of tiles is generally laid in 1 : 3 cement mortar over 15 mm thick layer of plaster in 1 : 3 cement plaster. The size of tiles is generally restricted to 30 × 150 × 53 mm. Typical sections are shown in Fig. 5.9 (*a*) and (*b*).

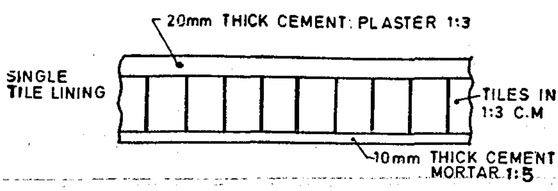


Fig. 5.9. (*a*) Single Tile Lining.

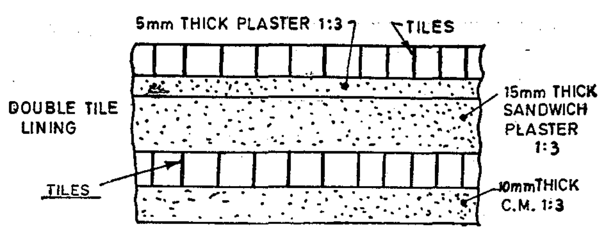


Fig. 5.9. (*b*) Double Tile Lining.

This type of lining gives a very satisfactory service. Even if there is a settlement of subgrade, the mortar joints between the bricks or tiles provide for numerous cracks so fine that seepage would be insignificant. In case of abnormal settlement, the local area can be repaired without any problem.

5.7.4. Asphaltic Concrete Lining. Asphalt has been used as a lining material at a very few places. It is still under the stage of evolution. Asphaltic concrete is a carefully controlled mixture of asphalt and graded stone aggregate, mixed and placed under elevated temperature. It provides a fairly cheap lining, especially where the asphalt is available within the country. It is flexible and readily confirms to the subgrade. The disadvantages or the limitations of this type of lining are :

(*i*) It does not decrease the rugosity coefficient of the channel.

(*ii*) It permits certain type of weed growth.

5.7.5. Boulder Lining. Boulder lining, also called **dry stone lining** or **stone pitching**, consists of lining the side slopes* of on earthen canal by proper placement & packing of stones, either after laying a filter layer over the soil surface, or without any such filter, depending upon the site requirement. Such a lining does not prevent seapage of canal water, though helps in retaining the shape of canal section, thereby reducing maintenance cost. The stones to be used for lining are rounded or sub-angular river cobbles, or blasted rock pieces with sufficient base area, so as to remain stable in their position.

Stones are generally placed on the levelled subgrade, and hand packed after dividing side slope length into compartments by the construction of *Dhamalis (ribs)* of stone masonry constructed at suitable intervals. The dhamalis do rest on a c.c. or R.R. masoury toe wall constructed on the drain bed along the Junction of drain bed and side slope. Usually, dhamalis in R.R. masonry @15 m centre to centre, and 0.6 m in width, having depth equal to the depth of pitching (22.5 cm or so) are usually provided.

The biggest advantage of such a lining however, is that it is a **pervious lining** allowing free flow of water from the submerged or saturated subgrade into the canal. Such a lining, therefore, does not need any drainage arrangements, in the form of pressure relief valves, etc. as may be required in concrete or brick linings. Such a lining may therefore be preferred when watertable is very high in the area, higher than DBL or even FSL of the canal.

The thickness of the lining and the size of the stones, which may be adopted depending upon the canal capacity, are given in table 5.7.

Table 5.7. Thickness of stone lining to be adopted for different canal capacities

S. No.	*Canal/Drain capacity in cumecs*	*Thickness of stone lining recommended in cm.*	*Size of stones to be used*	
			Av. dia along longest axis in cm	*Min. dia. at any section in cm.*
1.	less than 50	15	15	7.5
2.	above 50 and less than 100	22.5	22.5	11.0
3.	100 and above	30	30	15.0

5.8. Earth Type Linings

5.8.1. Compacted Earth Lining. Soil graded to obtain the required characteristics and containing enough fines, so as to make it impervious, is thoroughly compacted at optimum moisture content**, and is used to provide a lining of 30 to 90 cm thickness. The use of this type of lining is restricted to the availability of suitable soils in the area,

* *Such* **dry stone lining** is generally adopted only on the side slopes of canals or drains, and the canal beds are rarely lined with such a lining.

