Lining of Canals with Special Reference to Rajasthan Canal

A Dissertation
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WATER RESOURCES DEVELOPMENT

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CERTIFICATE

Certified that this dissertation entitled "LINING OF CANALS WITH SPECIAL REFERENCE TO RAJASTHAN CANAL" being submitted by Shri C.B.SHARDA in partial fulfilment of the requirements for the award of the Degree of Master of Engineering in Water Resources Development, University of Roorkee is a record of bonafide work done by him, under our guidance for a period of two years and one month from Ist October, 1966 to 31st October, 1968.

To the best of our knowledge and belief, this dissertation has neither been published any where nor submitted for the award of any other Degree.

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SUMMARY.

CHAPTER - 1

SUMMARY

Lining of canals had been done in the past but the subject has gained importance during the present century. Bikaner Canal was the first major canal in India which was lined in 1925. Construction costs of storage works have gone very high and the need of conservation of water lost in seepage is increasing day by day.

Factors affecting seepage losses from canals have been described in detail. Methods of measuring seepage losses are also mentioned. A review of various formulae used for estimation of losses has been given. On the basis of theoretical study it has been shown that under conditions similar to Rajasthan Canal area where a uniform sandy or sandy silt strata occurs for great depths and water table is also present at great depth, the seepage losses are proportional to permeability of soil and wetted perimeter of canal. A table showing the relation between coefficient of permeability and seepage loss per million square feet of wetted area has been worked out.

Lining of the canals may be necessary due to many reasons but the most important is the need to reduce seepage losses. Comparison of lined and unlined sections of various discharges reveals that on an average unlined section of the channel has its wetted perimeter 1.65 times that of corresponding lined section. Table showing the relationship between the cost of lining, the capital investment per cusec on unlined canal system and the seepage losses has been worked out.

Various formulae used for design of lined canals are discussed. Modern concept of flow phenomenon in open channels has also been described. The capacity of Rajasthan Canal has been

checked with all the formulae. Empirical criterion to design canals carrying silt laden water has been mentioned. Typical sections of canal with different minimum silt factors have been worked out. Attempt has been made to find out the bed load carrying capacity of canal with different bed slopes by Mayer Peter's and Einstien's equations. Methods of maximum permissible velocities and permissible tractive force for design of burried membrane and earth lined section have been given.

Modern concept of structural design of lined canals has been described in great detail. Emphasis has been laid to design economical as well as durable lining. Earthen embankment should be designed on the basis of principles of soil mechanics. Necessary arrangements to relieve external pressures are discussed. It has been shown that the thickness of lining or cement plaster in case of double tile lining should be increased with increase in depth of the canal.

Various types of linings, material used for their construction, methods of construction, and suitability of linings under different conditions have been described. Examples of important linings constructed in India and America are also given.

Suitability of tile lining for Rajasthan Canal has been discussed in detail. Various construction materials, their properties and sources are also described. Emphasis has been laid to adopt most rational method of construction (as described in detail) to achieve better quality of work.

Theoretical analysis has been made by applying theory of conduction of heat into semi-infinite solid to find out the effectiveness of the measures suggested by various authors in connection with insulation to temperature variation necessary for single and double tile linings. Special treatment required for tile lining on sandy sub-grades has been discussed.

Economic justification for lining of Rajasthan Main Canal has been worked out in detail. Effect of time lage between the period of construction and actual utilisation which is normally not considered has also been discussed.

Rajasthan Canal has been designed with a bed slope 1 in 12000 from head to tail to provide irrigation facilities to 36.5 lac acres C.C.A. (30 lac acres by flow and 6.5 lac acres by lift upto 150 ft.). Detailed study has been conducted to find out economical gradient for Rajasthan Canal for different unit cost of Power to provide Lift Irrigation facilities to areas falling under various heights of lift.

Gradient of 1 in 18000 is economical to provide lift irrigation facilities to entire area when the unit cost of Power is 6 Paise per unit.

Detailed scientific study is necessary on the prototype canals to determine the life of various types of linings average maintenance cost per year and other information regarding its hydraulic behaviour. Need for improved techniques to estimate the losses in lined and unlined canals is gaining importance. Research work on the development of new materials has still to travel a long way. For lining of old unlined channels, a lining material of suitable strength is to be developed that can reduce the period of construction to the minimum possible extent.

CHAPTER 2

"SEEPAGE LOSSES FROM CANALS"

Water is a precious commodity and its need is increasing. Constructional costs of storage works have gone very high with the result that need of conservation of water lost in canals by seepage is gaining importance.

On Ganges Canal in U.P. the total loss of water in canal system was found to be 44% (15% in Main Canal and Branches, 7% in Distributaries and 22% in water courses). In U.S.A. it has been estimated that nearly 1/3 of all the water diverted from western streams for Irrigation is lost in transit to the Farm land and it is known that in few individual cases this loss in transit is as great as 60%.

Seepage losses from Irrigation Canals are governed by Darcey's law:-

$$q = K\ i\ A$$

Where q = seepage losses.

K = Co-efficient of permeability.

i = Hydraulic gradient.

A = Wetted area.

Co-efficient of permeability of the soil forming the canal bed is the most important factor which governs the seepage losses. It depends on various factors mentioned below:-

1) The size of the grains of which the bed material consists.
2) Void ratio of the material.
3) Arrangement of grains.
4) Entrained air in the soil.
5) Temperature of water and soil.
6) Turbidity or silt concentration in the Canal Water.
7) Salt concentration in Canal Water or soil.
8) Age of the Canal.
9) Other biological factors.

C H A P T E R -2.

SEEPAGE LOSSES FROM CANALS.

Hydraulic gradient can be determined by drawing the flow net. The factors affecting the hydraulic gradient are as under:-

1) Depth of the ground water table below bed of canal.
2) Position of drainage or highly permeable layer below bed of Canal
3) Position of impermeable layer below bed of canal.
4) Size and shape of the canal.
5) Depth of water in the canal.
6) Ground water slope at right angles to the canal.

The effects of many of these above factors are difficult to determine and their relative importance has not yet been definitely known. Since all the factors may act simultaneously and some of them tend to counter-act each other, it is difficult to seggregate the effect of any of them. Because of so many variables involved and the complexity of their relation no satisfactory formula for computing seepage has been evolved. However, the effects of some of the factors mentioned above are generally known and are described in the following paragraphs:-

1) <u>Size of the grains of which the bed material consists.</u>

The influence of the size of grains on the velocity of filtering may be best explained by comparison with the flow in pipes. The larger the size of grains the wider are the channels through which the water percolates and therefore velocity of filtering is greater in a coarse material than in finer one.

According to Allen Hazen the following relation holds good for fairly uniform sands in loose state

$$K\ (\text{Cm/sec}) = C_1 D_{10}^2 \qquad C_1 (D_{10})^2$$

Where D_{10} is the effective size in centimeter

C_1 varies from 100 to 150.

2) Void ratio of the material:-

Permeability of soil decreases with decrease in void ratio. According to Case-grande's unpublished equation

$$K = 1.4 K_{.85} e^2$$

Where K = Co-efficient of permeability of the soil at any given void ratio e

$K_{.85}$ = Co-effieient of permeability of the soil at a void ratio .85

Above relation holds good for fine or medium clean sands with bulky grains.

A curve showing relationship between permeability and void ratio for ordinary tibba soil of Rajasthan Canal is given at figure 1.

3) The arrangement of grains:-

The arrangement of grains has considerable effect on the co-efficient of permeability specially for clayey soils. Test results on clayey soils reveal that co-efficient of permeability of remoulded clays decreases from original valve of K to a smaller valve K_r. For most inorganic clays the ratio K/Kr is not greater than 2. However for organic clays it may be as great as 30.

4) Entertained air in the soil:-

With more percentage of entertained air in the soil, seepage rate decreases.

5) Temperature of water and soil:-

With increase in temperature the viscosity of water decreases and hence the seepage rate also increases. Viscosity of water at any temperature is expressed as

$$\mu = \frac{.0003716}{1+.03368T + .000221\ T^2}$$

Where μ = Viscosity.

T = Temprature in degrees contigrade.

The velocity of flow and therefore absorption losses are inversely proportional to viscosity.

$\therefore$ Absorption losses $\propto$ ($1 + .00368T + .000221\ T^2$)

Absorption losses are expressed at 20° C, for other tempratures table showing the correction factor is given here under:-

Table showing temprature correction for absorption losses:-

Temprature in degrees contigrade.	Rate of flow relative to that at 20° C.	Correction factor to reduce losses at To to loss as 20 C. (in percentage)
0	0.5675	+ 76.21
5	0.6662	+ 50.10
10	0.7712	+ 29.67
15	0.8825	+ 12.32
20	1.0000	nil
25	1.1238	- 11.01
30	1.2538	- 22.24
35	1.3902	- 28.07
40	1.5328	- 34.76

The fluctuations in seepage rates due to temprature effect also depend on air water relationship involving the solubility of air in water temprature effects the vapour pressure of the entrained air bubbles as the vapour pressure rises the volume of entrained air increases and soil porosity diminishes hence decrease in permeability.

The increase in temprature may therefore be associated with both increase and decrease in permeability. The net effect may some times result in no change in permeability.

Tests carried out by U.S.B.R. for North Pondre supply canal in U.S.A. reveal that the seepage tends to vary inversely with the temprature difference of the water and the soil.

6) Turbidity or silt concentration in the Canal Water:-

Type and amount of silt contents of canal water considerably changes the soil forming the bed of the canal. Seeping water carries small particles in suspension into the soil and deposits them in pore spaces gradually reducing the soil porosity and thereby reducing the seepage rate.

7) Salt concentration of soil and water:-

Salt contained in the soil and water may have a marked effect on seepage rate. Water containing sodium tends to puddle clay soil and thus reduces seepages rates. On the other hand, soils and water containing calcium or Sulphur makes soil more porous resulting in increased seepage rate.

8) Age of the Canal:-

During the initial stage when the soil is unsaturated seepage losses are more but gradually the soil becomes saturated and seepage losses are reduced. The reduction of seepage with lapse of time may also be due to silt deposition as indicated above.

9) Biological Factors:-

Some organisms growing in the soil may decrease the rate of seepage while others may increase it. Tests reveal that addition of cottongin waste to the soil of water spreading grounds definitely increased seepage rate.

All the factors described above effect the co-efficient of permeability of the soil. Sound Engineering Judgement would be necessary to find out the correct co-efficient permeability.

The factors effecting the Hydraulic gradient can be best understood by considering the following conditions:-

Condition A:- Seepage into uniform soil under lain by material of much higher hydraulic conductivity. If the water table is at or below the top of the permeable underlying material, the condition reduces to the case of seepage to a drainage layer where $D_w = H_w + Dp$. (This condition is referred as Condition A′)

Condition B:- Seepage into uniform soil under lain by material of much lower hydraulic conductivity.

Condition C:- Seepage from canals with a thin slowly permeable layer at the wetted perimeter (clogged material, Chemical seals etc.).

Fig. 2:- Shows the geometry and symbols for seepage conditions A, B, C.

Using resistance net work analog Herman Bower (1) plotted graphs showing $\frac{\bar{I}s}{K}$ V/S Dw/Wb for trapezoidal channels with 1:1 side slopes for different valves of Dp/Wb and Di/Wb for three different water depths expressed as Hw/Wb in Fig. 3. Examples for flow systems are shown in fig. 4. $\bar{I}$s respresents seepage losses per unit length and per unit water surface width of the channel. K is the co-efficient of permeability.

The following important conclusions can be drawn from the above set of curves.

1) For condition A' valve of $\frac{\bar{I}s}{K}$ decreases as the depth of free draining coarse layer increases below the bed of the channel and when Dp → Wb or more precisely 0.6 Ws, the valve of $\frac{\bar{I}s}{K}$ is just close to $\frac{\bar{I}s}{K}$ for an infinitely deep drainage layer.

2) For condition A as well as B, the effect of permeable layer or impermeable layer at a distance greater than 5 Wb on the value of $\frac{\bar{Is}}{K}$ can be ignored as the value of $\frac{\bar{Is}}{K}$ is just close to $\frac{Dp}{Wb} = \frac{Di}{Wb} = \infty$

3) The curves for large Dp or Di show that the increase in seepage due to lowering of the water table decreases with increasing depth of the water table. With Dw = 3 Wb for shallow channel and equal to 6 Wb for deep channel which is approx. equal to 2.5 Ws, the value of $\frac{\bar{Is}}{K}$ is already close to $\frac{\bar{Is}}{K}$ for infinite depth of water table.

Note:- For Channels of other shapes graphs can be used to estimate $\frac{\bar{Is}}{K}$. In that case value of Wb is obtained from Ws and Hw as if the channel were trapezoidal with 1:1 side slopes.

<u>Seepage for condition C:-</u> If the slowly permeable layer restricts the flow sufficiently and if drainage of the underlying material is adequate to maintain water table well below the slowly permeable layer, the flow in the underlying material will be unsaturated and at unit hydraulic gradient provided that air is present in or can enter the material. —— Value of $\bar{Is}$ can be calculated by the formula given below:-

$$\bar{Is} = \frac{1}{WsRa} \left\{ (H_w - P_c)\, Wb + (H_w - 2P_c)\frac{Hw}{\sin\alpha} \right\}$$

Where $\bar{Is}$ = rate of fall of Water surface in the channel.

R = Hydraulic impedance $\frac{La}{Ka}$

La = Thickness slowly impermeable layer

H_w = Depth of water above the slowly impermeable layer

P_c = Critical pressure head of material

Wb = Bottom width of the channel.

On Rajasthan Canal where a uniform sandy or sandy silt strata occures for great depths and water table is also present at great depths it can be safely assumed that the depth of soil strata is infinite and water table is also at infinite depth. A theoritical study made by vendernikov (7) to find out the seepage losses from canals is given below. Inversion hydrograph method has been used in the analysis.

The section to be investigated is shown in figure 5 a. The hydrograph is given in fig. 5 b and the inversion of the hydrograph ~~ax~~ $\frac{dz}{dw} = \frac{1}{u - iv}$ in fig. 5 c.

Taking an auxilliary plane t as shown in fig. ~~5xx~~ 5 d we obtain for the mapping of the $\frac{dz}{dw}$ plane on the lower half of t plane

$$\frac{dz}{dw} = M \int_0^t \frac{t\,dt}{(1-t^2)^{\frac{1}{2}+\sigma}\,(\beta^2-t^2)^{1-\sigma}} + N$$

$$= M\,\phi(t) + N$$

Where $\sigma = \frac{\alpha}{\pi}$ and

$\phi(t)$ is the indicated integeral.

Vendernikov has determined the quantity of seepage loss in the form

$$q = K\,(B + AH)$$

Where q = Seepage Loss

K = Co-eff of permeability.

B = Water surface width.

H = Water depth

A = Factor (depending on what?)

$$A = \frac{2}{\tan \sigma \pi} \quad \frac{f_2(\sigma, \beta) - f_1(\sigma, \beta)/\cos \sigma \pi}{J_2 \, \pi/2 - f_2(\sigma, \beta)}$$

$$f_1(\sigma, \beta) = \int_0^{\beta} \frac{t \sin^{-1} t \, dt}{(1-t^2)^{\frac{1}{2}+\sigma} (t^2 - \beta^2)^{1-\sigma}}$$

$$f_2(\sigma, \beta) = \int_{\beta}^{1} \frac{t \sin^{-1} t \, dt}{(1-t^2)^{1/2+\sigma} (t^2 - \beta^2)^{1-\sigma}}$$

$$J_2 = \int_{\beta}^{1} \frac{t \, dt}{(1-t^2)^{1/2+\sigma} (t^2 - \beta^2)^{1-\sigma}}$$

$$\sigma = \frac{\alpha}{\pi}$$

α = Angle between side of canal and x axis

β = Co-ordinate of point 'c' on t plane

Taking a series of value for α and β. Vendernikov obtained the correspondence between A and $\frac{B}{H}$ as given in fig. 6. In this figure $n = \cot\alpha$ is the side slope of the canal.

Study has been conducted to evaluate losses for different shapes of channels, the value of $\frac{q_s}{K}$ has been determined in the table No.1 given below. In this case q_s represents the seepage losses per unit of wetted area.

TABLE NO. 1.

EVALUATION OF SEEPAGE LOSSES FOR DIFFERENT SHAPES OF CHANNELS.

$\frac{H}{B_1}$ (Assumed)	n	$\frac{2nH}{B_1}$ 2Col.1xCol.2	$\frac{B}{B_1}$ 1+Col.3	$\frac{B}{H}$ $\frac{Col.4}{Col.1}$	A from curve No.6.	A x $\frac{H}{B_1}$ Col.1xCol.6	$\frac{q}{KB_1}$= $\frac{B}{B_1}+\frac{AH}{B_1}$ Col.4+ Col.7.	$2\sqrt{n^2+1}\times\frac{H}{B_1}$ 2.82xCol.1 for n = 1 4.47xCol.1 for n = 2	Wetted perimeter / B_1 1+Col.9	$\frac{q_s}{K}$ (for unit peri meter) $\frac{Col.8}{Col.10}$	
1	2	3	4	5	6	7	8	9	10		
.75	1	1.5	2.5	3.3	2.7	2.02	4.52	2.12	3.12	1.45	Aver age= 1.4
.5	1	1.0	2.0	4.0	2.8	1.4	3.4	1.41	2.41	1.41	
.25	1	0.5	1.5	6.0	3.2	.8	2.3	.7	1.7	1.35	
.75	2	3.0	4.0	5.3	2.2	1.65	5.65	3.35	4.35	1.30	Aver age= 1.2
.5	2	2.0	3.0	6.0	2.3	1.15	4.15	2.23	3.23	1.28	
.25	2	1.0	2.0	8.0	2.6	.65	2.65	1.11	2.11	1.26	

Average $\frac{q_s}{K}$ = 1.34

Note:- From eqn $q = K(B+AH)$

We get $\frac{q}{K \times \text{Wetted Perimeter}} = \frac{B + AH}{\text{Wetted Perimeter}}$

or $\frac{q_s}{K} = \frac{B + AH}{\text{Wetted Perimeter}}$

From Table No.1 it is clear that for a trapezoidal channel with different side slopes value of q_s/k is more or less constant. The average value of q_s/k can be taken as 1.34 for the conditions prevalent in Rajasthan Canal area.

Seepage losses are, therefore, dependent on two factors:-

(i) Permeability of the soil

(ii) Wetted perimeter of the canal.

<u>Seepage Losses per million square feet of wetted area:-</u>

Seepage losses $q = k\ i\ A$ (Darcey's Law)

Where K = Permeability of soil

i = Hydraulic gradient

A = Wetted area

We have $q_s/k = 1.34$

or $\frac{q}{A \times k} = 1.34 = i$ (Hydraulic gradient)

$\therefore\ q = 1.34 \times A \times k$

$= 1.34 \times 10^6 \times k$ (Assuming $A = 10^6$ sq.ft.)

for k = 1 ft. per year = $\frac{10^{-6}}{30}$ ft/sec.