** Please refer chapter 8 in "Soil Mechanics and Foundation Engineering" by the same author to know about compaction of earth under OMC.

through which the canal is being constructed. It would be uneconomical to transport the selected soils from outside.

5.8.2. Soil-Cement Lining. Portland cement up to the extent of 2 to 8% is added to the soil having a high percentage of fines. The mixture is first mixed dry. Water is then added so as to bring the soil to its optimum moisture content, and again mixed thoroughly. Material is then placed at site and compacted. Curing is then required for atleast seven days by covering with wet sand, etc.

5.9. Requirements of Good Lining

The canal linings should generally possess the following **essential requirements.**

(1) *economy* ; (2) *structural stability* ;
(3) *durability ; and* (4) *repairability,* as discussed below :

(1) **Economy.** The selection of a suitable type of lining for any canal project is mainly a question of economics and availability of *material, skilled and unskilled labour, construction machinery and equipment, and time available for completing the work.*

The type of lining selected should not only be economical in initial cost, but also in repair and maintenance cost.

Economic analysis of different types of linings, which can technically be used on a given project, is therefore of vital importance to us.

(2) **Structural stability.** The lining should be able to withstand the *differential sub-soil water pressure** from behind the lining due to sub-grade** getting saturated through seepage or rain or due to sudden drawdown of the canal. The lining should also be sufficiently heavy and strong to withstand the effect due to local cavity formation, if any, behind the lining.

(3) **Durability.** The canal lining should be able to withstand the natural wear and tear, such as the effect of *velocity of water, rain, sunshine, frost, thawing (applicable only in cold countries), thermal and moisture changes, and chemical action of salts,* etc. It should also be able to withstand the damaging effects caused by *cattle traffic, weed and rodent growth,* etc.

(4) **Repairability.** Since the lining will get damaged with its use over a period of time, it should be such that it can be repaired easily and economically. *Brick tile* or *concrete tile* or *stone boulder linings,* or *precast slab lining* can be easily repaired, as compared to *cast in situ concrete lining.*

In addition to the above *essential requirements,* the following may be the **additional requirements,** *depending on the need of a particular project:*

(*i*) *impermeability* ;

(*ii*) *hydraulic efficiency* ; *and*

(*iii*) *resistance to erosion,* as discussed below :

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* Special drainage arrangements are provided for this, as discussed in article 5.11.

** Subgrade here means the soil surface of the ground against which the lining is placed on bed as well as sides of the canal.

(*i*) **Impermeability.** The permeability of lining may decide the quantum of seepage loss from a canal, which also is governed by the depth of water in the canal, and the type of subgrade soil. The permissible values of seepage losses from a canal for a particular area will depend upon the local conditions, such as the *values of land and water, population intensity,* etc. The lining chosen for a particular project should confirm to the allowable water losses.

(*ii*) **Hydraulic Efficiency.** The hydraulic efficiency of a canal, generally reduces with time, since the surface of lining gets eroded, increasing the friction factor (*n*), and thereby reducing its carrying capacity. The lining chosen for a given project must therefore, be such that its surface can be easily restored to original smoothness, if no reduction in its carrying capacity can be permitted. Cement plastered brick lining can be preferable in such a case.

(*iii*) **Resistance to erosion.** Sometimes, a canal may have to transport a considerable amount of sediment load, which may damage the lining by abrasion. Hence, in such a canal, the lining chosen should be able to withstand such abrasion. *Cement concrete and stone boulder linings may provide better abrasion resistance, as compared to brick tile lining.*

5.10. Factors Responsible for Selection of a Particular Type of Lining

Depending upon the project requirements as discussed above, the following factors may guide the selection of a particular lining for a given canal project :

(1) **Size and Importance of the canal.** For smaller canals, which may be used only intermittently, one may choose a lining, the construction of which may require little equipment and machinery. Larger canals on the other hand, may permit the use of cast in situ operations, with more elaborate T & P articles brought to site. Moreover, larger & important canals may require continuous operations, and, hence may need stronger linings, such as concrete lining.

(2) **Canal Slopes and Alignments.** These factors also need consideration since frequent changes in alignment and *steeper slopes* may encounter higher flow velocities, leading to selection of stronger linings. The limiting safe velocities, in generally used types of linings, are given in table 5.8, and may serve as a guide in this regard.

Table 5.8. Limiting Velocities in Different Types of Linings

S. No.	*Type of lining*	*Safe limiting velocity*
1.	Boulder lining	1.5 m/s
2.	Burnt clay tile lining	1.8 m/s
3.	Cement concrete lining	2.7 m/s*

(3) **Climate of the Area.** Higher quality linings should be used in areas which are susceptible to severe frosts and temperature changes such as in western countries.

* Other factors, like loss of head due to friction, would, however, limit the velocity in concrete lining to 2 m/s, or so.

(4) **Availability of Materials.** Every type of lining will require certain materials and ingredients. Some of these materials may be easily available at a certain place, and others may not be easily available. The type of lining should be such that the required materials are most easily available locally or in the vicinity of the area from where they can be carted to site with least cost.

(5) **Initial Expenditure.** Mathematically speaking, the most economical type of lining is the one which shows maximum annual benefit-cost ratio. This lining may have higher initial cost but longer life, than some other kind of lining having lesser value of annual benefit cost ratio. From long term planning point of view, the first type of lining should be chosen. But sometimes, the initial cost may be too high to be borne by the State, and hence, the lining with lesser initial cost may have to be adopted, even though its benefit-cost ratio may be less.

Keeping in mind the above factors, the suitable type of linings for different sizes of canals are given for *general guidance* in table 5.9.

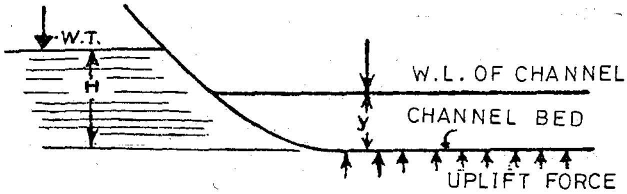
Table 5.9. General Guidelines for Choice of Linings for different sized Canals

S. No.	*Size of canal*	*Choice of Lining*
1.	Canals with bed width upto 3 m	(*i*) *Single burnt clay tile lining* ; or *brick lining* where seepage considerations are important. (*ii*) *P.C.C. slab lining* ; and (*iii*) *flexible membrane lining*, with adequate earth/tile cover.
2.	Canals with bed width between 3 to 8 m	(*i*) *single burnt clay tile lining* ; (*ii*) *P.C.C. slab lining* ; and (*iii*) *flexible membrane lining in the bed and rigid lining on the sides.* This may be adopted where channels have become stable and no danger of scour is expected.
3.	Canals with bed width greater than 8 m	(*i*) *insitu cement concrete lining in bed as well as on sides* ; (*ii*) *insitu cement concrete lining in bed and PCC slab lining on sides* ; and (*iii*) *burnt clay tile lining* (*single layer on bed and double layer on sides*) to be adopted at places where aggregates for manufacture of concrete are not available economically.

5.11. Under Drainage of Lined Canals (*i.e.* Drainage Behind Linings)

Many of the linings fail due to build up of water pressure behind the lining. Such a water pressure may essentially develop, when *the watertable rises above the canal bed* and there may be low flow or no flow in the canal. Such a situation will always cause an uplift on the lining, equal to the difference in the water heads, as shown in Fig. 5.10.

Such hydrostatic pressures may also be caused on the lining by the seeping rain water in the backfill, even *when the watertable remains below the canal bed, if the backfill is of low drainage* (*i.e.* of low permeability). In such a case, the backfill may



Uplift force = H metres of water
If $H > y$, a net uplift equal to $(H-y)$ metres of water will be exerted on channel bed. $(H-y)$ is called *Differential Head.*
Fig. 5.10.

get saturated over a period of time due to seepage of water through the joints and cracks; and in case of drawdown in the canal, the water in the backfill may not be drained out as quickly as the occuring drawdown, leading to building up of pressure behind the lining.

In all such cases, properly designed drainage arrangements must be provided, to help in reducing such hydrostatic pressures to safe limits. Such drainage arrangements may be provided in the form of *pressure release valves* for releasing the external water from the subgrade into the canal, through *drainage pockets* or through well connected *pipe drains* laid on the bed and sides of the canal, below the lining.