$q = \frac{4}{3} \times \frac{10^6 \times 10^{-6}}{30} = \frac{4}{90} = .04$

Table No.2 given below shows the seepage losses per million sq.ft. of wetted area for different values of coefficient of permeability:-

TABLE NO.2

Coefficient of permeability ft/year	Seepage loss per 10^6 sq.ft. of wetted area
1	.04
10	.4
100	4.0
200	8.0
500	20.0
1000	40.0
3000	120.0

Measurement of seepage losses:-

Seepage losses can be measured by the following methods:-

1) Ponding tests.
2) In flow out flow method.
3) By seepage meters
4) Well permeameter.
5) Laboratory permeability.
6) Electrical resistance of the areas where seepage occures.
7) Tracing radio active material in the seepage water.

The seepage meters although do not provide very accurate method of measuring seepage losses more than 1.0 ft. per day but give fairly accurate results for losses less than 1.0 ft. per day. For fore casting seepage from proposed canals, well permeameter test is quite useful.

Seepage losses can be expressed in any of the following systems:-

1) Cusecs per million square feet of wetted area.
2) Cubic feet per square feet of wetted area in 24 hours.
3) Percentage of flow per mile of the canal.

In India seepage losses are usally expressed as cusecs per million square feet of wetted area.

Various Empirical formula used for estimation of seepage losses are given below:-

1) David and Wilson formula

$$S = C\sqrt[3]{d}\ \frac{PL}{4,000,000 + 2000\sqrt{V}}$$

Where S = Seepage in cusec through length L ft. of canal.

C = Co-efficient depending upon the material for canal.

d = Mean water depth in the canal.

P = Wetted perimeter in feet.

L = Length of canal in feet.

V = Mean velocity of water in canal.

Value of C are given below:-

C = 1 for 3" to 4" thick concrete

= 4 for clay puddle 6" thick.

= 10 for thin oil lining, cement grout.

= 15 for clay loam unlined.

= 30 for coarse sandy loam unlined

(2) Moritz formula:- This is used in U.S.A.

$$S = 0.2\, C \sqrt{\frac{Q}{V}}$$

Where S = Seepage in cusec per mile of the canal

Q = discharge of canal in cusecs

V = Mean velocity of flow in ft/sec.

C = Cubic ft of water loss in 24 hours through each square foot of wetted area of canal prism.

C = .34 for gravel and hard pan with sandy loam

= .56 for sandy loam.

= 1.68 for sandy soil with rock

= 2.20 for sandy and gravelly soil

(3) Highham's formula:- For Punjab Canals

$$S = .55\ C \frac{BL}{10^6} \sqrt{d}$$

Where S = Seepage loss in cusec for length L feet of canal.

C = Coefficient (Av. value = 0.45).

B = Width of water surface of canal in feet.

L = Length of canal in feet.

d = Depth of water of canal in feet.

(4) **Dyas Formula:-**

$$P = C\sqrt{d}$$

Where P = Absorption loss in cusec/msft. of wetted surface.

d = depth of canal

C = Constant varying from 1.1 to 1.2

(5) **Punjab Formula:-**

$$P = 5\ Q^{.0625}$$

Where P = Seepage loss in cusecs/m sft. of wetted area

Q = Discharge in cusecs.

(6) **U.P. Formula:-**

$$S = 5\ Q^{.0625}\ \frac{WL}{10^6}$$

Where S = Seepage loss in cusecs per ft length of canal

W = Wetted perimeter in ft.

L = Length of the canal.

From Lacey's formula

$$W = 2.66\sqrt{Q}$$

$$\therefore\quad S = 5\ Q^{.0625} \times \frac{2.66\sqrt{Q} \times L}{10^6}$$

$$S = .0133\ L\ \left(\frac{Q^{.5625}}{10^3}\right)$$

Empirical formulae as discussed above reveal that seepage loss per million square feet of wetted area is greater in big canals than in small ones. Theoretical investigations as discussed in this Chapter show that in an area similar to Rajasthan Canal area where water table is at great depth, the seepage loss per million square feet of wetted area depends only on the permeability of the soil and does not vary with the capacity of the canal. Therefore, empirica-l formulæ as discussed above are not applicable in areas similar to that of Rajasthan Canal area.

In Rajasthan Canal area average coefficient of permeability is 200 ft/year, therefore, seepage losses per million square feet of wetted area are taken as 8 cusecs (See Table 2). In tibba reaches where the coefficient of permeability of the soil is of the order of 1000 to 3000 ft/year, the loss may be of the order of 40 to 120 cusecs per million square feet of the wetted area.

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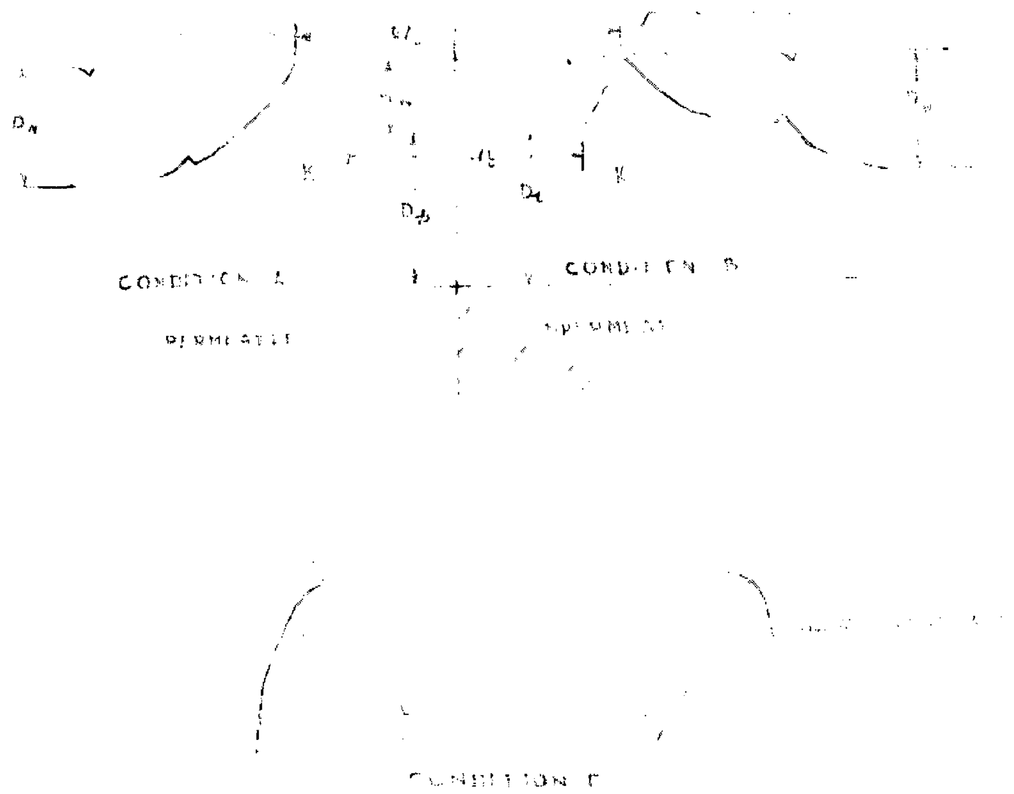
CONDITION A

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C H A P T E R - 3

N E C E S S I T Y OF L I N I N G S.

CHAPTER 3

NECESSITY OF LINING

Lining of canals may be primarily necessary due to any of the following reasons:-

1) To save absorption losses as anti logging measure.

2) To check seepage losses to irrigate more land.

3) To prevent erosion of the canal section.

4) Economic considerations.

In humid countries where water table is high, with the introduction of canal irrigation the land is likely to become water logged if the water losses are not prevented (to enter into the ground deep). Hence lining of canal is essential.

In arid countries where water has to be brought from distant sources water table is very deep and generally brackish, lining of the entire canal system would generally be necessary to save absorption losses to irrigate other areas.

In semi arid countries where water is available at shallow depth economic consideration would play an important role to determine the necessity of lining. This is because of the fact that the lining of canals is very costly and pumping of water from shallow depths may be more economical.

From economic considerations lining of canals may also be necessary due to the reasons mentioned below:-

1) For the same discharge the cross sectional area is less in case of lined canal and therefore cost of construction is considerably less.

a) Quantity of earthwork is less.

b) Lesser land width is required.

c) Cost of masonry structures such as regulators bridges etc. is considerally reduced.

2) The operation and maintenance cost of a lined canal system is cheaper as compared to unlined canals.

3) There is very little danger of breaches in lined canals. Breaches in unlined canals cause loss of money and irrigation.

4) In case of lined canals the water carried by it does not pick up salts from soil there by damage to crops from salty water is reduced.

5) Weed growth is no problem in case of lined canals.

6) Lined canals is free from damage by cattle and burrowing animals.

Necessity of Lining Rajasthan Canal.

The State of Rajasthan has very inadequate water resources as compared to its requirement. Out of 86 million acres area nearly 30 million acres is a complete desert.

Rajasthan Canal as proposed at present will supply irrigation facilities to a gross area of 8.0 million acres of the desert area near the Indo-Pak-Border. The annual rain fall in this tract is 6" to 8" only. Ground water table is 150 ft. to 300 ft. deep and the water is highly brackish and not fit for drinking purposes. The food production in the area is negligible.

Even after the completion of the Project there will be scarcity of water in this area, if necessary precautions to conserve the water are not taken now. It might therefore be necessary to line all branches, distributaries and water courses of the Irrigation system.

In this area water, even for construction, is not available and there are no other sources of water for irrigation. To extend the scope of irrigation available water should be used in most economic manner.

The reasons for lining the Rajasthan Canal are summarised below:-

1) There is more area but less water to irrigate the lands. The rain fall is very poor and no other source of water is available for irrigation.

2) As the Main Canal is a contour canal more land can be irrigated by adopting a flatter slope in a lined canal. A flatter slope in a unlined canal will cause heavy silting and there by the proposal would not be economical/feasible.

3) The extra cost of construction of lined canal system is compensated to a large extent on account of following reasons:-

i) The cost of construction of storage dams, Head-works and feeder channel is constant and is nearly 40% in case of Rajasthan Canal.

ii) The canal has to cross very high dunes and low valleys, the cost of earthwork in such reaches is much less in lined canal as smaller bed width is required.

iii) In sand dunes lining can permit winding of canal alignment to cheapen the cost of excavation of high dunes.

iv) Lesser land width is required for lined canal system.

v) Cost of masonry structures such as regulators, bridges etc. is considerally reduced as lined canal has lesser width.

4) Maintenance of unlined canal is a desert area x would be very costly specially during non perennial stage. Huge maintenance expenditure (roughly 40 to 50% of the original cost of earthwork) has been incurred on the Suratgarh Branch of Rajasthan Canal in 5 years. The average maintenance cost works out 8 to 10% per year of the original cost of earthwork. The maintenance cost could have been saved considerably in case the branch was lined.

5) In the Rajasthan Canal area water is not available for the

construction and domestic purpose. The only source of water supply would be the canal itself. In case the canal is unlined, storage of water in the canal is not possible and many thousand cusecs discharge would be lost as seepage losses in the canal system to get only few cusecs of water for construction purposes. In winter season when the available discharge in the river is less such a colosal waste of water would force the irrigated areas to suffer from irrigation. In case of lined canal, the completed length of canal serves as storage reservoir for supplying water for construction purposes.

6) For successful colonization and development it is essential that ample water should be available for drinking purposes and sowing of fodder during winter also. Even for drinking water, Kunds are being constructed at huge costs. The filling of such ponds during the winter season is a problem even from unlined branches, because of heavy absorption losses. Had the main canal been unlined the absorption losses would have been much more (and also the danger against breaches).

In short, the development of irrigation is quick in lined canals as water can be fed to the tails soon after the construction.

7) The danger of silting in lined canals is considerlly minimised because of high velocities.

The lining of all the channels on Rajasthan Canal is essential. It would be more practical to line the branches in the initial stage. The question of lining of distributaries and minors can be taken up at a later stage as cheap materials can be used on small channels. The lining of field channels (water courses) should also be taken up at a later stage when the necessity arises.

Cost of Lining V/S seepage losses.

As discussed above it is clear that the lining of canals is necessary due to many reasons, the most important being the reduction in seepage losses specially in desert areas. Attempt has been made to work out the economical capital investment that can be made on lining in different reaches where the rate of seepage losses is known.

Cross-Section of unlined and lined canal.

The assumptions as mentioned here under have been made in working out the cross sections.

1) Bed slope of both lined and unlined sections has been taken from Lacey's diagram with f=1. In practice also the actual bed slope for lined and unlined canal would mostly remain the same and will correspond to the actual ground slope of the country. In most of the cases steeper or flatter slopes would increase the cost of earthwork thereby the total cost of the canal.

2) Lacey's formulae/curves have used for design of unlined section.

3) Manning's formula with value of n = .017 has been used for design of lined section.

4) In case of lined section for discharges of 100 cusecs and 1000 cusecs dimensions have been worked out close to the bed width-depth curves as per American practice. For 10,000 cusecs discharge a practical depth of 20 ft. has been assumed.

TABLE 1

Calculations for Unlined Section.

Discharge Q in cusecs	Lacey's f	Slope per ‰	Bed width B in feet	Depth D in feet	2.24 D	Wetted perimeter in feet.
100	1.0	.26	21	2.6	5.8	26.8
1,000	1.0	.175	72	5.2	11.6	83.6
10,000	1.0	.12	240	11.0	24.6	264.6

TABLE NO.2.

Calculation for lined section

Discharge Q in cusecs	Bed slope per %o	Side slopes	Bed width in ft.	Depth in ft.	Hydraulic radius in ft.	Velocity in ft/sec.	Side perimeter in ft.	Wetted perimeter in ft.	Perimeter length of lining in ft.
100	.026	1½:1	5.0	3.9	2.27	2.42	14.0	19	24.4
1000	.175	1½:1	11.0	10.2	5.7	3.72	36.7	47.7	54.9
10000	.12	2:1	54.0	20.0	13.1	5.45	89.4	143.4	154.6

TABLE No.3

Comparison of unlined and lined sections.

Discharge in cusecs.	Wetted perimeter of lined section in feet.	Wetted perimeter of unlined section in feet.	$\frac{\text{Col.3}}{\text{Col.2}}$x100	Perimeter length of lining. in feet.	$\frac{\text{Col.5}}{\text{Col.2}}$ x 100
1	2	3	4	5	6
100	19	26.8	141	24.4	128
1000	47.7	83.6	175	54.9	115
10000	143.4	264.6	185	154.6	109
			$\frac{501}{3}$		$\frac{352}{3}$

Average = 167 % Say. 165 % 117% Say. 115%

It is thus clear that unlined cross-section of channel has its wetted perimeter 1.65 times that of corresponding lined section. Length of lining required is 1.15 times of wetted perimeter of the lined section.

Further assumptions .

1) 10^6 sq.ft. of wetted area of lined section has been considered for study.

ii) Let the losses in unlined section be 'q' cusecs per 10^6 sq.ft. of wetted area.

iii) Let the loss in lined section be 2 cusecs per 10^6 sq.ft. of wetted area.

iv) Let 'r' be the cost of lining per sq.ft.

v) Let 'R' be the capital investment per cusec in lac Rs. on unlined system of the Project.

Corresponding section of unlined canal would have 1.65×10^6 sq.ft. of wetted area. Therefore losses in unlined section would be 1.65 q cusecs.

Saving in losses due to lining = 1.65 q - 2 cusecs.

Max^m capital investment justifiable for lining on account of saving in losses works out to $10^5 \times R\ (1.65\ q-2)$

Area of lining = 1.15 wetted area.

$= 1.15 \times 10^6$ sq.ft.

- cost of lining in Rs. $= 1.15 \times r \times 10^6$

Equating the cost of lining to max^m capital investment justifiable for lining we get

$$10^5 \times R\ (1.65\ q-2) = 1.15 \times r \times 10^6$$

$$\therefore\ 1.65\ q - 2 = \frac{1.15 \times r \times 10^6}{R \times 105}$$

$$\text{or } 1.65\ q = \frac{1.15 \times r \times 10}{R} + 2$$

$$\text{or } q = \frac{6.3\ r}{R} + 1.21$$

For different values of r and R, the value of seepage losses ~~of~~ beyond which lining of canal is justified are given in the table No.4 shown here under.

TABLE 4

Cost of lining per sq.ft 'r' in Rs.	Value of q where capital investment R lac Rs. per cusec is		
	1.0	.75	.5
.4	3.73	4.57	6.25
.5	4.36	5.41	7.51
.6	4.99	6.25	8.77
.7	5.62	7.09	10.03

CHAPTER - 4

HYDRAULIC DESIGN OF LINED CHANNELS

CHAPTER -4

HYDRAULIC DESIGN OF LINED CHANNELS

Carrying capacity :- Carrying capacity of a channel is determined by Chezy formula which is usually expressed as follows:-

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

Where V = mean velocity inft./sec.

R = Hydraulic mean depth in ft.

S = Water surface slope

C = Chezy's constant.

Various formulae used for determination of Chezy's constant and their limitation are described in the following papagraphs:-

Gaguillet and Kutter formula:- According to this formula Chezy's C depends both on R and S. The formula is expressed as follows:-

$$C = \frac{4.16 + \frac{1.8112}{n} + \frac{.00281}{S}}{1 + \left(41.6 + \frac{.00281}{S}\right)\frac{n}{\sqrt{R}}}$$

Where n = co-efficient of rugosity known as Kutter's n.

The use of this formula is questioned due to undermentioned reasons:-

i) The term containing S was introduced to suit Humpherys and Abbot data which are known to be inaccurate.

ii) Due to complexity of the formula.

In India it is still used for design of earthen channels with Kennedy's equation as Garrot charts are available.

Bazin formula:- The formula was proposed by French Hydraulician H. Bazin from data of small experimental channels. The formula is expressed as:-

$$C = \frac{157.6}{1+m/\sqrt{R}}$$

where m = co-efficient of roughness whose value may vary from 0.11 for channels with very smooth plaster surface to 3.17 for earthen channels in rough conditions.

Use of this formula is less satisfactory for bigger channels as it is derived from small experimental channels.

<u>Manning's formula</u>:- This is mostly used for design purposes. The formula was originally developed by Manning, an Irish Engineer. In its well known form it is expressed as :-

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where V = velocity in ft./sec.

also n = roughness co-efficient.

It can also be expressed as

$$C = \frac{1.49}{n} R^{1/6}$$

Determination of n, the roughness co-efficient requires sound engineering judgement and experience. Ven Te. chow (48) has described in detail factors affecting n and has also given its value in charts. Numerous photographs showing the conditions of the channels are also illustrated by him.

According to Chow the value of n depends on many factors such as surface roughness, vegetation, channel irregularity, channel alignment, silting or scouring, obstruction, size and shape of channel, stage and discharge, seasonal change and suspended material and bed load.

The value of n may vary from .008 for very smooth surfaces to .20 for thickly wooded streams.

<u>Modren concept of flow phenomenon in open channel</u>:-

The flow in open channels is mostly in turbulent stage. The flow is classified as hydraulically smooth when the roughness height is less than critical roughness expressed by

$$K_c = \frac{5\,C\,\nu}{\sqrt{g}\,V}$$

Where K_c = critical roughness

C = Chezy's co-efficient.

ν = Dynamic viscosity

V = Velocity

Under these conditions all the surface irregularities are submerged in the laminar sub-layer (fig.1 a) and roughness has no effect upon the flow outside this layer.

When the roughness height is greater than the critical roughness (fig 1b), stable laminar sub-layer can no longer be formed. The surface is classified as rough surface.

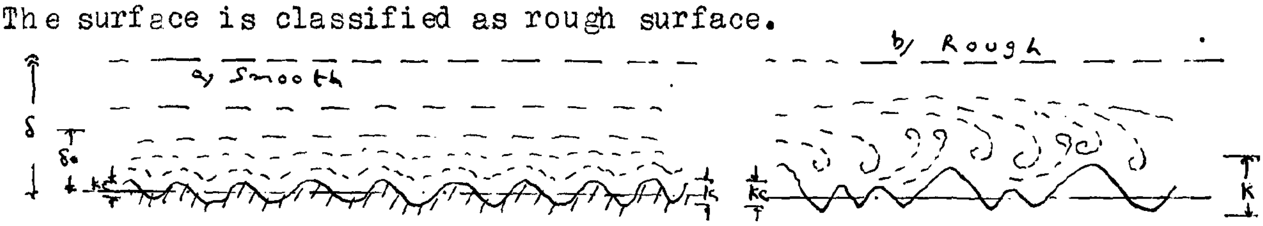


Figure 1:- Nature of surface roughness.

According to Morris the loss of energy in turbulent flow over a rough surface is due to largly to the formation of wakes behind each roughness element.

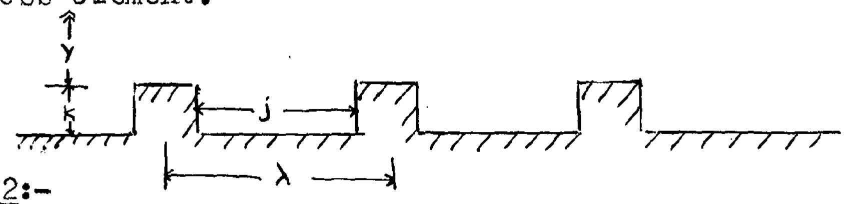


Figure 2:-

Depending upon the spacing of roughness elements flow can be further classified as :-

a) Isolated sufrace flow:- Ratio $\frac{K}{\lambda}$ plays a significant influence upon the apparent friction factor. In this case roughness elements are far apart and wake and vortex at each element are dissipated separately.

b) Wake interference flow:- Ratio $\frac{Y}{\lambda}$ governs the apparent friction factor. In this case wake and vortex at each element will interfere with those developed at the following element.

c) Quasi smooth:- Roughness elements are so close that the flow skims over the crests of elements and surface acts as hydraulically smooth. The ratio $\frac{K}{\lambda}$ (J / λ) is significant parameter.

Limitation of Manning's equation in view of modern flow concept:-

On the basis of the logrithmic law of velocity distribution and Bazin's data Keulegan arrived at the following equation for flow through channels.

$$V = V_f \left(6.25 + 5.75 \log \left(\frac{R}{K}\right)\right)$$

or $$C = 32.6 \log 12.2\left(\frac{R}{K}\right)$$

By manning's formula $C = \frac{1.49}{n} R^{1/6}$

Eliminating C we get

$$n = \phi\left(\frac{R}{K}\right) k^{1/6}$$

Where

$$\phi\left(\frac{R}{K}\right) = \frac{\left(\frac{R}{K}\right)^{1/6}}{21.9 \log 12.2 (R/K)}$$

From the data of several streams strickler found that

$\phi(R/K) \simeq .0342$

Where K is median size of the material

$$\therefore n = \frac{K^{1/6}}{29.3} \simeq \frac{K^{1/6}}{30}$$

From the above equation it is clear that manning's n depends upon roughness height. Thousand fold change in the linear measure of the roughness height results in about a three fold change in n.

Keulegan has shown that within range $15 < \frac{R}{K} < 500$ mannings formula gives satisfactory results but outside this range use of different value of 'n' would be necessary even for the same roughness projection.

Sectionof Rajasthan Canal:-

Rajasthan Canal is lined with single tile lining with cement plaster on top in bed and double tile lining on side slopes.

A sub-committee under the chairmanship of Mitra decided to adopt mannings co-efficient of roughness as .017. According to Dr. Uppal co-efficient of roughness does not vary much with the type of lining due to deposition of very fine material on the bed and sides.

A typical design of section of Rajasthan Canal and its carrying capacity on the basis of various formulae is given below:-

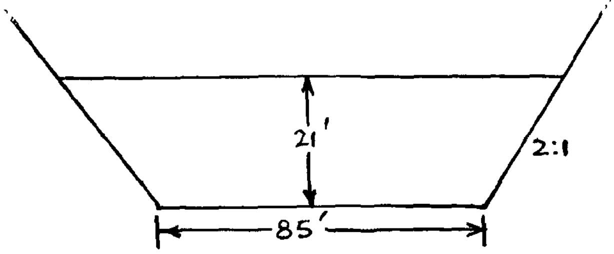
Data:- B = 85 ft.

D = 21 ft.

S = 1 in 12000

n = .017

Side slopes = 2:1



Area of section $(85+42) \times 21 = 2667$

Wetted perimeter $= 85 + 2\sqrt{5} \times 21 = 178.7$

$$R = \frac{2667}{178.7} = 14.95$$

a) Manning's formula

$$C = \frac{1.49}{n} R^{1/6} = \frac{1.49}{.017} \times 14.95^{1/6} = 137.5$$

$$V = C\sqrt{RS} = 137.5\sqrt{14.95 \times \frac{1}{12000}} = 4.86$$

$\therefore$ Discharge = 2667 x 4.86 = 12950 cusecs.

b) G.K.Formula :-

$$C = \frac{41.6 + \frac{1.8112}{n} + \frac{.00281}{S}}{1 + \left(41.6 + \frac{.00281}{S}\right) \times \frac{n}{\sqrt{R}}}$$

$$= \frac{41.6 + \frac{1.8112}{.017} + (.00281 \times 12000)}{1 + (41.6 + .00281 \times 12000) \times \frac{.017}{\sqrt{14.95}}}$$

$$= \frac{41.6 + 106.5 + 33.6}{1 + (41.6 + 33.6) \times \frac{.017}{3.86}} = \frac{181.7}{1.33} = 136.5$$

$$V = C\sqrt{RS} = 136.5\sqrt{14.95 \times \frac{1}{12000}} = 4.82$$

$$Q = 2667 \times 4.82 = 12850 \text{ cusecs.}$$

c) Keulegan equation:-

$$n = \frac{K^{1/6}}{30} \text{ or } K = (30 \times n)^6$$

$$K = (30 \times .017)^6 = (.51)^6 = .0177 \text{ ft.}$$

$C =$ ~~XXXXXXXXXX~~ $32.6 \log \left(12.2\frac{R}{K}\right) = 32.6 \log 12.2 \times \frac{14.95}{.0177}$

$$= 32.6 \log 10030 = 130.4$$

$$V = C\sqrt{RS} = 130.4\sqrt{14.95 \times \frac{1}{12000}} = 4.61$$

$$Q = 2667 \times 4.61 = 12300$$

It would be clear that the discharge as calculated from Keulegan equation is less than from Mannings formula by nearly 5%. The variation is due to the fact that R/K is equal to 845 which is outside the limit of 500 as suggested by Keulegan.

Keeping the above facts in view it would be desirable to design the section of Rajasthan Canal from Keulegan equation and not by Manning's formula as is being done.

<u>Critereon for design of rigid surface lining section</u>:-

Hard surface and exposed membrane linings can be classified as non-erodible. Maximum permissible velocity is governed by the type of lining used but the same is not critical in most of the cases. Where flow is desilted or clear a mean velocity of 2 to 3 ft. per second would be safe to prevent weed growth.

In Northern India and Pakistan rivers carry huge amount of sediment. Inspite of exclusion of coarse silt through various silt exclusion work, water in the canals has to carry sufficient amount of silt. Removal of silt is very costly specially from lined canals. Therefore, it is necessary to specify minimum velocity in lined channels to prevent silt deposition.

According to K.R.Sharma "The roughness of the perimeter of earthen channel section is greater than that of the lined channel. The silt supporting eddies in earthen channel sections are relatively stronger and more efficacious to support and roll the silt charge in channel as compared with lined channel. In actual practice 10% higher value of Kennedy's C.V.R. or Lacey's silt factor is allowed in the brick lined sections and 15% more in the cement concrete or cement plastered sections".

Kanwar Sain has recommended that the actual velocity in lined canals should not be lower than Vo the non silting velocity. He has compared the actual velocities with Lacey's critical velocities for value of f = 0.8. He had stated that the actual non-silting velocity would be different than Vo given by either Kennedy's or Lacey's formula.

Mahbub (11) had recommended that as per Irrigation practise in Pakistan minimum velocity should be such that a minimum ~~velocity~~ value of f as 1.2 is obtained. Minimum value of f as 1.2 has also been recommended in the book lining of Irrigation canals (49)

<u>To check up section of Rajasthan Canal with minimum permissible velocity criterea:-</u>

Assuming the same design particulars as given above.

Velocity as per manning's formula =4.86 ft./sec.

a) Lacey's silt factor.

~~For~~ Lacey's formula $f = .75 \frac{V^2}{R} = .75 \times \frac{4.86^2}{14.95}$

$\therefore$ f= 1.09 against minimum permissible value of 1.2

b) Kennedy's formula in conjunction with K.R.Sharma

$V_o = .84\, D^{.64} = .84\, (21)^{.64} = .84 \times 7 =$ ~~.825~~ 5.88

$\therefore \frac{V}{V_o} = \frac{4.86}{5.88} = .825$

Assuming minimum value of $\frac{V}{Vo}$ as 0.9 for earthen canal of similiar capacity, minimum value of $\frac{V}{Vo}$ for brick lined canal should be 1.0

c) Kanwar Sain criterea:-

As per lacey's formulae

$V_o = 1.15473 \times \sqrt{fR}$

$= 1.15473 \times \sqrt{.8 \times 14.95}$

$= 4.0$ ft./sec.

Assuming f = 0.8

$\therefore \frac{V}{Vo} = \frac{4.86}{4} = 1.21$

It would be seen that there is possibility of silting of Rajasthan Canal keeping in view the first two critereon but as per Kanwar Sain criterea there is no possibility of silting. However, it would be desirable to study the behaviour of canal in the light of above discussions.

Section of Rajasthan Canal with different minimum silt factors:-

On Rajasthan Canal bed slope 1 in 12000 has been adopted considering the commanded area. In fact it would have been better from economical point of view to adopt still flatter slope (refer chapter 10). In this para effect of minimum permissible silt factor of 1.0, 1.1 and 1.2 on the section of canal would be considered. For a particular minimum silt factor a particular minimum depth would be necessary.

As per manning's formula $V = \frac{1.49}{n} R^{2/3} \times S^{1/2}$

For Rajasthan Canal n = .017, S = 1 in 12000

and side slopes = 2:1

$\therefore V = .8\ R^{2/3}$

As per lacey's formula $f = .75\ \frac{V^2}{R}$

or $V = 1.15\ f^{1/2}\ R^{1/2}$

$\therefore\ .8\ R^{2/3} = 1.15\ f^{1/2} R^{1/2}$

or $R^{1/6} = \frac{1.15}{.8} f^{1/2}$

$\therefore\ R = 9.2\ f^3 \cdots (A)$

$V = 1.15\ f^{1/2} \times 9.2^{\ 1/2} \times f^{3/2}$

$= 3.47\ f^2 \cdots (B)$

Area $\frac{Q}{V} = (B + 2D)\ D$

$\therefore\ BD + 2D^2 = \frac{Q}{3.47\ f^2} \ldots (C)$

Wetted perimeter $= \frac{A}{R}$

$= \frac{Q}{3.47\ f^2} \times \frac{1}{9.2\ f^3}$

or $B + 4.46\ D = \frac{Q}{31.9 f^2} \cdots\cdots (D)$

From C and D we get

$2.46\ D^2 - \frac{Q}{31.9 f^5}\ D + \frac{Q}{3.47\ f^2} = 0$

Substituting different values of Q and f inthe above equation and solving for D different values are obtained. These values are shown in the table No.1 and are also plotted in fig. 1

Similarly for S = 1 in 15,000 general quadratic equation is as given below:-

$$2.46\ D^2 - \frac{Q}{88.1 f^5}\ D + \frac{Q}{4.9\ f^2} = 0$$

and for S = 1 in 18,000 , general quadratic equation is

$$2.46\ D^2 - \frac{Q}{181\ f^5}\ D + \frac{Q}{6.2\ f^2} = 0$$

The k value of depths for different values x of f so obtained are also tabulated and shown in fig.1

TABLE NO. 1

Particulars :- n = .017,

side slopes = 2:1

Section trapeozodial

(A) Slope = 1in 12,000

S.No.	Discharge in cusecs (Q)	Lacey's silt factor (f)	Water depth (d)ft.	Bed width (B) in ft.	Remarks.
1.	2.	3.	4.	5.	6
1.	18500	1.2	19.25	154.0 ft.	
2.	15000	1.2	21.5	97.0	
3.	13000	1.2	25.00	50.0	
4.	12000	1.2	31.25	17.5	Limiting.case.
5.	18500	1.1	13.5	300.0	
6.	15000	1.1	13.75	232.0	
7.	12000	1.1	14.3	171.0	
8.	16200	1.1	24.7	10.0	Limiting case.
9.	18500	1.0	9.5	531.0	
10.	15000	1.0	9.6	432.0	
11.	12000	1.0	9.75	336.0	
12.	6000	1.0	10.50	144.0	
13.	2870	1.0	18.3	8.5	Limiting case

B) Slope 1 in 15000

1.	2.	3.	4.	5.	6.
14.	24000	1.0	22.75	170.0	
15.	18500	1.0	24.5	105.0	
16.	15500	1.0	36.0	16.0	Limiting case.
17.	24000	.9	14.5	562	
18.	18000	.9	15.0	397	
19.	15000	.9	15.5	313	
20.	12000	.9	16.0	234	
21.	9000	.9	18.25	139	
22.	6700	.9	26.2	37	Limiting.case
23.	15000	.8	10.5	622	
24.	12000	.8	11.0	470	
25.	6000	.8	11.5	212	
26	3000	.8	15.6	55	
27.	2800	.8	19.7	24	Limiting case.
<u>Slope 1 in 18000</u>:					
28	52000	1.0	58.5	139	Limiting case.
29	22300	0.9	44.0	92	Limiting case.
30	24000	.8	12.1	870	
31	18000	.8	16.5	460	
32	12000	.8	19.8	233	
33	9000	.8	24.5	137	
34	8700	.8	29.8	71	Limiting case.

Note:- 1) Depths calculated are minimum for any particular discharge and minimum silt factor.

2) Limiting case is the discharge below which design is not possible

Interpretation of the results:-

For discharges higher than 9,000 cusecs, suitable design is possible with depth = 25 ft., minimum silt factor = .8 and bed slope of 1 in 18000.

From 4000 to 9000 cusecs suitable design is possible with depth from 15 to 25 ft., minimum silt factor = .8 and bed slope varying from 1 in 18000 to 1 in 15000.

Silt carrying capacity of the canal with different bed slopes

For an average discharge of 12700 cusecs and gradients of canal varying from 1 in 12000 to 1 in 30,000 study has been conducted to find out the silt factors by Lacey's and Kannedy's formula and ~~formula and~~ bed load carrying capacity with semi-theoritical formula such as Meyer Peter's equation and Einstein's equation.

(1) Meyer Peter's equation

$$g = 33900 \left(\tau_o \left(\frac{n'}{n}\right)^{3/2} - \tau_{cr} \right)^{3/2}$$

where gs = Rate of bed load transport in lbs./ft.per hour

n'= Manning's co-efficient pertaining to the grain size on a plane, unrippled bed.

n = Actual value obtained on rippled bed.

τ_o = Total tractive force intensity on the bed

τ_{cr}= Critical tractive force.

Assuming the silt factor as .8. From Lacey's equation $f = 1.76 \sqrt{m_r}$, ratio of m_r is obtained.

$$m_r = \frac{f^2}{1.76^2} = \frac{.8^2}{1.76^2} = .206 \text{ mm} \qquad \text{Say .2 mm.}$$

$$\tau_{cr} = \frac{5 \times .2}{305} = .003 \text{ lbs./sq.ft.}$$

$$n' = \frac{K_s^{1/6}}{30}$$

K_s = Grain diameter for closely spaced uniform grain and may be taken as d_{65} or the diameter than which 65% of the material is finer for graded sand.