However, no such drainage arrangements may be necessary if the subgrade is made of clear gravel or sand of good permeability (more than 10^{-3} cm/sec or so) and the watertable is also not likely to go above the canal bed, because in such a case, there will be no appreciable time lag in the dissipation of drawdown pore pressures in the subgrade.

Drainage arrangement to be adopted will therefore depend upon : (*i*) *the position of the watertable* ; (*ii*) *upon the type of soil below the lining* ; and (*iii*) *the type of lining to be adopted.* Soil investigation is thus, of vital importance in designing such drainage arrangements.

5.11.1. Drainage Arrangements. Drainage arrangements, as stated above, may be accomplished by the following methods :

(1) **By providing drainage relief pockets**. Drainage relief pockets filled with *graded filter,* containing *gravel, coarse sand,* and *fine sand,* and provided with *pressure relief valves*, as shown in Fig. 5.11, may be used. The graded filter must, however, be properly designed on the considerations indicated below :

Design of graded filter. *The graded filter should be designed in such a way that there is no loss of bed soil. The gradation curve of the bed soil should be obtained from the sieve analysis. The D_{15} size of the adjoining layer A of the filter material should be atleast 4 times as large as D_{15} size of the bed soil, and less than 4 times its D_{85} size. Design of the other layers should be made in the similar way, till the requirement of the filter opening is met.*

Such *drainage relief pockets* may be provided at **isolated locations** in the bed as well as sides of the lined canal, below the lining at suitable spacings. They may be cubical

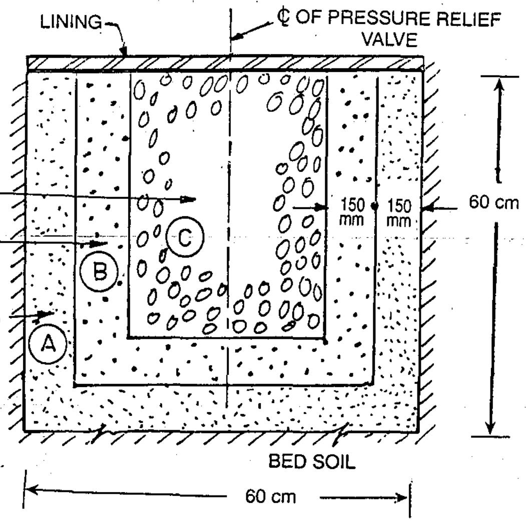


Fig. 5.11. Details of graded inverted filter to be used in drainage relief pockets.

in shape with 60 to 90 cm size, and may be provided @ 15 to 20 m intervals, along rows in such a way that atleast one row is provided on the bed for every 10 m bed width, and one row on sides for every 4 m side width, as shown in Fig. 5.12.

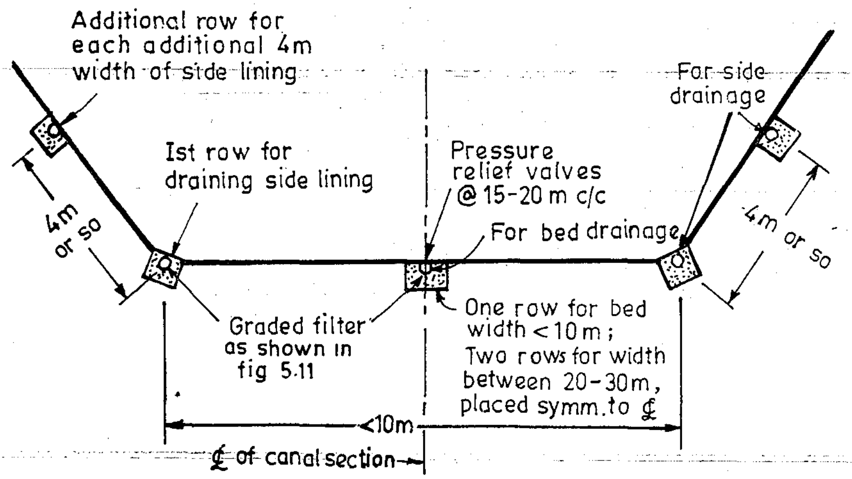


Fig. 5.12. Fig. showing locations of isolated drainage relief pockets.