Assume K_s = .3 mm = .000985 ft.

$$n' = \frac{.000985^{1/6}}{30} = .011$$

$$g_s = 33800 \left(62.5 \times R \times S \times \left(\frac{.011}{.017}\right)^{3/2} - .003\right)^{3/2}$$

$$= 33800 \left(32.5 \times R \times S - .003\right)^{3/2}$$

Calculation are done in the table No.2 given below:-

Table No.2

Gradient	Bed width B	Hydraulic radius (R)	32.5xRxS	32.5 RS-.003	g_s	Total bed load lbs/hr	Parts per 10^6 ft.
1 in 12000	85	14.95	.041	.038	245	20900	7.3
1 in 15000	95	15.25	.033	.03	176	16700	5.8
1 in 18000	105	15.50	.028	.025	134	14100	4.9
1 in 21000	115	15.75	.0245	.0215	106	12200	4.2
1 in 24000	125	16.00	.0212	.0182	83	10400	3.6
1 in 27000	135	16.25	.0195	.0165	71	9600	3.3
1 in 30000	145	16.45	.018	.015	62	9000	3.1

2) **Einstein's equation:-**

The euqation co-relates the dimension less parameters Φ and Ψ where Φ is given by

$$= \frac{g_s}{s_s}\left\{\frac{1}{S_s-1}\right\}^{1/2} \left\{\frac{1}{g\,d^3}\right\}^{1/2}$$

Where S_s = specific gravity of grains.

$$\Psi = \frac{(S_s - 1)d}{R'S}$$

$$= \frac{(2.64 - 1).000985}{R' S} = \frac{.00161}{R' \times S}$$

$$g_s = \phi \times S_s \times \gamma \times (S_s - 1)^{1/2} (g d^3)^{1/2}$$

$$= \phi \times 2.64 \times 62.4 \times 1.64^{1/2} \times 32.2^{1/2} \times .00985^{3/2} \times 36000$$

$$= 135\,\phi$$

$$R' = \frac{(.011)^{3/2}}{.017} \times R$$

$$= .52 \times R$$

Detailed calculation are shown in the table No.3 below:-

Table No.3

Gradient	Bed width (B)	Hydraulic radius (R)	R' = .52R	ψ	ϕ from graph	$g_s = 135\phi$	Total bed load lbs./hr. B x g_s	Bed load in parts per 10^6
1 in 12000	85	14.95	7.8	2.48	2.1	283	24100	8.5
1 in 15000	95	15.25	7.9	3.05	1.8	243	23100	8.6
1 in 18000	105	15.50	8.1	3.57	1.3	175	18400	6.5
1 in21000	115	15.75	8.2.	4.13	0.8	107	12300	4.3
1 in 24000	125	16.0	8.3	4.55	0.7	95	11900	4.2
1 in 27000	135	16.25	8.5	5.11	0.5	67	9050	3.2
1 in 30000	145	16.45	8.6	5.61	0.45	61	8800	3.1

For an average discharge of 12,700 cusecs on Rajasthan Canal, the bed load carrying capacity and silt factors with different discharges are given in table No.4 below:-

$$V_o = .84\, D^{.64}$$

$$= .84 \times 21^{.64} = 5.88$$

TABLE NO.- 4

Gradient	Bed width	R	Bed load carrying capacity in parts per 10^6		Velocity	Lacey's f	Kennedy's $V/_{vo}$
			Peter Meyer's eqn.	Einstein's eqn.			
1 in 12000	85	14.95	7.3	8.5	4.77	1.07	.81
1 in 15000	95	15.25	8.5	8.6	4.39	0.95	.745
1 in 18000	105	15.50	4.9	6.5	4.08	.81	.694
1 in 21000	115	15.75	4.2	4.3	3.81	.69	.65
1 in 24000	125	16.00	3.6	4.2	3.57	.60	.605
1 in 27000	135	16.25	3.3	3.2	3.41	.54	0.58
1 in 30000	145	16.45	3.1	3.1	3.26	.48	.555

Field tests should be conducted on Rajasthan Canal to find out the quantity and amount of silt on Rajasthan Canal. After the construction of Bong Dam the quantity and amount of silt entering into the Rajasthan canal would be comparatively less. As per Kanwar Sain minimum silt factor of 0.80 can be adopted on lined channels. In case of Ratwasar Disty. (unlined) of Rajasthan canal a minimum Lacey's silt factor of 0.5 has been adopted. No rigid limit can be specified for the silt factor to be adopted. In case a minimum silt factor of .60 is allowed a gradient of 1 in 24,000 can be adopted. In case minimum silt factor of 0.8 is allowed a gradient of 1 in 18000 can be adopted. It is also clear that difference in bed load carrying capacities of canal with gradient of 1 in 12000 and 1 in 18000 is small. Recent tests conducted in Pakistan on large canals had revealed that silt carrying capacity of canals is much more than given by Einstien's formula. It can, therefore, be assumed that Rajasthan Canal would not silt even if gradient of 1 in 18000 is adopted.

3. Criterea for Design of Burried membrane & Earth Linings.

Burried membrane and earth lining are usually erodible. Therefore, canal section has to be designed in such a manner that neither erosion takes place nor silting occures. These can further be classified under two heads.

a) Erodible channels carrying clear or desilted water

b) Erodible channels carrying water with sufficient amount of silt.

In India burried membrane and earth linings are seldom used. There is possibility of using the same on Branches, Distributaries and minors of Rajasthan Canal, therefore, only principles of design will be discussed.

3.1 Erodible channels carrying clear or desilted water.

As the water carried by the channels is clear or desilted there is no danger of silting. The channels are designed such that erosion does not take place. Actually physical and chemical properties of the material forming the channel section are mainly responsible for stable channel section. However, at the present State of Knowledge following methods are employed for the design:-

1) Method of maximum permissible velocity.

2) Method of tractive force.

3.2 Method of maximum permissible velocity:-

Various Research Workers have published maximum permissible velocities for different materials such as Etchevery, Fortier and Scobey. U.S.S.R. Data on permissible velocities for non co-hesive and co-hesive soils along with correction factor for different depths of water in canal are as available in ref (48) are based on the principles of soil mechanics. Lane has suggested reduction of 5, 13 and 22% for slightly, moderately and very sinuous canals. It is important to note that the data's are for well seasoned channels.

3.5 Method of permissible tractive force:-

Unit Tractive force is the average pull of water on the wetted area in the direction of flow. Permissible tractive force is the maximum tractive force which would not cause serious erosion of the material forming the channel bed on a level surface. For non co-hesive materials gravity force acting on side slopes is also significant. To account for this permissible tractive force on side slopes is reduced in the ratio of tractive force. Tractive force ratio.

$$K = \sqrt{1 - \frac{\sin^2\phi}{\sin^2\theta}}$$

Where ϕ = inclination of the sloping side.

θ = Angle of repose.

For co-hesive and fine non co-hesive materials even with clear water angle of repose need not be considered as the co-hesive forces are great compared to gravity forces.

Curves showing permissible tractive force are available in ref (48)

Lane has suggested reduction of 10, 25 and 40% for slightly, moderately and very sinuous canal.

Baron W.F. Van Asbeck has suggested the following values of attainable tractive force for cover materials as given in table No. 5

TABLE NO 5.

Type of cover	Minimum % retained (by weight)	Secreen size.	Allowable tractive force.
1. Earth	--	--	.04
2. Gravelly material.	25	No.4	.06
3. Gravel	50	No. 4	
	25	3/4 inch	.10
4. Screened Gravel	90	No.4	
	45	3/4 inch	.13
	10	3 inch	

The design of channel section shall have to be carried out by trial and error method.

Erodible channels carrying water with silt:-

For these channels in addition to satisfying the critereon for channels with clear or desilted water, it has to be assured that no silting takes place.

For non silting velocity empirical formulae of Kennedy or Lacey or Semo empirical formula of Einstein shall have also to be satisfied.

Lot of research work still remains to be done for clear understanding of the design principles of such channels.

C H A P T E R - 5

STRUCTURAL DESIGN OF LINED CANALS

CHAPTER – 5

STRUCTURAL DESIGN OF LINED CANALS

Till recently steeper side slopes (1:1) were provided on lined canals. It was thought that the thickness of lining would be sufficient to resist earth pressure in cases where side slopes of canal were steeper than the angle of repose of the soil forming the banks. In America reinforced concrete linings were designed. On Haveli canal (now in Pakistan) reinforced brick lining was provided. On Thal canal side slopes (1:1) were provided but re-inforcement was ommitted. On Bhakhra canals $1\frac{1}{4}:1$ side slopes were adopted. Proper compaction of embankments was also ensured. On Rajasthan Canal $1\frac{1}{2}:1$ side slopes were adopted upto mile 18 and 2:1 afterwards. Better understanding of principles of soil mechanics and need for economic lining has changed the concept of new design of linings. It is now considered that the banks of the canal supporting the lining should be properly designed and constructed on the basis of modern principles of soil mechanics so that no pressure is exerted over the lining. Drainage filters and relief valves should be provided, where-ever, necessary to relieve the lining from external hydraulic pressures. The lining, should, moreover, be designed to resist compressive and tensile stresses caused by temperature and hydraulic pressures. It should be strong enough to with stand abrasion, disintegration, wetting and drying etc. Generally the thickness of the lining is decided to make it impervious against the high head of water in the canal.

Etchevery (46) had worked out the following thickness of concrete lining corresponding to various depths, of canals, on the basis of coulomb's theory of earth pressures (caused by dry earth), these are shown in table No.1 below:-

Table No.1

Side slope of canal	Angle of repose of earth	Maximum depth of canal in feet							
		No surcharge & thickness of lining of				Max.surcharge & the thickness of lining of			
		1"	2"	3"	6"	1"	2"	3"	6"
$\frac{1}{2}$:1	1:1	5.3	10.6	16.0	32.0	1.6	3.3	5.0	10.0
"	$1\frac{1}{2}$:1	1.6	3.2	4.8	9.6	0.6	1.2	1.8	3.6
"	2:1	1.0	2.0	3.0	6.0	0.4	0.8	1.2	2.4
"	3:1	0.5	1.1	1.6	3.2	0.3	0.6	0.9	1.8
1:1	1.5:1	15.8	31.6	47.5	94.8	4.8	9.7	14.5	29.0
"	2:1	3.8	7.7	11.5	23.0	1.9	3.8	5.7	11.4
"	3:1	1.9	3.8	5.7	11.4	0.8	1.7	2.5	5.0
1.5:1	2:1	37.0	74.0	111.0	222.0	11.3	22.6	24.0	68.0
"	3:1	6.2	12.4	8.6	17.2	2.5	5.1	7.6	15.2

It was specified that the thickness required would be much more if provision has to be made for external hyrdaulic pressures.

Figure No.1 shows the thickness of lining for concrete, reinforced concrete, gunited and asphalt concrete linings ~~for concrete,~~ as adopted in America. Abrasive action of silt, unusual were etc. would also need additional thickness.

Thickness of concrete lining as specified by I.S.I. are given in the table No.2 below:-

Table No.2

Canal capacity m^3/s	Thickness of M-150 concrete, cm.		Thickness of M-100 concrete cm.	
	controlled	Ordinary	Controlled	Ordinary
0 to less than 5	5.0	6.5	7.5	7.5
5 to less than 15	6.5	6.5	7.5	7.5
15 to less than 50	8.0	9.0	10.0	10.0
50 to less than 100	9.0	10.0	12.5	12.5
100 and above	[illegible]	[illegible]	[illegible]	[illegible]

Thicker lining would be necessary for surface deterioration in freezing climate, uplift of floor, over turning of side slopes and other forces.

Thickness of plaster for tile lining v/s head of water:-

Generally double tile lining (total thickness 5¼"), with 5/8" thick 1:3 cement sand mortar (sand-witched) had been used both on side slopes as well as in bed irrespective of the size of the canal and its full supply depth. On Rajasthan Canal, single tile lining(total thickness 3-1/8") with ¾" thick plaster is being adopted in bed for F.S.Depth varying from 15 to 21ft. In case of canals lined with concrete different thickness of lining are specied for varying discharges as shown in table No.2. In case of tile lining, the property of imperviousness is controlled by 1:3 cement sand plaster. The minimum thickness of the plaster can be fixedto make it structurally safe against cracking due to temperature etc. The thickness of mortar required for different headsof water from permeability considerations would be discussed:-

Seepage losses in the laboratory:-

As reported by Central Board of Irrigation & Power (47) the seepage losses from various mortars are given in table No.3 below:-

Table No.3

Description	Water head	Losses in cusecs per 10^6 sq. ft.of wetted area
1/2" thick 1:6 C.S. mortar	10'	.12
1/2" " 1:5 " "	15'	.0037
1/2" " 1:3 " "	15'	.0006

Recent experiments conducted in laboratory on different types of specimen shows that the losses are much more as compared to above. Nazir Ahmed (13) has reported that the seepage losses per million square feet of wetted area from 1" thick 1:10, 1:6 and 1:3 cement sand plasters under 10 ft. head of water are 25 Cs. 15 cusecs and negligible resp. In case of 1/2" thick 1:3 cement sand plaster seepage losses per 10^6 sq.ft. of wetted area are .47 cusecs under 10 ft. head of water.

Seepage losses through 2 ft. x 2 ft. stab of 1" thick made of 1:3 cement sand mortar and cured for three weeks are given in table No.4 below:-

Table No.4

Water head in ft.	7.6	11.1	14.4	17.6	20.4	21.6	26.6	32.4	34.0
Seepage in cusecs per million sq.ft.	Nil	Nil	.22	.40	0.47	0.57	0.87	0.33	0.36

Results of tests performed on various specimen to find out the effect of replacement of cement by Surkhi are given in the ~~above~~ table No.5 and 6 below:-

Table No.5

Experiments performed in 6.0" dia. Cylinderical apparatus Thickness of mortar (1:3) 1/2" , percolation reduced to 20° C

S.No.	Water head in ft.	Percolation in cusecs per 10^6 Sq.ft.of area % replacement of cement by surkhi equal to			
		25	30	35	40
1	11.0	0.71	0.22	0.86	0.13
2	13.5	0.52	0.40	0.88	0.13
3	15.0	2.09	0.84	2.75	0.64
4	21.2	3.54	2.23	3.94	1.38
5	24.1	2.90	2.75	6.76	2.06
6	28.2	3.90	2.77	8.26	4.75

Table No.6

Experiments performed on 2'x2' specimen of 1/2" mortar (1:3) cured for month:-

S.No.	Water head in ft.	Seepage in cusec per million sq. ft. of area % replacement of cement by surkhi. 15	25
1	8.3	---	---
2	10.7	---	---
3	14.4	0.88	0.377
4	17.6	0.87	1.77
5	21.3	1.53	2.08
6	23.1	1.77	2.36
7	28.3	2.48	3.54
8	31.7	3.66	4.13
9	33.1	3.82	4.37

It is clear from the above results that head of water has marked influence on the rate of seepage .

Seepage losses in the field:-

Actual seepage losses in the field would also depend upon the permeability of the material forming the subgrade and other factors which vary considerably from one place to ahother. Table No.7 below shows the seepage losses from Bhakra Canal & Rajasthan Canal as observed on various sites. Complied from (9)

TABLE NO 7

Type of lining. 1	Description of site. 2	Head of water inft. 3	Seepage losses in Cs.per million sq.ft. of wetted area min.^{m} 4	max.^{m} 5.
Double tile lining	Bhakra Main Canal R.D. 1,70,000 to 3,34,000	Max.^{m} depth 18 ft.	0.341	.870

1.	2.	3.	4.	5.
Double tile lining	260'x75' tanks near R.D.11700 of Raj.Feeder	2.0	.0083	Average
Single " "			.0069	Average
Double " "	Tanks 260'x150' at R.D.89440 of		~~.0069~~ .36	~~Average~~ .595
Single " "	Raj.Feeder	14.58	.07	.3
Double " "	Tanks 125'x182' at R.D.242800		2.76	3.79
Single " "	of Raj.Feeder	21.0	0.88	1.64

These results also show that the head of water has marked influence on the rate of seepage.

If seepage losses upto 0.5 cusecs per 10^6 sq.ft.of wetted area are permissible under field tests (2.0 cusecs under field conditions) the folllowing conclusions can be drawn.

i) 5/8" thick 1:3 cement sand plaster in case of double tile lining is just sufficient for a head of 14 to 15 ft.of water.

ii) 3/4" thickness 1:3 cement sand plaster in case of single tile lining gives higher losses under a head of 21 ft. Therefore, 1" thick 1:3 cement sand mortar would be required for 21 ft. or slightly more head of water. For higher heads a thickness of more than 1" would be necessary.

iii) For heads lower than 15ft. it is possible to reduce the thickness of 1:3 plaster upto 1/2" or cement content of plaster can be decreased i.e. 1:4 or 1:5 cement sand mortar can be used.

Nazir Ahmed (13) has, however, recommended that the thickness of the impervious course should in no case be less than 3/4". For high heads up to 25ft. it will be perferable to use 1.0" thick plaster. Dr.Uppal recommends single tile lining with 3/4" mortar on bed and side slopes for all types of channels.

The thickness of the mortar as suggested would be applicable in case no additives are used to reduce the co-efficient of permeability of mortars. In case, additives are used it may be possible to reduce the thickness of the mortar if economy allows.

Embankment Design:-

It has been experienced that the lining of certain canals failed due to inadequate inner side slope of the canal. Therefore, it is now customary to keep the slopes flatter than the angle of the repose of the soil. On Rajasthan Canal a side slope of 2:1 has been adopted beyond mile 18. Generally a side slope of 2:1 would be safe in Rajasthan Canal. In specially heavy filling reaches it would be advisable to conduct shear tests to determine the shear parameters of the soil and banks should be designed by slip circle method for stability of slopes.

Types of shear tests to be performed depend on the type of soil as detailed below:-

(1) For in compressible fills with co-efficient of permeability more than 10^{-6} cm/sec., slow shear tests should be performed.

(2) For clayey soils, quick shear tests should be performed for stability computations immediately after construction.

(3) For compressible silts, stability computations should be based on the most unfavourable combination of slow and consolidated quick shear values compatible with the contemplated operation conditions:-

The values of angle of internal friction (ϕ) for different soils are given in table No.8 below as complied from (45)

Table No.8

Type of soil	Strata	shape	ϕ	Cot ϕ
Sand	Loose dry or moist	Round uniform	28.5°	1 in 1.8
"	"	Well graded angular	34°	1 in 1.45
"	Dense dry or moist	Round uniform	35°	1 in 1.43
"	"	Well graded angular	46°	1 in 0.97
"	Dense saturated	Round Uniform	33°	1 in 1.54
"	"	Well graded angular	44°	1 in 1.0
Silt & sandy silt	Loose	--	27° to 33°	1 in 1.96 to 1 in 1.7
"	Dense	--	30° to 35°	1 in 1.73 to 1 in 1.43
"	Consolidated quick test	--	17° to 22°	1 in 3.3 to 1 in 2.5

For stable banks of sandy and silty soils (neglecting co-hension in case of silty soils) angle of shear must be more than the angle of the slope.

It is generally considered that the upstream side slope can fail under sudden draw drawn conditions. This would, however, depend upon the type of fill material and its properties.
In actual practice draw down occures more or less gradually. The effects of draw down are discussed below:-

(1) If the material forming the bank is in-compressible with high permeability as that of course sand, the water draws out of the voids of the fill as rapidly as the level of the water drops

down inthe canal & there is no danger against failure due to draw down.

(2) In case the permeability of the in-compressible fill is low but draw down is associated with and followed by a decrease in the volume of the fill due to consolidation. Therefore, the effect on the properties of fill material is even more important during gradual draw down than after suddendraw down. It has been experienced that draw down failures are most common in case the bank material contains silty or mixtures of silt and sandy soils.

On Rajasthan Canal (in Rajasthan portion) the soil consists mostly of fine sand or fine sand silt mixtures. For sand silt mixtures it is desirable to design the inner slope under sudden draw down conditions. As compaction of soil is done to proctors maximum density it would be advisable to keep the side slopes as 2.5 : 1 in such reaches. In sandy reaches inner side slopes of 1.5 :1 or 1.75 : 1 would be sufficient. Keeping this in view a side slope of 2:1 has been adopted and the same would be sufficient in most of the reaches.

<u>Soil compaction:-</u>

To minimise settlement of banks, to reduce their permeability and to increase the stability (of banks) compaction of the embankment material is necessary. Compaction increases the density of the fill as well as shear perameters of the soil. On Rajasthan Canal, compaction is generally specified to achieve 90% of the optimum density obtained in the laboratory. U.S.B.R. specifies 95% of the standard density in case of clayey or silty soils at uniform optimum moisture. 6" compacted layers are desired. Co-hesionless & free draining soils are compacted ~~xxxxxxxxxxxxxxxx~~ to 70% relative density. Compaction in 6" layers is desired in case rollers or tampers are used and in12" layers if tractors tread or other vibrating equipment are used.

C.L.Dhawan and J.C.Bohri (34) are of the opinion that soil should be compacted upto stable density and a density higher than 1.65 is not necessary for canal embankments of 20 to 25 ft. height. The arguments put forth by them are as under:-

(1) In case of canals, permeability and settlement are the main considerations. Shearing strength and bearing capacity are not important as the canal embankments are subjected to lesser loads.

(2) For normal soils, under lighter loads, more moisture is required to attain stable density. With increase in moisture of the fill, there is saving in the compaction effort.

(3) With passage of time, soils compacted at higher densities have tendency to loose densities and therefore it is futile waste to compact the soil at higher density.

(4) By increasing the compacting effort from 15 blows to 25 blows, the max^{m} settlement can be reduced from 2.4% to 1.4%

While with 35 blows the settlement can be reduced to 0.9% By increasing the moisture content to obtain stable density, the settlement of the fill can practically be reduced to nil.

Considering the above facts in view, they have recommended that the stable density for any particular soil should be determined in the consolidation apparatus by imposing a load equivalent to the height of the embankment or the probable pressure to which the soil is subjected.

Four types of soil of the mechanical composition as given in table No.9 were tested. Stable densities as observed by them at different loads are given in table No.10.

Table No.9

Mechanical analysis of soils.

Sample No.	Clay particles below .002	Silt particles	Sand particles
1	18.4	17.6	64.0
2.	21.28	30.88	47.84
3.	24.4	43.52	32.08
4.	43.92	33.28	22.08

Table No.10

Stable Densities:-

Sample No.	%age of optimum moisture	Max^m density	Stable density at different leads:-							
			1/2 Ton.		1 Ton.		2 Ton		3 Ton	
			Mositure	Density	Moisture	Density	Moisture	Density	Moisture	Density
1.	12.0	1.865	15.4	1.78	14.3	1.82	14.7	1.86	14.0	1.8[illegible]
2.	14.6	1.765	19.3	1.65	18.0	1.72	12.5	1.775	13.8	1.8[illegible]
3.	18.4	1.72	21.7	1.615	20.4	1.65	19.6	1.68	19.7	1.6[illegible]
4.	15.6	1.805	25.6	1.485	21.3	1.533	23.9	1.572	12.9	1.62[illegible]

On Rajasthan Canal (in Rajasthan portion) the soil consists mostly of fine sand or fine sand silt mixtures. In few reaches soil certain clay particles but the percentage of clay is generally less than 20%, Even as per Dhawan there is partically no difference between stable density and optimum density. It would, however, be advisable to compact such types of soils at 2 to 3% more moisture than optimum.

Holtz (18) has reported that in case of silty soils there is a loss of density with passage of time. The loss of density is more noticeable in the top 6" to 12" layers. In case of Rajasthan Canal as the sub-grade is covered by the lining there would be no loss of density. Hence shearing strength would not be practically effected with the passage of time. To avoid failure due to draw down conditions it would be advisable to compact silty types of soils to the maximum possible extent.

External hydraulic pressure on canal lining:-

External hydraulic pressure on the canal lining may be due to:-

a) High sub-soil water above the bed of the canal.

b) Differential heads on the lining in draw down conditions.

c) Saturation of the back fill due to rain water.

It has been experienced that a lining designed to counteract the external pressure by its flextural strength would be very costly. In case the lining is designed to counteract a part of the external hydraulic pressure the possibility of its failure still remains there.

It is, therefore, adviseable to study the cases where external hydraulic pressure acts under the lining and the ways and means to counteract be same.

a) High sub-soil area:-

In reaches where canal passes through a high sub-soil area, the measures as detailed below can be adopted to safe gaurd against the uplift pressure.

1) Depth of the canal can be reduced so as to keep the bed of the canal above the water table if possible or as little below the bed of the canal as possible.

2) Certain depth of the water can be maintained in the canal by constructing humps or regulators to counter balance the extra hyraulic pressure.

XX XXXXXX

3) By providing drainage arrangements and pressure relief valves in the bed as well as on sides of the canals.

b) <u>Due to differential head on the lining:-</u>

In case the soil of the bank is 80% or more sand, no differential head is likely to be exerted on the lining. This is due to the fact that the permeability of the sand is high, water drains out of the voids of the fill almost as fast as the water level goes down.

In case the soil forming the bank is impervious, the entire water is practically retained by the fill and practically no differential head is exerted during draw down conditions.

Incase the soil forming the bank is semi-impervious (permeability co-eff. varying from 3 to 50 ft./years) differential head would be exerted on the lining and, therefore, remedial measures are necessary to safe guard the same.

c) Saturation of the bank fill due to rain water:-

Where the soil has poor drainability differential head may be exerted on the lining due to rainwater entering behind the lining. This causes the capillary moisture to become free and exert the pressure. Therefore, adequate surface drainage arrangements are necessary to prevent rain or flood waters to enter the fill.

<u>Drainage arrangements:-</u>

The following techniques can be adopted to provide an effective measure against the external hydraulic pressure.

i) <u>French drains:-</u> This system consists of transverse drains along the side slopes of the canal, discharging into the longitudinal drains at the junction of the sides and bed. A longitudinal drains along the centre line of the canal bed is also provided. The longitudinal drains empty into the canal through valves which open only when a differential head is exerted. These are made of opened jointed brick work, open jointed pipes or slotted pipes stranded with gravel to avoid clogging. The gravel is to be provided on the basis of filter design critereon.

ii) Continuous blanket:- It consists of 2 continuous layers of filter (one layer of 3" to 5" thick of course material underlain by a layer of 2" thick fine material. Three longitudinal drains two at junction of the bed and sides and one at centre line of the bed are provided.

iii) French drains plus continuous blanket:- This consists of system of french drain plus 3" layer of sand between transverse drains. This is commonly adopted because of economy and efficiency.

iv) Boulder pitching, porous concrete or brick pitching can also be used as drainage methods.

Disposal of the water collected from drains:-

This can be done in two ways:-

i) By continuous drainage out side the canal provided the level permits. This prevents the building of pressures behind lining.

ii) By providing flap valves at close intervals. This arrangement reduce the seepage loss but there is danger of pressure being built up in case the drains get checked.

Structual strength of lining:-

In India cement concrete lining of 2" thickness varying from 2" to 6" and mix proportions varying from 1:6:10 to 1:2:4 have been adopted on various canals. Double tile and single tile linings are also used on major canals. Different forces such as compressive, tensile pure, tensile in bending, shear, impact, torsion or twist etc. may be acting on the canal lining under field conditions. It is difficult to evaluate these forces and therefore, linings are designed on the basis of past experience and rule of thumbs.

In order to understand these forces and design different types of lining on the same uniform standard itis necessary to know the various types of strengths of the lining under varipus load conditions.

(1) Compressive stress - Compressive stresses are caused due to increase in length of lining block or rise in temperature or moisture.

(2) Tensile stresses are caused due to decrease in length of lining block on decrease in temperature or moisture.

(3) Flextural strength of lining comes into picture under the following conditions:-

a) Under draw down conditions due to external hydraulic forces.

b) Canal running with full supply discharge with settlement of sub-grade.

4) Punch shear:- Brick tile under which the sub-grade had settled is pushed down or in case of back pressures it is pulled outward.

5) Torsion or twist, impact etc. may be the other forces

Therefore, flextural, tensile and compressive strength are important to compare the different type of linings on the same standard. Punch shear may be important for brick lined canals.

In fact the question of testing the strength of lining came in picture when Dr.Uppal suggested to adopt single tile lining both on the bed as well as on side slopes of Rajasthan Canal. A decision to do single tile lining in bed of Rajasthan Canal was taken and the same is under execution. While, double tile lining on side slopes is still being adopted.

<u>Flextural strength:-</u>

Flextural strength of a test specimen is given by the following formula

$$R = \frac{M \times Y}{I}$$

Where R = Flextural strength in Lbs/sq.in.

M = Bending moment at failure load in in.-lbs.

I = Moment of Interia in(inches)^4

Y = Distance of the neutral axis from top in inches.

If the test piece is rectangular in shape of width = b" and depth = d", the formula can be written as

$$R = \frac{M \times \frac{d}{2}}{\frac{1}{12} bd^3}$$

$$\text{Or } R = \frac{6M}{bd^2}$$

Flextural strength of different type of concrete mixes are shown in table No.11.

Table No.11

Type of mix		Flextural strength in lbs/sq.in At 7 days	Permissible.
M(250)	1:1:2	375	112
M(200)	1:1½:3	335	100
M(150)	1:2:4	300	70
M(100)	1:3:6	240	42

Incomparision to above the flextural strength of lining blocks of single and double tile linings cut from Rajasthan Canal and Kankar lime block ffom GangCanal as reported by Uppal (26) are shown in table No.12 below:-

Table No.12

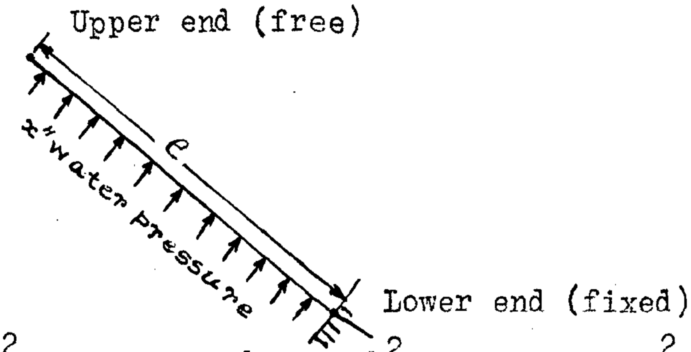
Type of lining	Sample from R.D.	Load applied on 1/3 points	Flextural strengh lbs./sq.in.
Single tile lining	232 of R.F.	On bed side	137.4
-do-	73-74 "	"	211.5
-do-	207 "	Top Side	58.9 broken on straight edge.
-do-	94-95 "	"	83.2
Double tile lining	166-67 "	On bed side	127.1
-do-	161-167"	"	116.4
-do-	165-166 "	Top Side	216.5
Bikaner Kankar	57-58 Gang Canal	"	69.0
Lime concrete	" " "	"	76.4

In another experiment few specimen of double tile lining, single tile lining with plaster ontop and single tile lining with plaster on bottom were tested under their own weight. It was observed that double tile lining and single tile lining with plaster on top failed at approximately 8.5 ft. span, while single tile lining with plaster on bottom failed at approximately 10.0 ft. span. Flextural strength of the lining specimen as worked out from the above formula are 101, 155 and 201 lbs./sq.in for the three specimen.

It would be thus clear that the flextural strength of single tile lining is better compared to double tile lining.

Flextural strength v/s external hydraulic pressure:-

It is generally presumed that the external hydraulic pressure acts under the lining onside slopes. This force is balanced by the sub-merged weight of the lining and its flextural strength. Part of the force resisted by the flextural strength of the lining can be calculated by treating the lining span as cantilever (lower end fixed and upper end free) and external pressure acting uniformely. (This is possible under sudden draw down conditions).



$$B.M. = \frac{W l^2}{2} \times 12 = \frac{x}{12} \times 62.5 \times l^2 \times 6 = 31.25 \times l^2 \text{ in lbs.}$$

$$\text{Resisting moment} = \frac{R\ b\ d^2}{6}$$

$$= \frac{100 \times 12 \times 5.25^2}{6} = 5500 \quad \text{(For double tile lining)}$$

$$= \frac{150 \times 12 \times 3.125^2}{6} = 2920 \text{ in lbs. (For single tile lining)}$$

Assuming R = 100 lbs./sq.in for Double tile lining

150 lbs/sq.in. for single tile lining.

By equating B.M. and resisting moments for various span lengths, value of x (external hydraulic pressure in inches) can be determined Table No.13 below shows the detailed calculations:-

Table No.13

Span of lining in ft.	Bending moment (in lbs.)	Values of x in inches	
		Double tile lining Col.2 = 5500	Single tile lining Col. 2 = 2920
10'	3125 x	1.76"	.94"
20'	12500 x	.44"	.23"
30'	28125 x	.20"	.10"
40'	50000 x	.11"	.06"
50'	78125 x	.07"	.04"

It is clear from the above that upto 10' ft. span (depth of the canal say 5 ft), tile linings are able to with stand external hydraulic pressures of more than 1" to 2" by their flextural strength. Beyond 10' span their resisting power due to flextural strength is negligible and the entire pressure would be resisted by its weight.

Flextural strength v/s water pressure:-

So long as the sub-grade is sound, no apperciable pressure is exerted on the lining. In case of settlement of the sub-grade, the flextural strength of lining would have to resist the water pressure as well as its own weight. The lining would actually behave as two way slab. However, for simplicity, the lining has been treated as ordinary slab and its resisting power for different depths of water is shown in the table No.14 below:-

Table No.14

Depth of water in canal	Bending of moment in inches-lbs. for		Span of lining in ft. at which failure is expected	
	Double tile lining	Single tile lining	Col.2 = 5500	Col.2=2920
1	2	3	4	5
5'	$545 \times l^2$	$515 \times l^2$	3.18	2.38
10'	$1015 \times l^2$	$985 \times l^2$	2.33	1.71
15'	$1500 \times l^2$	$1470 \times l^2$	1.91	1.41
20'	$1950 \times l^2$	$1920 \times l^2$	1.68	1.23
25'	$2420 \times l^2$	$2390 \times l^2$	1.5	1.1

It is clear from the above that neither double nor single tile linings would be able to with stand forces caused by the settlement of the sub-grade. It is, therefore, very clear that the sub-grade should be compacted uniformely and effectively so that there is no possibility of unequal settlements. In case sub-grade settles, the lining would crack and settle. Cracked linings are no better than unlined canals as for as seepage losses are concerned.

Due to settlement of the lining co-efficient of rugosity would increase. Full scale tests conducted by Uppal had provided that there is no settlement of the sub-grade under fully loaded condi--tions. However, the importance of uniform compaction is to be kept in view to avoid settlement.

Compressive strength:-

Compressive strength of various concrete mixes vary considerabaly. However, typical compressive strength are shown in table No.15.

Table No.15

Type of mix.	Cube strength lbs/sq.in.at 28 days	
	Lab.tests	Field tests
M250 (1:1:2)	4500	3500
M200 (1:1½:3)	3600	2800
M150 (1:2:4)	2800	2100
M100 (1:3:6)	1900	1400

Compressive strength of 8" and 6" square samples of single tile lining (3" to 4" thickness) and double tile lining (5" to 6" thickness) cut from the prototype lining are shown in Table No.16 below:-

Table No.16

S.No.	Type of lining	R.D.	compressive strength in lb/sq.in	
			When tested dry	When tested wet
1	Single tile lining	73-74 of R.F.	1119	961
2.	-do-	94-95 of R.F.	1772	1582
3.	Double tile lining	165-166 " "	607	594
4.	-do-	166-167 " "	676	633

~~Note~~:-

Note:- Compressive strengths of single tile lining are higher than double tile lining due to the fact that the thickness of single tile lining is 3" to 4" and that of double tile lining is 5" to 6" while the size of cube is 6" or 8" square.

Compressive strength of single tile lining is shown in Table No.17

Table No.17

S.No.	R.D.	Compressive strength Wet	When tested dry (lbs./sq.in)
1	94-95	1171	2776
2.	"	3371	1718
3.	"	1333	2161
4.	"	702	2419
5.	"	921	827
6.	"	---	1231
		7498 / 5	11132 / 6
	=	1500	1850

Compressive strength of single tile lining depends upon the compressive strength of brick tile which vary considerably. In one of the test series it was observed that compressive strength of 2" side cubes of brick tiles on various kilns of Sirhind Feeder varied from 1200 to 2500 lbs./sq.in average being 1200 lbs./sq.in.

On Rajasthan Canal in Rajasthan, compressive strength of tiles from various kilns from R.D.70 to 135 was observed to vary from 800 to 2500 lbs./sq. in. averaging to 1600 lbs./sq.inches.

Temperature stresses:-

Due to rise in temprature, compressive stresses are created in the lining block. If the co-efficient of expansion of concrete is $5x10^{-6}$ and modulus of elasticity $E=3x10^{6}$ psia, the compressive stresses due to 100^{o}F. rise in temperature would be $5x10^{-6}x3x10^{6}x100$= 1500 lbs./sq. Ordinarly good concrete would be able to resist these stresses.

For tile linings:-

$E = 5 \times 10^{5}$

$\alpha = 3x10^{-6}$

∴ Compressive stresses = $E \alpha t$

$= 5 \times 10^{5}x3x10^{-6}x100$ = 150 lbs./sq.inch.

Both single as well as double tile lining would be able to resist these stresses.

Due to fall in temprature tensile stresses are created. Average temperature of the lining laid in winter is 60^{o}F. and that in summer is 120^{o}F. Minimum temperature to which the lining can be subjected would be 40^{o}F.

Tensile stresses for linings laid in winter $= E \alpha t$

$= 5x10^{5}x3x10^{-6}x20$ = 30 lbs./sq.inch.

Tensile stresses for lining laid in summer $= 5x10^{5}x3x10^{-6}x80$ = 120 lbs./sq.inch.

The linings laid in winter are subjected to less tensile stresses than linings laid in summer. Therefore, lining laid in winter would crack less than the lining laid in summer. It has also been experienced at site that lining work done at site during winter season has lesser no. of cracks than work done in summer season.

Due to differential temperature on the top and bottom surface of the lining, the lining would be subjected to curling or warping. Exact theoritical analysis for the above is not possible and therefore it is presumed that factor of safety would bear these stresses.

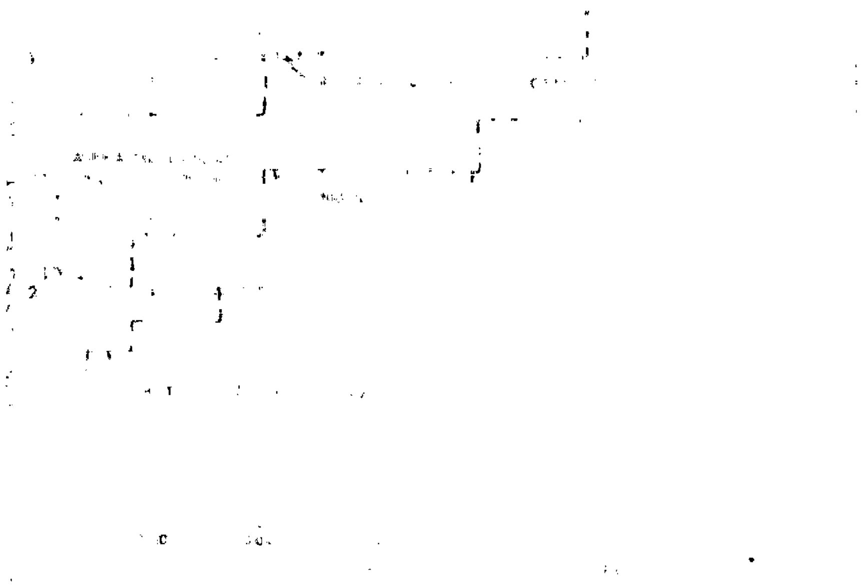
Conclusion:- The-oritical studies and practical tests have revealed the following important points:-

(1) Thicker linings designed for pressure can't be absolutely free from failure. It is, therefore, better to adopt cheaper type of linings and provide safety measures to counteract the forces.