Better drainage may sometimes be provided by providing **continuous drainage pockets** throughout the perimeter of the lined section of the canal, in 1 to 2 m width @ 15 to 20 m spacings, as shown in Fig. 5.13.

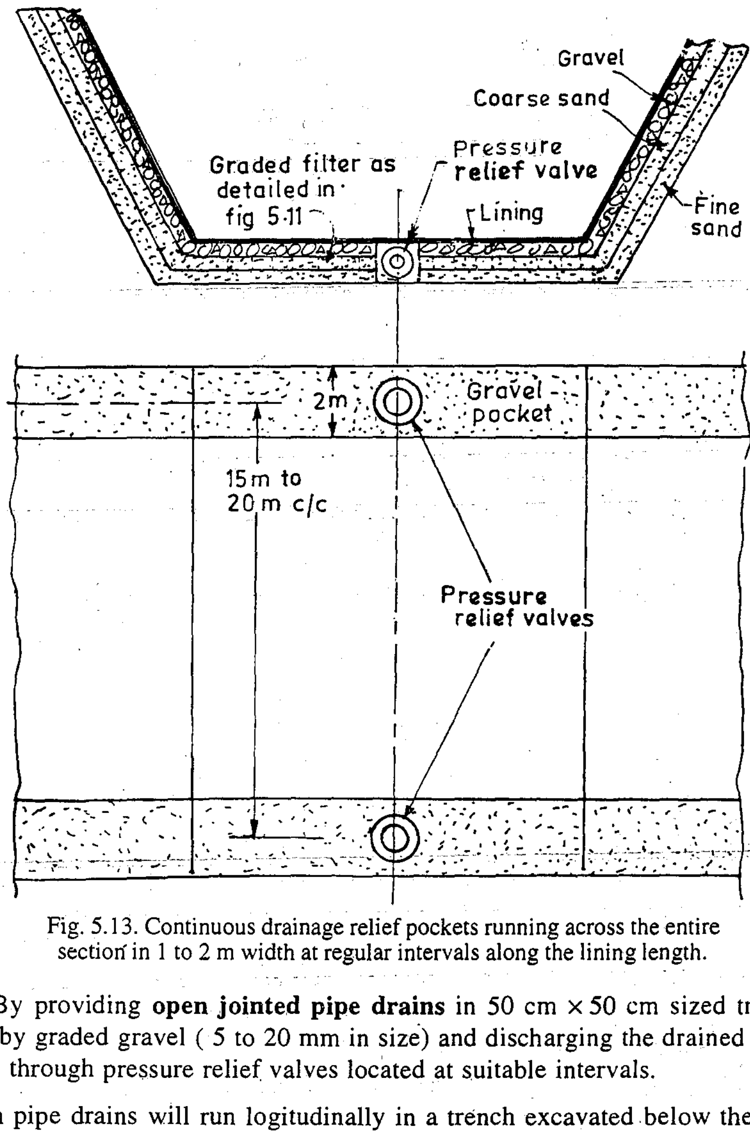


Fig. 5.13. Continuous drainage relief pockets running across the entire section in 1 to 2 m width at regular intervals along the lining length.

(2) By providing **open jointed pipe drains** in 50 cm × 50 cm sized trench, surrounded by graded gravel (5 to 20 mm in size) and discharging the drained water into the canal through pressure relief valves located at suitable intervals.

Such pipe drains will run logitudinally in a trench excavated below the lining on the canal bed along the length of canal, and transverse to the length of canal on the side slopes.

Water from the drains is collected in suitable masonry or precast concrete boxes, having pressure release valves placed on the top of the boxes, as shown in Fig. 5.14. This water is finally released into the canal through opening of the flap shutter of a pressure release valve, as and when the differential head exceeds 10 cm or so.

In case of **impervious subgrades,** these drainage arrangements may have to be further supplemented by laying sand or inverted filter, in say 75 cm thickness, underneath the entire lining.