(2) Uniform compaction ~~of~~ to achieve Max^m density is desirable so that sub-grade failures are minimised.

(3) Thickness of lining or cement plaster in case of double tile lining should be designed from the consideration of hydraulic head (hydraulic gradient).

(4) Earthen embankments should be designed on the basis of modern principles of soil mechanics so that the chances of its failure are minimised.



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C H A P T E R -6

TYPES OF LININGS.

CHAPTER 6

TYPES OF LININGS

Linings were generally classified on the basis of the lining materials used. These are now classified on the basis of design considerations involved in the various types of linings and can be grouped under three main sub-heads.

A) Exposed Lining.

a) Hard surface or rigid linings.

1) In situ concrete.

2) Precast concrete.

3) Gunited or shotcrete.

4) Lime concrete.

5) a) Hot mixed asphaltic concrete

b) Cold mixed asphaltic concrete.

6) Brick (Tile)

7) Stone masonry.

8) Soil cement.

b) Exposed Membrance Linings.

1) Prestressed flexible sheet

2) Asphalt macadam

3) Prefabricated asphaltic

4) Plastic and synthetic rubber

B) Burried membrane Linings.

1) Asphalt Membrance (hot-applied)

2) Prefabricated asphalt membrane

3) Plastic Membrane

4) Bentonite membrane

C) Earth Linings

1) Thick compacted earth

2) Thin compacted earth

3) Loosely placed earth blanket

4) Bentonite soil mixture

5) Soil sealants.

Various types of linings, materials used fortheir construction and methods of construction are described briefly in this chapter. Suitability of these types of linings under different conditions has also been discussed. Examples of important linings constructed in India and America are also given.

A (a) Rigid type of Linings:-

Hydraulic and sturctural design considerations for these types of linings have already been discussed. In this chapter various constructional aspects of these types of linings are described.

1) In situ concrete Linings:-

As the name implies these are so called because these are cast in situ. Depending upon the availability of labour, machinery and economy any of the following methods can be adopted for placing concrete:-

i) Hand placing:- Where cheap labour is available as in case of India, placing the concrete and screeding is done by hand.

ii) Mechanical screeding:- For large size of canals the operation of placing the lining takes sufficient time. Screeding of concrete by hand in such cases imposes a great problem. Therefore, to save time mechanical screeding is adopted.

iii) Sub-grade guided slip forms:- With the rise in cost of living and to improve the efficiency of construction placing and screeding of concrete by mechanical means is adopted. In United States of Amercia slip forms supported directly on the sub- grade operating longitudinally along it are used for moderately large canals.

iv) Rail guided slip forms:- In order to effect economy slip forms supported on Rails placed on berms of canal are used for laying concrete incase of large canals.

Mix proportions:- Design of mix should be done as per I.S.S., depending upon the strength and slump required. Use of air entrining agents improve the durability of the lining.

Care in construction:- Proper sub-grade as in case of tile lining is also essential for this type of lining. Sub grade should be moistened 24 hours before laying to ensure penetration of water to a depth of 6 inches. Good finishing of concrete surface using long handled steel trowel is desired. In India curing is started by covering the concrete with gunny bags and watering by cans or mushaks a few hours after concreting. This should be continued for 28 days. Better curing can be done by sprinkling water from a perforated pipe fed from an over-head tank. In bed curing is done by allowing 6" depth of water in bed in between earthen bunds for 2 to 3 months. ____________________

______________. In Amercia curing compounds are used:-

Reinforcement:-

Due to volume change caused by decrease in temperature or moisture, shrinkage cracks are usual in concrete. Provision of reinforcement steel upto 0.25 to 0.3 percent of the area of concrete reduces the width of these cracks thereby minimising the seepage. Theoritically, the maximum amount of steel necessary to hold the edges of cracks ~~xx~~ tightly together would be that required at a crack in the longitudinal centre of the slab to over-come the external frictional force developed between the slab and sub-grade as each half tends to shorten during any volume change.

This is expressed in the formula.

$$A = \frac{FWL}{2 \times S}$$

Where a= area in sq. inch of steel per feet of width in the direction in which L is measured.

L= Distance in feet between free longitudinal joints where computing transverse steel or between free transverse joints when computing longitudinal steel.

W= Weight of concrete slab in lbs. per sft. plus weight of water per sft. in the Canal.

F= Co-efficient of friction between slab and sub-grade (1.5 to 2.0 for average conditions).

S= Allowable working stress in steel (usually 1/2 x ultimate strength of steel)

Max^m 20 ft. length of slab is adopted to prevent excessive opening at the joint. Reinforcement should be broken at the joints.

Expansion and contraction joints:-

Due to rise in temperature, compressive stresses are produced in concrete. If α =. 000005, E = 3×10^6 lbs/sq. in, then with 100° F rise in temp. 1500 lbs/sq. in compressive stresses are produced. These can be resisted by good concrete even without expansion joints. Concrete dries out shortly after placing resulting reduction inlength. Tensile stresses produced cause cracks in concrete. These stresses produced are of two kinds:-

i) Those caused by a decrese in temperature or moisture, Simple tensile stresses are produced which can be computed.

ii) Those cause by differential variation between the upper and lower edges. of the slab. This results in curling and warping o-f slabs. Formulae for computation of these stresses are yet to be investigated.

The later is the major factor which causes working stresses in Canal lining. Cracking can be minimised by the following.

1) By providing re-inforcing steel.
2) By making grooves to a depth of about 1/3 of the thickness of the slabs at proper spacing both transversely and longitudinally.

As per I.S.:- 3873 - 1966 clauses 6.2.1" where lining operations are continuous, transverse grooves or longitudinal and transverse grooves both in cases of concrete lined canals with perimeter more than 10m shall be formed as shown in Figure in accordance with Table given.

Table:- Contraction joint spacing.

t mm	b mm	c mm	Approx. Groove spacing centre to centre m
50	8	17	3
65	8	20	3
75 ad 80	11	27	4 to 5
90	11	30	4 to 5
100 ad more	11	33	4 to 5

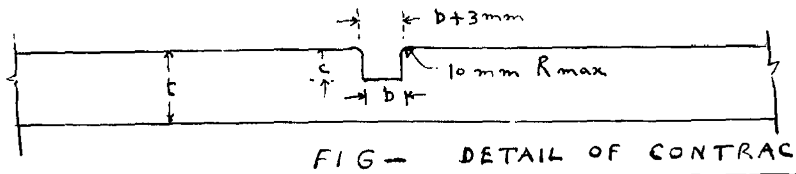


FIG – DETAIL OF CONTRACTION JOINT

Allowable tolerance on b and c shall be ± 1.5 mm. When lining is cast in panels not more than 3 m, faces of previously placed concrete shall be painted with a sealing compound to assure that no bonding takes place. Provision of grooves is not necessary in this case.

In situ sleepers in case of bed and precast in case of sides shall be provided under the joints. The sleepers shall be 20 mm cm. wide and 10 cm. deep in case of Canals with capacity more then $15m^3/S$ or less. The sleepers shall be of the same grade as for lining and should be placed under the joint.

Joint fillers:- Fillers should be water tight for given heads, stable over the temperature range, fairly plastic, durable and economical. It should permit, without fracture or failure of its adhesion with concrete, the slow movement set up by expansion and contraction of joints.

In Amercia semi liquid compound consisting of powdered ashalt short fibred asbestos, diatomaceous earth and powdered lime stone with asphaltic flux oil and plasticizer are used. In India hot pour expansion jointing compound of Shalimer Tar product is recommended for use.

Examples of in Situ concrete Linings in India.

Name of Project or Canal.	Specification employed	Length in miles
Tungabhadra Project Low Level Canal.	3" thick 1:6:10 concrete in bed 3" to 4" thick 1:4:7 concreteon sides	13.5
Kurnool Branch canal	3" thick 1:6:10 concrete in bed 3" to 4½" thick 1:4;7 concrete on sides	10.25
Left Bank Main Canal	4" thick 1:6:10 concretein bed 4" thick 1:6:10 concrete on sides	62.0

Kurnool Cuddapah Canal Project	4" thick 1:4:8 concrete in bed 4" thick 1:4:8 concrete on sides	74.7
Lower Bhawani Project Distributaries.	$2\frac{1}{2}$" thick 1:4:7 concrete	14.0
Santhur Project Main Canal.	3" thick 1:6:10 concrete in bed 3" thick 1:4:7 concrete on sides	8.1
Nangal Hydel Channel.	5" thick 1:2:4 concrete in bed 6" thick 1:2:4 concrete on sides	2.0
	5" thick 1:3:6 concretein bed 6" thick 1:3:6 concrete on sides	27.0

Examples of some Amercian Canals (Un-reinforced concrete Linings:-

Name & location	Capacity (Cs.)	Side slopes	Thickness inches.
1) Delta Mendota Canal Central Valley Project	399	$1\frac{1}{2}$:1	4"
2) Friant Kern ~~Central~~ Central Valley Project.	4000 to 5000	$1\frac{1}{4}$:1	$3\frac{1}{2}$"
3) Ceochella Canal Bonlder Canyon Project.	425 to 625	$1\frac{1}{2}$:1	$3\frac{1}{2}$"

2) Precast concrete Linings:- Precast concrete slabs are cast in in factory by machines under controlled conditions, therefore, these have more strength for the equivalent thickness. Quality control of raw materials, proportioning, grading, mixing and casting can be effectively done with less skilled labour. Finishing with plaster & and form work are not necessary. It is easy to repair and less costly for small canals. Various types of joints are possible.

On the other hand slow progress, unsuitability for curves being casted flat and rectangular and difficulty in handling large size slabs limits its use.

Where the slabs are required in small quantity, these are casted by hand in steel or timber moulds. 1:3:6 concrete is generally used. Normal size of slabs for manual handling is 10"x20"x2" or 2½".

Laying:- The precast slabs are laid directly over the sub-grade, the joints are sealed with cement mortar of dry consistency and properly packed to eliminate shrinkage. Expansion joints are provided at regular intervals of 12 to 16 ft. Details showing the constructional procedure of Rosa-cometta slabs are at figure 1 ,

Examples:- 1:3:6 cement concrete precast slabs size varying from 24x15" to 24x24" were used on Tungabadhra Canals.

Recently on Yamuna Hydro Electric Scheme Stage I, 12"x12"x2" precast concrete tiles have been used over flat bricks, Sandwit-ched in between ½" thick mortar on sides of Power Channel with 7000 Cs. discharge.

Amercian experience:- In U.S. Precast slabs have been used to a large scale for lining small drainage ditches. Some of the examples of large canals are tabulated below:-

Year	Name of Project	Length	Size of slabs.
1940-41	Branch Canals on Yuma Project.	6 Miles	4'x6'x1½" reinforced with 3/8" dia. bars in each of two ribs on the underside.
---	Carls bed Project.	--	3"x12"x18" and 3"x12"x9"
1910	Hill side Canal On Tietan Project	10 Miles	4" thick x24" long cast in metal forms curved to 8 ft. dia.
1946	Branch Canal of Yakima Project	400 ft.	a) 2'x2'x2½" b) 2'x8"x2½"
	--do--	---	8"x24"x2" curves left unlined and grounted later.

Blocks with special shapes have been used on various Canals inJapan in preference to stone and concrete linings. The details are given in an article 'Lining of Canal in Japan' in the third Congress on Irrigation and Drainage 1957'. (20)

3) <u>Shotcrete Lining:-</u>

It usually consists of 1½" to 2" thick layer of cement sand mortar applied by means of airjet at 30 to 50 lbs/sq. in. Maximum size of sand used is 3/8", however, for finish coats ¼" maximum size should be used. Sand must contain moisture varying from 4 to 8%. Dry sand does not hydrate properly while wet tends to clog the equipment. Before placing in machine cement and sand should be thoroughly mixed. 3 gallons of water per cwt. of cement is added.

No reinforcement is generally provided, however, the same can be provided in the form of wire gauge of 12 gauge.

Grooves of ½" depth are provided at 6 to 12 ft. intervals. Joints are not provided as cracks can be repaired with cement gun.

This type of lining can be used on irregular sub-grades such as rocky formation. Due to small size of equipment it is also suitable for small and scattered jobs. Because of smaller thickness it is more useful for small Canals. And at places of mild climates. Due to difficulty of placing in uniform thickness it is liable to fail where the thickness is less than specified.

<u>Examples:-</u> Eleven miles of Tigra Canal in Madhya Pradesh were lined by guniting in 1934-45. The lining is still in good condition.

A list of some shotcrete lining works inAmerica are given in the table:-

Year	Project.	Capacity (Cusecs)	Thickness (inches)	Remarks
1941	New Briar Canal	350 to 700	1½	Reinforced

1945	Gila Canal laterals	14 to 70	1½	Reinforced.
1946	Pasco Pump laterals	15	2	Unreinforced.
1946	Pasco Pump laterals	5 to 15	1½	Unreinforced.
1946	Yuma Mesa laterals.	15 to 60	1½	Reinforced.
1946	'A' & 'B' laterals			
	'Gila'.	15 to 60	1½	Reinforced.
1950	Fort Summer	20	1½	Unreinforced.
1950	Fort summer	80 to 100	--	-----

4. Hydraulic lime concrete linings:-

Bikaner Canal was the first major Canal in the India which was lined in 1925 to conserve water. Due to availability of Kankar on the alignment, Kankar lime concrete of proportion 1:1:6 was adopted. Kankar was burnt in Kilns at every 5 miles to get lime. The same Kankar was used as coarse aggregate as well as sand also. The designed capacity of Bikaner Canal was 2144 Cusecs. with 8 ft. as F.S.D., side slopes as 1:1 and free-board 1 ft. The section was raised subsequently.

Concrete slabs 44x44 ft. and 22x13 ft. were casted at site in bed and sides respectively V and Y shaped pieces 6" long the former being 1" wide at top and ¼" wide at bottom were used for providing joints.

Recent experiments in India as well as in America have proved that lime or lime cement as binding agent has very poor compressive strength, high permeability, less resistance to cracking and disintegrates with less than 10 cycles of freezing and thawing.

5. Asphaltic concrete:-

The most important advantage of this type of lining is the plastic property which enables the lining to adjust to sub grade settlements. It can be laid in winter in extreme cold climates. It can be used for repair work. This type of lining is only suitable for small Canals.

It has less life than concrete lining. Velocities are limited to 5 ft. per sec. Resistance to hydrostatic or soil pressure is insufficient. Due to dark colour and plasiticity, more heat, light, air and water impedes resulting in weed growth.

Weed growth can be prevented.

a) by increasing the density of Lining:- It has been found experimentally that denser lining (with less than 3% voids prevents weed grouth more than lighter lining with high percentage of stone.

b) By applying soil sterilizer.

Sodium Chlorate is the strongest soil sterilizer more so far killing underground parts of plants. 5% sodium in water at 2 liter 5 per square meter is generally applied. To avoid leaking under open revetment, 200 gm. per square meter of a mixture of 10 parts borax and 4 parts sodium chlorate (by weight) are spread and then fogged with water.

Petroleum products such as Diesel fuel or gas oil can be used with 3 to 5% of any of the following phytocidal chemicals is spread at 1 liter per square meter and soil left undisturbed for 4 days.

a) Pentachlorophenol.

b) 2, 4 dichloro phenoxy acet-ic acid (hormone product),

c) 2, 4 dinitro butylphenol.

d) dinitro ortho-cresol (DNOC)

Injection of D.D. are carried out at 40 cm.

intervals to a depth of 3.0 cms. for plants with long routes.

Hot mix asphaltic concrete:-

Design of Mix:- Asphaltic concrete or sheet asphalt as per typical grading shown in the following table are generally used as criterea for design of mix.

a) Asphaltic concrete

Passing A.S.T.M. Sieve	1" grading	½" grading	¼" grading
1"	100%	--	--
3/4"	80%	--	--
1/2"	60%	100%	--
1/4"	46%	77%	100%
NO 10	33%	57%	75%
NO 40	17%	33%	45%
NO 80	12%	22%	30%
NO 200	5%	12%	15%
Bitumen in mix	5.5-7.5%	6.5-8.5%	7.5-9%

b) Sheet asphalt

Passing A.S.T.M. Sieve	
No 10	100%
NO 40	60-90%
NO 80	30-50%
NO 200	10-20%
Bitumen in mix	9-11%

Grade of bitumen from 30/40 (in hot climates) to 80/100 in cold climate is used. Both for Asphaltic concrete and sheet asphalt.

As design of mix involves trial and error, gradings are so chosen such that the void content of the final mix does not remain more than 4%. Filter may consists of cement, lime stone dust or dust of any other mineral such that 70% of it passes through seive No. 200.

<u>Process of mixing:-</u> The equipment such as mixer, aggregate boiler and bitumen boiler are used for mixing the concrete at site of work. The aggregate and bitumen are heated to a temperature of 180°C to 190°C and then are mixed. Batch mixer or continuous mixer can be adopted for mixing both being pug mills with the mixing blades mounted on twin shafts.

<u>Laying and compacting:-</u> The mix is taken by lorries, some times insulted, to the site and is then dumped ~~mixture~~ either on the steel plates for subsequent spreading by hand with showels rakes or into some form of mechanised spreader.

Compaction is done by roller ~~wit~~ with weight of 10 to 40 Kg. per cm. width. For hot mix on steep slopes the formation of hair cracks by the roller into the surface can be avoided by using a lighter roller for initial compaction. Experience with light rollers of 300 kg. weight indicates that this type of equipment can be satisfactorily used.

Normally asphalt lining is laid continuosly without joints but in case of loose sandy soil laying in alternate layers is prefered. For joining near concrete with old one, the edge of cold concrete should be cut to an ~~angel~~ angle of 45° and primed with pure hot bitumen before the laying of new layer.

A seal coat of cut back bitumen if laid will fill all the pores.

<u>Drainage:-</u> The drainage behind asphaltic linings is very important factor. These linings are very sensitive to up-lift against hydrostatic pressure being plastic.

<u>Examples:-</u> This type of lining has not been used on the Canals of India. Examples of some of the Amercian Canals where this has been used are given below:-

Examples of some Amercian Canals:-

Name of Canal or Project.	Type of Lining	Average capacity C.F.S.	Average thick. ness of lining	Total length in miles	Date of install-ation.
Pasco Pump laterals & sub-laterals (Columbia Basin Project)	Asphaltic concrete	3-96	2 inches	11.2	1947
Ygnacio Canal Central Valley Project.	-do-	9-30	2 inches 6" edge.	4.2	1947-48
Wyoming Canal & laterals-	-do-	10-45	2 inches	15.65	1951

6. Brick (tile) Lining:- In India this type of lining is largely being used specially in the regions where other suitable materials are not available. This type of lining is being used on Rajasthan Canal. Detailed description have been given in a seperate chapter. In this type of lining cement plaster sand-witched or on the top serves as impermeable material while the brick or tile serves as skeleton.

Names of various canals where brick lining has been used are given below:-

Name of Canal	Description	Length in miles.
Sarda Canal	6" thick sandwitch mortar (two layers burnt tiles with cement mortar in between).	4.5
Nangal Hydel Channel.	5¾" thick sandwitch mortar two layers burnt tiles with cement mortar in between.	11.0
Bhakhra Main lime.	-do-	108
Narwana Branch	-do-	64
Sirhind Feeder.	-do-	53
Sadul Branch.	-do-	40.25
KaniSingh Branch.	-do-	9.0
Amar Singh Sub-Branch.	-do-	28.5
Ghaggar Sub-Branch.	-do-	8.0

7- Stone Linings:-

Stone lining is the oldest type of lining constructed. Mainly two types of linings have been constructed.

1) Rough stone linings.

2) Ashlar or stone masonry.

1) Rough stone lining:- In clayey soils which are impermeable, only protection to slope is necessary. Stone pitching has been used in these circumstances. The main draw back of stone lining is the doubtful durability and are therefore used where rough building stone and manual labour is available in abudance.

2) Ashlar or stone masonry:- Ashlar masonry type of lining was used in old days but because of high cost this has been given up entirely. Examples of rough stone lining and masonry linings used in Spain are given in table below. These have stood the taste of the time. Some of the linings have been repaired.

In India stone masonry in lime mortar has been used on Chambal Canals. On Tungbadhra Canals shahbad stone slabs 1½" to 2" were tried. But because of their high cost and less durability these were given up.

In Japan block type of masonry is now a days prefered because of less cost, more durability and better understanding of mechanies.

Year	Name of Canal	Type of lining.	Remarks.
1930	Henares Canal	Rough Stone on clayey soils	a) Where velocity is above 2^m/sec. erosion occures & is encourged by swelling of clay. b) Where vel. is between 1 to 2 meters/sec. formation of crest is noticed.

			c) Where vel. is less than 1 meter/sec. appreciable deposits of slim.
1740	Jarama Dike	Large rough stone on Gravel(soil with sand.	Repaired in 1953 with 15 mm concrete coating.
"	--do--	Lime stone with lime mortar in clayey sandy soils with chalky soil in some sections.	Repairs in1927 with coating of cement mortar & concrete coping.
"	--do--	Masonry lining on Chalky soil.	Abandoned in1953. Replaced by another portion with concrete walls.
1875	Henares Canal	Masonry lining & coping of lime stone picked ashlars in coglomerate soil with high proportion of small & clayey sand.	Only periodical clearing was necessary.
1580	Aranjuez Irrigations.	Masonry lining of clayey loamy soil.	----

8- Soil cement Lining:-

a. This type of lining has low resistance to erosion and is therefore adopted for small canals. In America two types of mixes are adopted.

1) Standard soil cement:- It has optimum moisture centent determined under Laboratory condition. Mixing is done at site and compacted by pneumatic or flat rollers.

2) Plastic soil cement:- On side slopes where compaction and mixing are difficult, plastic soil cement is used. It contains

more moisture and flows like concrete. Slip forms can be employed for its placing.

In India Standard soil cement is used. The details of design and construction are narrated below.

1) <u>Grading of soil:-</u> The following specifications prepared by Central Board of Irrigation & Power for soil cement blocks can be used as guide for soil cement lining. Cement should be 5% by wright of dry soil.

Clay (below 0.002 mm) 8 to 15% (by weight)

Silt (.002 to.02 mm) 12 to 25% (by weight)

Sand (.02 to 2.0 mm) 60 to 80% (by weight)

Where natural soil confirming to the above specifications are not available blended soils with the following specifications can be adopted:-

Plasticity index = 8.5 to 12.0

Sand content $\nless$ 35% by weight.

PH value = 8.5 to 12.0

Organic matter $\ngtr$ 1%

As per American practice following gradation should be adopted.

Maxm. particle size =3" - should not remain more than 5% on 3" sieve.

Passing NO 4 ASTM sieve = minimum 40% (preferbly should not retain more than 45%)

Passing NO 40 ASTM sieve = 15 to 100%

" 100 " " = Not more than 50%

Liquid limit $\ngtr$ 40

Plasticity index $\ngtr$ 18

Through compaction of sub-grade is essential. Loose pockets should be filled with selected material in layers of not more than 6" and compacted.

Soil used as Lining material should be crushed and sieved while in 'watter' conditions such that 80% pass the NO 4 sieve .

Soil should be added with calculated quantity of water to bring its moisture content to optimum. Consideration for evaporation and absorption losses should be taken into account. After over night absorption of moisture cement should be added and mixed thoroughly by hand or pug mill.

In India soil cement is placed carried to site and placed by hand labour. Compaction is done by pneumetic or flat rollers.

For 7 days curing is done by spreading 2" of soil straw or gunny bags and kept wet as necessary. 28 days curing is done by sprinkling water.

Examples:-

Name of Project Length.	Specifications:
Jagadhri Tub-well 3 miles.	4-1/8" thick soil cement (with 5% cement) in bed and sides. Wearing coat of 1:2 cement sand mix.
Krishanasagar Project Shimsa Branch Channel of Visvesvaraya Canal } Short lengths.	6" thick soil cement.
W.C. Austin Project Okalahana.	4" to 6" thick soil cement gradation -100% passing ASTM sieve No 4 & 60% passing ASTM NO. 200 10%-12% cement instandard mix 18% cement in plastic mix.

Exposed membrane linings:-

These types of linings are generally under experimental stage. In India these have not been considered owing to their high cost. With the advancement in Industry and necessity of linings old canals in operation condition may force the adoption of this type of lining in future.

a) Plastic linings:- Plastic membrances have low resistance to puncture. On exposure these are liable to disintegerate. Thicker membrances are more costly. Experiments are being conducted.

b) Prefabricated asphaltic membrane:- Prefabricated asphaltic sheet 1/2" or more in thickness can be used as lining. On one of the Bureau Canals this type of lining has been used to satisfactory line the canal in running conditions. Canal 30 feet wide, with 3½ to 4¼ depth of water and 1 to 3.0 ft/sec velocity was tried with 1/2" thick asphaltic membrane. Prefabricated panels were allowed to drop in from both ends and pulled by means of barges. Centre joint was sealed with mastic. The process of sealing is yet under improvement. A hot melt asphalt appeared best. Use of large air driven stopler have been advised for sticking the pannels. Prefabricated lining can also consist of tiles $85^{cm} x 80^{cm} x 2.5^{cm}$ with a booking of burlap extending 15 cms. ontwo adjacent tiles, are laid with joints filled by a blown bitumen containing 12% filler. The tiles are composed of asphaltic concrete containing about 12% bitumen 50/60 and the mineral aggregate graded from 1/8" max^{m} to 15% passing 200 mesh.

Asphalt macadams:- To make the Canal water-tight large quantity of asphalt is required hence it is costly. On exposure it shrinks and cracks are developed. Hence maintenance is also costly.

This has been used as cover material to asphaltic membrane on experimental basis to obtain impermeable lining. But its high cost compared to other earth cover materials limits it use.

Prestressed flexible sheets and synthetic rubber are also under experimental stage.

Burried Membrane linings:-

A The basic design considerations for Canal section are the same as that for unlined Canal. This is because a burried membrance lining essentially consists of an earth or earth cum gravel cover placed over the membrane. 2:1 side slopes are generally prefered but in no case it would be steeper than 1.75:1. For earth and gravel cover, cover thickness as determined by the following empirical formule should be adopted:-

$$\text{Cover thickness} = \frac{d}{10} + 10$$

Where d = depth in inches.

Similar to earth lining it has also the advantage of deffering the decision to line the Canal at a later stage without any extra cost. In fact after the excavation of Canal vulnerable reaches requiring lining can be determined effectively.

Actual construction procedure involves of the following operations:-

1) Over excavation of Canal section to a depth equal to the thickness of lining.

2) Finishing of the Canal section to a true section. The process is termed as dredging when done by dredger. It is called dressing when done by manual labour.

3) Smooth steel roller is also used to obtain satisfactory surface. Rolling is not required to increase the density of the sub-grade.

4) Where weed growth is a problem sub-grade is also treated with sterilant.

5) Laying of membrane is accomplished as detailed under various kinds of linings.

6) Protective cover consisting of earth or earth cum gravel is then laid over the top of gravel.

Depending upon the type of membrane used burried membrane lining are further classified as under:-

1) Asphalt Membrane (hot applied)
2) Prefabricated asphalt membrane.
3) Plastic membrane.
4) Bentonite membrane.

1) <u>Asphalt membrane (Hot applied).</u>

Catalytically blown asphalt cement prepared by the catalytic blowing treatment of asphaltic petroleum, conforming to the specifications shown in Table is used.

Essential requirement of material are:-

1) It should have high softening point to prevent sagging, flow down the canal on exposure.

2) It should be sufficiently plastic at operating temperatures to minimise rupture from earth movements.

3) It should not have cold flow ten-dencies to resist high hydraulic head.

<u>T A B L E.</u>

Description.	Type I	Type II.
Penetration grade.	50-60	55-70
Flash point (c.o.c)not less than	425°F	425°F
Softening point (R&B)	175°-200°	175°-200°
Penetration at 77°F, 100 grams, 5 seconds	50-60	55-70
Penetration 115°F, 50 grams 5 seconds, not more than 120	120	135

Ductility at 77°F,5 centimeters per minute not less than	3.5 cm.	3.5 cm.
Loss at 325°F, 5 hours not more than	1.00	1.00
Penetration of residue at 77°F,100 grams,5 seconds as compared to penetration before heating not less than	60%	60%
Bitumen (Soluble in carbon tetra chloride not less than)	97%	97%

Type I is used for all membrane construction and type II where more resistance to craking is required.

Membrane application:-

On the prepared sub-grade, water is sprinkled very lightly to prevent formation of holes. Catalytically blown asphalt of above specifications is heated to 400°F and is applied to sub-grade in three layers at 50 lbs. pressure through hand sprayers, or distributor with spray bars. 1.25 gallons to 2.0 gallons per sq. yard gives sufficiently impermeable membrane of 1/4 to 5/16 in thickness.

Precautions to be taken at the time of application:

1) Second or third coating should be applied immediately after the first as high softening point asphalt cools down rapidly.

2) To prevent freezing in hose pipes, spray bars should not be shut for more than 1 to 2 minutes at a time.

A canal in Wyoming with saturated and extremely unstable sub-grade was treated satisfactorily with asphaltic membrane after 25 years of running.

2) Prefabricated asphaltic membrane & plastic membrane:-

With advancement in industry prefabricated membrance are becoming more popular. These are manufactured under controlled conditions hence of better quality. Prefabricated asphaltic membrane of 1/8" to ½" thick material were generally manufactured. Experience on U.S.S.R. Projects indicates that minimum thickness of 3/16" to ¼" is desirable. Rolls of 30 ft. 3 ft. consisting of 4 to 5 kg. per sq. meter of blown bitumen on craft paper backing or reinforcing a layer of aluminium or fibre glass fabric coated on both side with blown bitumen to a total thickness of 3 mm. Polyvinl and polythene plastic films 60 ft. in width and 1000 ft. length have been manufactured. It has the following advantages over burried membrane (hot applied):-

1) No special equipment is required for laying these films.
2) Time required for laying these films is very much less.
3) Careful trimmin-g of Canal section is not necessary and due to extreme flexibility it will conform to the minor settlement in sub-grade surface.

Short term tests and artificial aging studies indicate that these type of linings will effectively control seepage. Long time test data is yet awaited as these linings are in use since recent period.

(3) Bentonite membrane:- 1½" to 2" thick layer of bentonite can be laid as membrane material. Bentonite consists of mostly clay mineral of montmorillonite group, which swells on wetting. This swelling property is mainly responsible for the seepage control. Earth or earth cum gravel cover is necessary to protect the membrane.

Examples:- These types of linings have not been used on Indian Canals. However, there appears to be a great scope for these types of linings in future works. Examples of some of important American Canals are given below:-

Name of Canal of Project.	Type of lining.	Average capacity C.F.S.	Average thick-ness of lining.	Total length in miles.	Date of installation
Laterals on Columbia Basin Project.	Burried -alt membrane	15 to 200	$\frac{1}{4}$"	-	1950-1951.
Riverton Project.					
Wyoming Canal & laterals.	-do-	25 to 566	$\frac{1}{4}$"	10.35	1951.
Pilot Canal	-do-	470	$\frac{1}{4}$"	4.6	1951
--do--	-do-	105 to 850	$\frac{1}{4}$"	7.6	1951.

THICK COMPACTED EARTH LINING.

It consists of a thick layer 1½ ft. to 3 ft. of selected graded soil containing sufficient fine material compacted on the bottom and sides of the canal section.

This type of lining can be adopted where suitable materials are available at site. It has the following advantages:

1. The section of Canal required for this type of lining is same as far unlined Canal. It can be done in the pervious reaches which require lining. Normally 1000 ft. length is taken as a unit due to compacting equipment and machinery.

2) It can resist several feet of ground water due to its weight ~~and bank stability because of its weight and flexibility~~ ~~3)~~ without proper drainage.

3) It is suitable over expansive clay sub-grades from uplift and bank stability because of its weight and flexibility.

4) Compaction of fill materials is not necessary, except, for high fills, as earth linings can with stand nominal movements.

DESIGN AND CONSTRUCTION CONSIDERATIONS.

a) Large Canals:- Where bed width of Canal is more than 28 ft, bed and ~~dies~~ sides can be compacted in 6" layers by rolling equipment. 2 ft. thick lining on bed and 6 ft. to 8 ft. thick as measured horizontally on sides is usually adopted. see fig 3.

b) Medium sized Canals:- Where bed width of Canal is 4 to 28 ft, 1 ft. to 2 ft. thick lining on bed and 3 to 6 ft. measured horizontally on sides is usually adopted. Compaction can be done by rolling equipment in horizontal layer. Some times layers on slope of 4 :1 are used.

c) Small laterals:- Where bed width is less than 4 ft. 1 ft. thick lining in bed and 3.0 ft. thick measured horizontally on sides is required. Some times overall bank sections are compacted as one full section and later on Canal section is cut.

Requirement for compaction fill under earth-lining depends upon:

1) Height of fill 2) Earth construction material.

3) Material of fill construction.

When Canal is constructed by excavating and hauling equipment in layers not more than 8" thick, additional compaction is seldom required for heights upto 20 ft. and 10 ft. for coarse and fine grained soils respectively. Where draglines are employed the safe heights are upto 50%. Above criterion can also be applied for upper reaches of high fills. Coarse grained soils are then classified as GW, GP, SW and S P, while fine grained soils are classified as ML. CL. CL. MH, CH and OH.

Materials:- Following tests are performed for the final selection of lining material.

1) Gradation and plasticity tests are performed to determine data on particle size and for liquid and plastic limits. The information is useful to determine suitability to erosion, detrimental shrinkage and expansion characteristics.

2) Compaction test determines the expected density at placement moisture. The information is useful for construction control and determination of permeability in the laboratory under similar condition.

3) Permeability tests determines the suitability with respect to seepage control.

4) Shear tests:- These are performed for deep channels or steep slopes to determine stability characteristice.

SUITABILITY OF MATERIALS.

Silty or sandy soil with plasticity index less than 7 are not suitable even for small Canals. Minimum plasticity index for large canals should be 10. Soils having liquid limit more than 50 are not suitable from stability consideration. Most suitabile soils in order of merit are as below:

1. GW - GC
2. G C
3. SW - SC
4. G M

Design consideration:- While designing the thickness ~~and~~ of ~~lin~~ lining it is kept in view that seepage losses are kept to 0.1 cubic ft. per square ft. per day and in exceptional cases even upto 0.2 cubic ft. per square ft.per day. Economic considerations regarding the availability of proper materials with reasonable distances, blending of materials and other site conditions play important role in the design of lining.

Construction Control. It has been generally found that with densities from 95 to 98% of laboratory maximum, lining is impermeable and stable. Hence rigid quality control is essential.

Estimated lift of lining is 60 years. Seepage losses in certain cases are found to be even less than concrete lining

SUITABILITY OF SOILS FOR THICK COMPACTED LINING.

TYPICAL NAMES OF SOIL GROUPS	GROUP SYMBOLS	SOIL PROPERTIES			SUITABILITY FOR CANALS	
		premiability	Shearing strength	Compacted density	Erosion resistance	Compacted earth linings.
1.	2.	3.	4.	5.	6.	7.
1. Well graded gravels, gravel-sand, mixtures, little or no fines	GW	14	15	15	2	---
2. Poorly graded gravels gravels-sand, mixtures little or no fines	GP	16	14	8	3	---
3. Silty gravels, poorly graded gravel sand clay silt mixture.	GM	12	10	12	5	6
4. Gravel with sand clay binder	GW-GC	8	13	16	1	1
5. Clayey gravels, poorly graded grave-sand clay mixture.	GC	6	8	11	4	2
6. Well graded sands, gravelly sands, little or no fines	SW	13	15	13	8	--
7. Poorly graded sands, gravely sands, little or no fines	SP	15	11	7	9 Course.	--

1.	2	3	4	5	6	7
8. Silty sands, poorly graded sand silt mixture	SM	11	9	10	10 Course	7 Erosion critical
9. Clayey sands, poorly graded sand-clay mixture	SC	5	7	9	7	4
10. Sand with clay binder	SW-SC	7	12	14	6	3
11. Inorganic silts and very fine sands, rock flour silty or clayey fine sands with slight plasticity	ML	10	5	5	--	8 Erosion critical
12. Inorganic clays of low to medium plascity, gravelly clays, sandy clays, silty clays, lean clays	CL	3	6	6	11	5
13. Organic silt & organic silt clays of low plasticity	OL	24	2	3	-	9 Erosion critical
14. Inorganic silt, micaceous or diatomaceous fine sandy or silty soils elastic silts	MH	9	3	2	--	--
15. Inorganic clays of high plasticity for clays	CH	1	4	4	12	10 volume change critical
16. Organic clays of medium						

to high plasticity, fat clays	OH	2	1	1	--	--
16. Peat & other highly organic soils	P	**				***

** Numbers above indicate the order of increasing values for the physical property named.

*** Numbers above indicate relative suitability (1=best)

Thin compacted lining:- As the name implies this type of lining consists of 6" to 1 ft. layer of thin compacted soil laid on bed and sides of Canal section. Due to high cost of compacting thin layer and the loss of density with time. it is not considered favourable except where funds are very limited.

The lining consisting of soil clay (impermeable even at densities less than optimum) covered with gravel may be suitable.

Loose earth blankets:- It consists of a blanket of loose earth of selected fined grained soil dumped on Canal bed and sides. This type of lining through cheap in cost is not suitable as permanent barrier. It can be used in emergency but shall have to be replaced by convential type of lining when the funds or the time permit the same.

Bentonite soil mixture:- Where sandy or gravelly soils without impermeable particles are available it may be feasible to mix bentonite on the sides and bed and compact the same. This type of lining is generally not found economical as hand mixing has to be adopted which is costly.

Soil sealants.