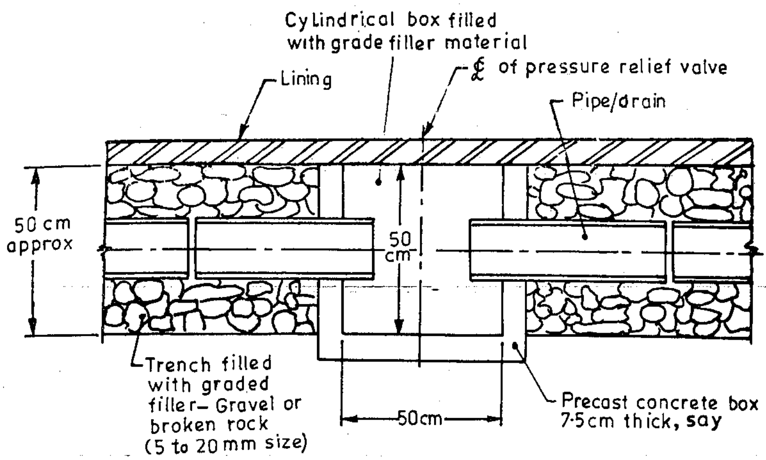


Fig. 5.14. Outlets for open jointed pipe drains.

5.11.1.1. Pressure relief valves. The flap valves, opening upwards into the canal, called pressure release valves, may help in releasing the hydrostatic pressure, as soon as the differential head exceeds the safe pressure for the given lining with a safety factor of at least 2. Generally, these valves open out, as soon as the differential pressure becomes 10 cm or so. These valves are available in the market in different sizes, say from 50 to 150 mm diameter size. 150 mm diameter valves may generally be used in the bed, and 50 mm diameter valves on side slopes. Typical details of both these types of valves are shown in Fig. 5.15 and 5.16, respectively.

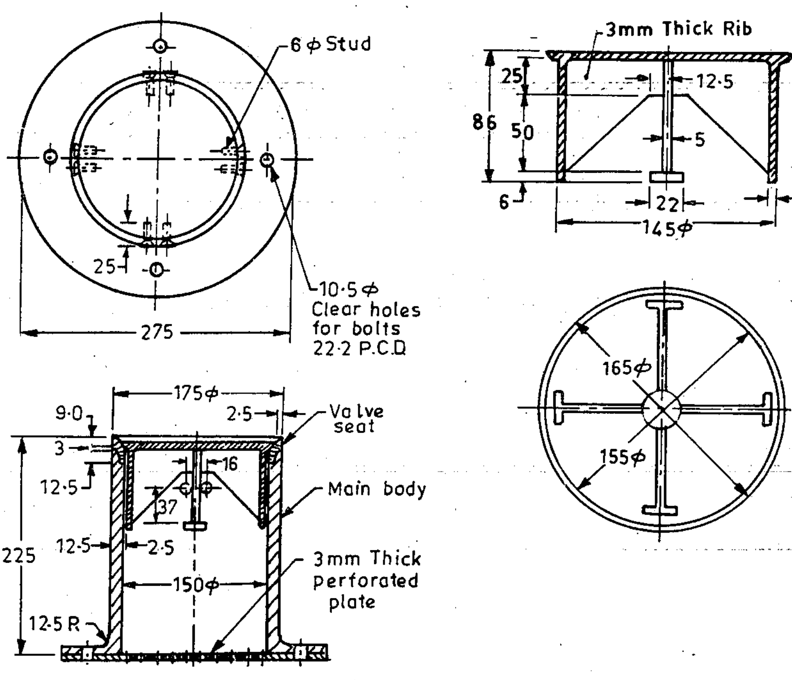


Fig. 5.15. Typical details of a 150 mm dia vertical pressure relief valve, useful on beds of lined canals.

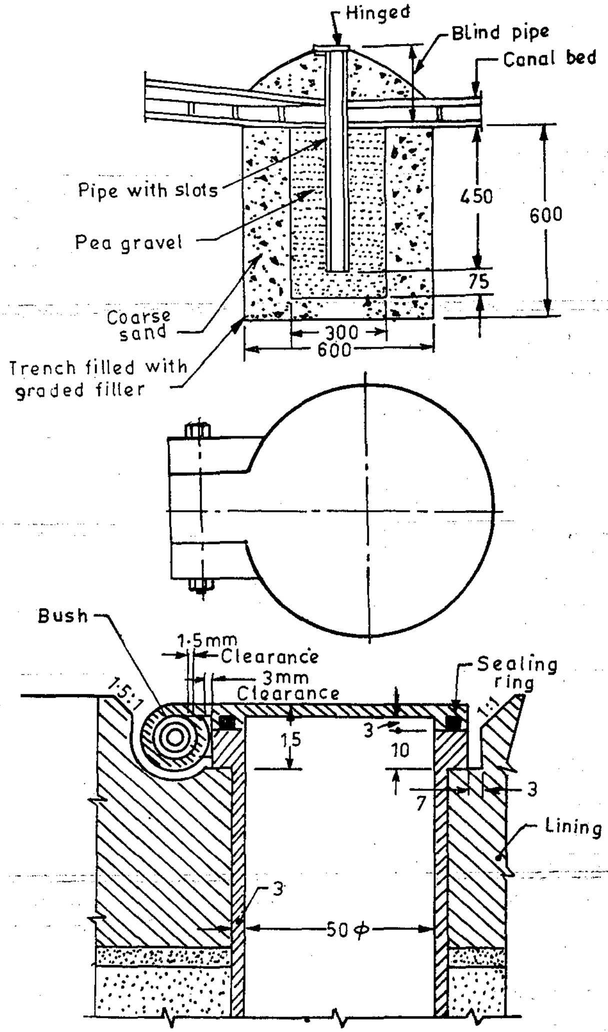


Fig. 5.16. Typical details of a 50 mm dia vertical pressure relief valve, useful on sides of lined canals.

These valves are generally made of such a material, which is resistant to abrasion and is not affected due to its submergence in water. Cast iron valves are generally available. Plastic valves are also making entry in the market with good potential.

5.12. Lining of Canals in Expansive Soils

Expansive soils are those soils, which exhibit *shrinkage* and *swelling* properties. Such soils are inorganic or organic clays of plasticity, with high compressibility, and liquid limits more than 50.

Commonly found expansive soils in India are called **black cotton soils**. Different varieties of black cotton soils, varying from *black* to *yellowish* to grey are found in our country. The chief property of such a soil is its *swelling pressure.* The larger is the swelling pressure, the more problemsome is the soil.

For canals excavated in such soils, lining is found to be very advantageous, because earthen canals in such soils pose serious problems of instability of slopes ; and it is thus, very difficult to maintain their regular sections.

But when lining materials are directly placed in contact with the expansive soils, they undergo deformations by *heaving*, disturbing the lining and throwing the canal out of commission. This deformation is dependent upon the swelling pressure developed by the given expansive soil, when it imbibes water in its intra-layers.

In order to counteract such swelling pressure, it is found advantageous to place a layer of some *cohesive non-swelling soil* (CNS)* like *muram* having some cohesion, over the given expansive soil surface. The larger the thickness of CNS introduced over the expansive soil, the lesser would be the resulting swelling and deformations.

Hence, in order to line canals in expansive soils, we generally place a layer of cohesive non-swelling soil over the soil subgrade, before placing the lining materials over the same.

The thickness of CNS to be used is more for more expansive soils and less for less expansive soils. Table 5.10 shows the CNS thickness to be adopted for soils of different swelling pressures.**

Table 5.10. Thickness of CNS Layer to be Used for Lining over Expansive Soil Sub-Grades

S. No.	*Swelling pressure of soil in KN/m²*	*Thickness of CNS material in cm**
1.	50—150	75 to 85
2.	200—300	90 to 100
3.	350 to 500	105 to 125

After providing a CNS layer, the lining can be done as usual. Precast cement concrete, burnt clay tiles, bricks, insitu cement concrete, or even boulder linings may be adopted. The under-drainage arrangements and joints in lining would also be provided, as usual.

5.13. Safety Ladders in Lined Canals

In large canals, safety ladders are generally provided on side slopes, at suitable intervals along the canal length. Such a ladder consists of a number of *ladder rungs*, constructed in canal lining at the given section, at different elevations, as shown in Fig. 5.17. The ladder rungs are made of smooth round mild steel bars, galvanised or coated with coaltar after installation, and are U-shaped as shown.

The ladders are provided on both banks, alternatively at about 300 metres-staggered distance, in straight reaches. Such ladders shall also always be constructed on both banks at about 30 m upstream of the point, where the canal enters some underground structure.

* CNS material shall be non-swelling with a min. of 10 KN/m^2 (1020 kg/m^2) of cohesion, and swelling pressure not more than 15 kN/m^2 at optimum moisture content. Most **murums** with some cohesive property perform satisfactorily as CNS material.

** Optimum thickness can be determined only be actual experiments in the field or the lab.

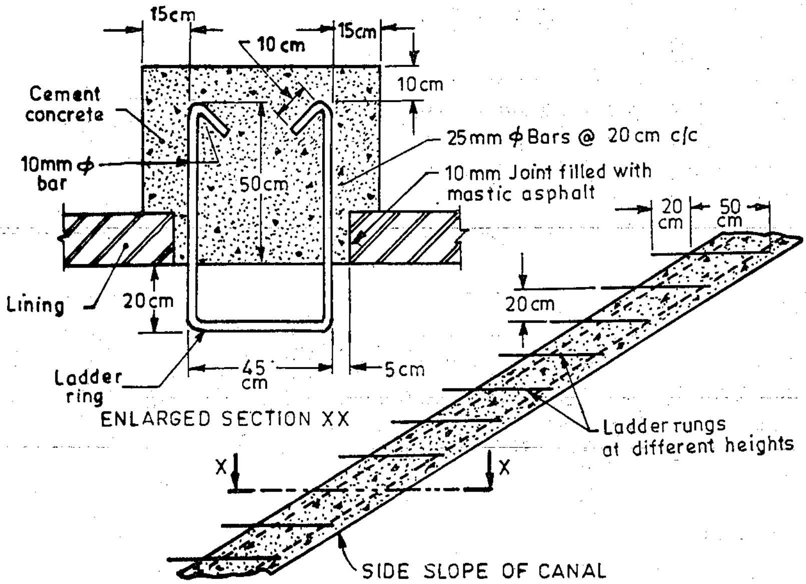


Fig. 5.17. Details of safety ladder.

These ladders can be used by persons or cattle, that may be swept away with the flowing water in the canal. Such a person, who may otherwise get drowned, may catch hold of one such ladder rung at the level of the flowing water, and can climb the higher rungs to get out of the canal, easily.

PROBLEMS

1. What is meant by 'canal lining', and what are its advantages ?

Enumerate the different types of canal linings, and discuss the design and construction features of concrete linings.

2. (*a*) Enumerate the different types of lining materials, and discuss the factors which are responsible for selecting a particular material in a particular project.

(*b*) Design a triangular concrete lined channel to carry a discharge of 20 cumecs at a slope of 10 cm/km. The side slopes of the channel are $1\frac{1}{4}$: 1. The value of n may be taken as 0.015.

[**Hint** : Follow example 5.3].

3. (*a*) Explain the necessity of lining of canals. Enumerate the various types of linings practised in Tamil Nadu State.

(*b*) Design a trapezoidal concrete lined channel to carry a discharge of 350 cumecs at a slope of 1 in 6400. The side slopes of the channel may be taken as $1\frac{1}{2}$: 1. The value of n for the lining material may be taken as 0.013. Assume the limiting B/D ratio to be 5. [**Ans.** Use $B = 20$ m, $D = 4$ m]

4. What are the main types of channel linings ?

Design a concrete lined trapezoidal channel to carry a discharge of 200 cumecs at a slope of 1 in 5000. The side slopes of the channel are 1 : 1 and Manning's coefficient of rugosity may be taken as 0.014. Assume the limiting velocity in the channel as 2 m per second.

[**Hint** : Follow example 5.4]

5. (*a*) How will you justify economically the necessity of lining an existing canal ? What added benefits you will expect if the canal to be lined is new and yet to be constructed ?

[**Hint** : Please see articles 5.3 and 5.4]

(*b*) What is meant by 'under-drainage of lined canals', and how is it provided ?

6. Write short notes on the following :

(*i*) Lining of irrigation canals.
(*ii*) Under-drainage of lined canals.
(*iii*) Use of cement concrete for lining canals.
(*iv*) Economics of canal lining.
(*v*) Various types of canal linings.
(*vi*) Financial justification for lining new canals.
(*vii*) Advantages of lining irrigation canals.
(*viii*) Safety ladders for large canals.