Seepage losses are generally observed to be much more in a newly constructed canal compared to an old canal with silted berms. In a Canal flowing with muddy water seepage losses are less than with clear water. This is due to natural deposition of silt or clay carried by flowing water. The same process is accomplished by adding sediments, bentonite or chemicals to the flowing water. Injection of these materials into leaky and pervious zones makes the Canal water tight. The important requirements of the sealing material are

1. It should remain stably dispersed and suspended in the water.
2. It should produce an adequate sealing in depth effect within the previous soil during percolation.
3. Sealing effect should be permanent.
4. It should not be harmful to irrigated land.

Trial and error procedures are essential to find out best sealing material under varying site conditions. This type of lining though yet in experimental stage might replace the conventional types of linings in future due to the following advantages.

1. Placement cost of this lining is very much less.
2. Sub grade preparations are not essential.
3. Hauling of materials i-s greatly reduced.
4. Time required for linings a Canal is negligible compared to conventional type of lining.
5. Can be suitable for lining old Canals, without closures.

Process of lining consists of the following stages:

1. Evaluation of site conditions under dry and normal flow conditions are necessary:

2. Selection of sediment:- Depending upon the local availability of material and keeping in view the essential

requirement of lining material, the material is chosen. High swell bentonite of various grades serves as all purpose lining material.

3) Final testing and planning:- This is accomplished by trial and error.

Bentonite concentration is usually set at 1%, viscosity being very close to that of water. Concentration of dispersand range from none for soft waters to 20% by weight of bentonite for hard waters.

1) 0.5 to 1.0 ft. of bentonites per sq. ft. of pervious wetted area is required :2) $\frac{1}{4}$ to 2 Ton per cubic ft. per second capacity per mile of Canal. (3) Volume of largest pond plus volume of estimated shrinkage in up stream sedimenting ponds.

(4) Installation procedures:-

The detailed construction procedures are beyond the scope However, basic information is summarised as below:-

(a) Presendimenting work required at each site consists of the following:

1) Release of water for sedimenting run.
2) Assembly of equipments and materials and construction of mud pit if necessary at the head of Canals.
3) Preliminary mixes of water sediment and dispersant to check the stability and to caliberate hydrometres.
4) Cleaning of water from Canal and water proofing of check structures.
5) Arrangement for mixing and water running crews.

(b) Mixing of sediment:

Mixing of sediment into the water can be done by multiple jet devices , compressed air jetting. After mixing slurry is kept in mud pit for retention and then diluted to concentration for sedimenting.

c) <u>Routing of sediment mixture:-</u> Where structures are closely spaced ponding under low flow conditions and where structures are spaced at distances full flow procedures are adopted. Care is to be taken that sufficient ponding time is given to secure good sealing in depth effect.

d) <u>~~RxxRk~~ Follow up phase:-</u>

After completion of sedimenting run the ~~filling~~ following courses of action are taken.

1) Clear water after drives run if penetration seems to be a problem.

2) Canal is allowed to dry if penetration is achieved but sealing is a problem.

3) Normal deliveries of irrigation water are also resumed depending upon the site conditions.

<u>Chemical sealants</u> Such as vesinous polymer with heavy atmos, petroleum emulsion, cationic asphalt emulsion etc. are also used. It must be ascertained that these are nontoxic to human, animal and crops.

<u>Soil stabilization:</u>

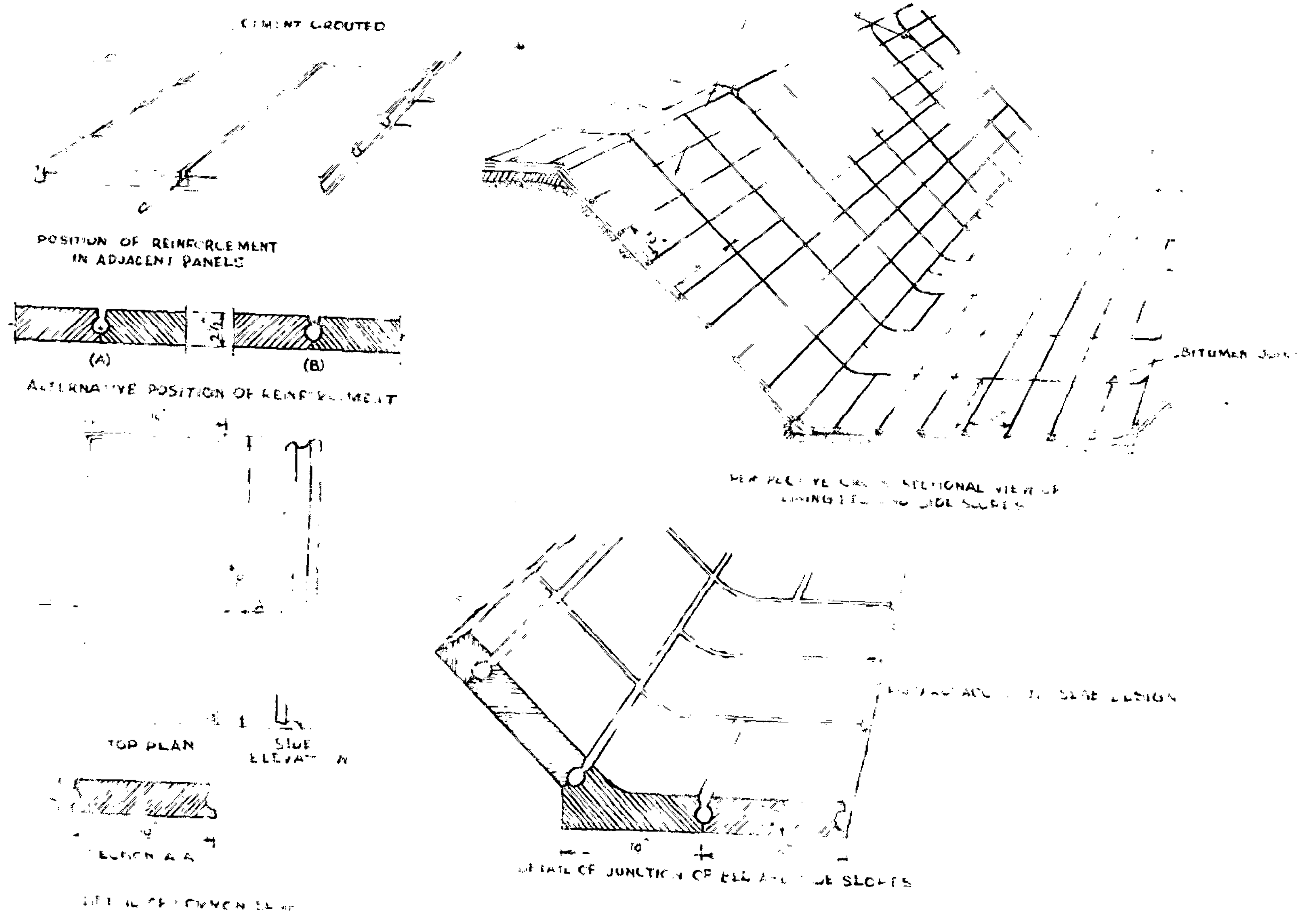
According to G.T.Dadeyev (21) "Experimental investigations effected under laboratory, field and operation conditions have proved that by stabilizing of soils of natural texture emplaced into the embankment ~~x~~ the ~~xxxxxx~~ filteration passages are disrupted and the soil porosity at a depth of 1 -1.5 meters is reduced, this leads to a decrease in filteration losses of water from canals with earth bed from 15 to 20 times. Stabilization of soils is accomplished by impact and vibrational action of machines.

Machines have been designed for construction of canal by punching with an elemination of excavation both in soils of natural texture and in soils placed in side slopes."

<u>Examples of earth linings:-</u> Earth linings have not been tried as such in India. Indirectly compaction of banks behind regid type of lining also serve as thick compacted earth lining. There is a great scope for this type of lining to be tried on Indian Canals. Examples of some of America Canals are given below.

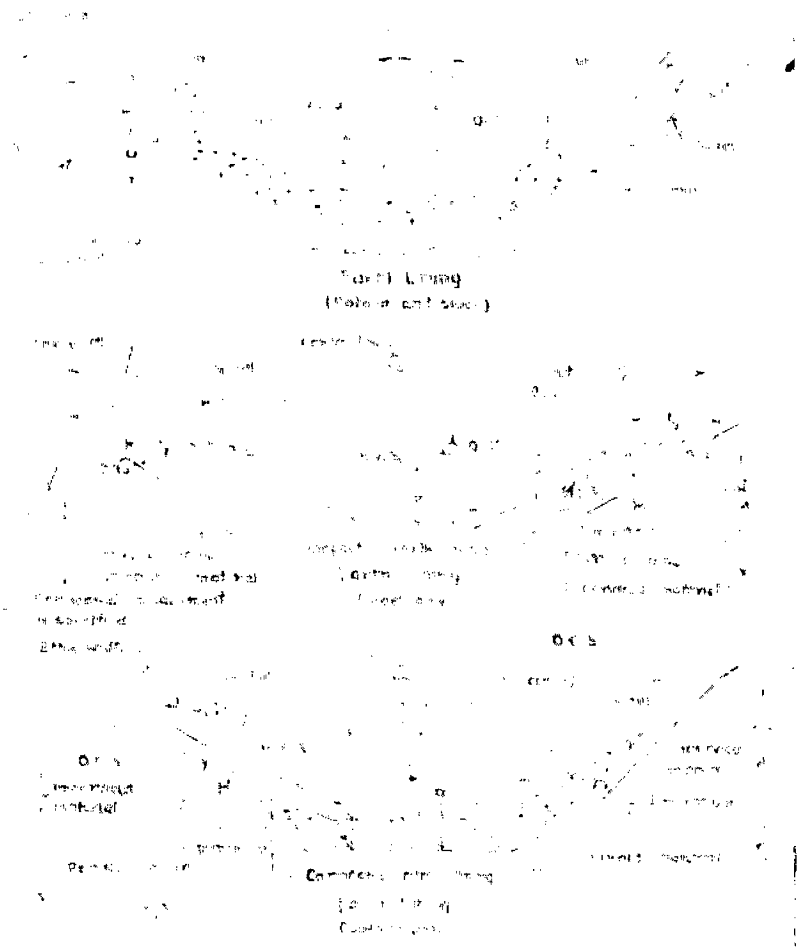
Name of Project or Canal. 1.	Type of Lining 2.	Av. capacity cusecs. 3.	Thickness 4.	Length in Miles 5.	Date of installation 6
Central valley Project.					
i) Friant Kern Canal	Heavy compaced earth.	5000	2 ft on bottom 3 ft on sides	25	1947-48
ii) Delta Mendota Canal	-do-	3310-3211	-do-	18	1947-48
Laterals on Klamath Project.	Thin compacted earth	50	6" on bottom 12" on sides	1.85	1948.
All American Canal Project	Loose earth	1600	8"	1.84	1947
Coachella Canal. Lower Colorade River Project	Heavy compacted earth.	1300	2 ft.	6.45	1949
Paonia Project	Loose Earth	165	6"	9.6	1950-51

FIG.



DETAILS OF ROSACOMETTA SLABS USED FOR LINING CANALS.

FIG.



CHAPTER -7

SUITABILITY OF TILE LINING FOR RAJASTHAN CANAL, MATERIALS FOR CONSTRUCTION AND CONSTRUCTION DETAILS.

CHAPTER 7

SUITABILITY OF TILE LINING FOR RAJASTHAN CANAL, MATERIALS USED FOR CONSTRUCTION AND CONSTRUCTIONAL DETAILS.

As already discussed only hard surface or rigid linings are suitable for Rajasthan Canal. Tile lining has been adopted on the Rajasthan Canal due to the following reasons:-

1. The soil for manufacture of tiles is available at nearer distances than most other construction materials.
2. Labour for construction of tile lining is also available.
3. It is cheaper in initial cost.
4. It has the same degree of impermeability as concrete.
5. Co-efficients of expansion and contraction are less, hence it is liable to lesser cracking.
6. Tile lining is flexible.
7. It can be repaired easily.
8. Stone and Cement Concrete linings are very costly as stone is not available nearby.
9. Due to extreme hot climate, asphaltic concrete cold mix or hot mix are not durable.
10. Gunited or shot crete concrete is also costly and has rough surface thereby the co-efficient of rugosity is higher.
11. Lime and aggregate for lime concrete lining are not available. Strength of lime concrete is comparatively less.
12. No foreign exchange is required for the tile lining as the work is done by manual labour.

Materials of construction and specifications.

The main construction materials required for tile lining are Tiles, Cement, Bajri and Sand.

Tiles:- Tiles are manufactured in continuous kilns. Soil for the manufacture of tiles should have the specification as below:-

Clay content between 12 to 20%

Sand content not more than 65%

Kankar Less than 3.0%

Total soluble salts less than 0.3%

Sodium Sulphate less than 0.1%

Calcium Carbonate less than 5%

The tiles are manufactured in size 12"x6"x2". The permissible tolerances on the dimensions of tile are ¼" in length, 1/8" in width and 1/8" in thickness. Compressive strength of tiles as per Indian Standards should be 2000 lbs./sq in, when tested for 24 hours immersion in water. However, on this Project tiles with compressive strength varying from 800 lbs/sq in to 3000 lbs/sq. in have been used. Average water absorption shall not be more than 15% by weight after immersion in water for 24 hours.

Tests for transverse strength and permeability of tiles are not specified on this Project.

Upto mile 38 of Rajasthan Canal soil for the manufacture of tiles was generally available very near the canal alignment. Kilns at every 1 to 1½ miles were established for the supply of tiles. From mile 38 to 55 of Rajasthan Canal good soil for the manufacture of tiles was not available at site. Experiments were conducted to manufacture tiles by mixing Nali Soil (containing nearly 30% clay) carried to site from Suratgarh with the soil available at site. It was found that neither the results of mixing by manual labour were satisfactory nor the contractors were ready to manufacture tiles by this process. Therefore it was proposed to manufacture tiles at Suratgarh which is 10 to 15 miles away from the site of work. For reaches down below mile 55 kilns are being established at site.

Sand:- Tibba sand with F.M. varying from .1 to .4 generally from .2 to .3 is already available at site. F.M. of sand required for the preparation of mortar of specified strength is 1.00. Bikaner Bajri with F.M. 2.5 is available at Bikaner nearly 100 miles away from Birdhwal Rail head. Bikaner Bajri is to be further carried to site which is 5 to 20 miles from Rail heads and may be even more than 50 miles in down stream reaches. Keeping in view the economy in cost, without loosing much strength it was decided to use 25 to 30% Bikaner Bajri in place of Tibba Sand.

Cement:- Cement is transported from Cement Factories to the nearest Rail head inRailway Wagons, from where it is carried to site by means of trucks and Tractors. Cement packed in gunny bags is used as requirement is scattered in large length of the canal.

Agency for execution.

Generally 10 to 12 miles length of Rajasthan Main Canal is controlled by a Divisional Officer who is assisted by three to four Sub Divisional Officers. Four to five sectional Officers (Overseers) are working under each Sub Divisional Officer. Practically (1/2 mile) length of MainCanal is under the charge of Sectional Officer. While the earth work is executed by the contractors as well as Departmental Machines, the lining work is done entirely by the contractors.

Divisional Officers are responsible for the satisfactory execution of work in time consistant with good quality. The quality of work is also checked by a seperate agency under the charge of Research Officer. Assistant Research Officers, Research Assistants and work Mistries work under Research Officer for controlling the quality of work.

Normally the work of lining is alloted to contractors in 1/2 mile reaches. Some contracting agencies are allotted 3 to 4 miles length but the work is done considering 1/2 mile as one unit of lining commonly called 'headings'.

Water supply arrangements:-

As already stated water table is very deep and water is brackish. Special water supply arrangements are therefore necessary. Water supply arrangement, onthis Project is a very difficult and costly job. Water is also required for earth work compaction, Kilns and drinking purposes. Water requirements at the peak time of construction of lining works out to nearly 1 cusec per mile length of Main Canal.

For the construction of Rajasthan Feeder in Rajasthan and Main Canal upto mile 19, a pilot channel (mostly lined) was constructed along the toe of bank on outer side. The terrain of area from mile 18 to 38 was highly undulating hence the construction of usual Pilot Channel near the bank was not economically feasible. Beyond mile 19 to 38, a battery of 6" pipe line was laid and water pumped through them, but the arrangement proved hardly satisfactory for the excavation work, kiln etc. In reach near mile 20 of Rajasthan Pilot Channel on the top of bank was constructed but this did not prove to be satisfactory as there was heavy seepage ~~losses~~ losses which resulted in wetting of the inner side slope of the bank. This caused hinderance to lining work and was subsequently abondoned. Finally the construction of bed pilot channel of 10 cusecs capacity was resorted to from mile 24 of Rajasthan Canal. This proved to be quite satisfactory arrangement for water supply.

The work on the construction of Rajasthan Canal from mile (38 to 48) was started simultaneously with the construction of Main Canal from mile 18 to 38. Therefore independent arrangement for the water supply was made from mile 38 - 48 of Rajasthan Canal. A pilot channel with 6 cusecs capacity was constructed from Pilibangan Disty. (Bhakra Canals) near Suratgarh to Mile 43 of Rajasthan Canal. The water was lifted at two points by pumping. Construction of reservoirs, pilot channel and laying pipe lines was resorted. This arrangement helped in the excavation of Rajasthan Canal in part reach. The major part of lining work was, however, done after the construction of Pilot Channel in the bed from water supply received from the upper reaches of Main Canal.

From mile 48 to 60, 6" pipe line was laid for preliminary works and ultimately bed pilot channel with 20 cusecs discharge has been constructed.

For the construction of works on Rajastham Canal from mile 60 to 122 simultaneously and indepenent water supply scheme was executed. Capacity of Karniji distributary of Gang Canal was raised and a minor was constructed to feed reservoir at Kupli. From Kupli to mile 80, 2 pipe lines of 18" dia have been laid. From mile 80 to 70 and 70 to 60 one pipe line of 15" and 12¾" dia have been laid. From mile 80 to 90 one pipe line of 18" dia and one of 16" dia and from mile 90-100 one pipe line of 18" dia and one of 12¾" and from mile 100-107 and 107-110 one pipe line of 16" and 14" ~~xx~~ dia have been laid. Various reservoirs have been constructed/are under construction and the water would be lifted by electric power/diesel generation sets.

It is now anticipated that this arrangement would also be satisfactory for the preliminary stages such as for earthwork, Kilns, buildings etc. The construction of bed channel would be necessary as well as economical for the construction of lining work. The cost of construction of bed channel is very nominal and cost of pumping water would be reduced considerably.

Specifications of Lining.

A typical cross section of Rajasthan Canal is shown in figures No. 1. Double tile lining on Side slopes and single tile lining in bed is provided. Double tile lining consists of 2" thick tiles laid in 1:5 cement sand mortar, over 3/8" thick mortar of the same specification. 5/8" thick sand witched plaster of 1:3 cement sand Mortar can be laid on the second day in summer and third day in winter after curing, testing and repairing the first layer of tiles. After one day curing of this layer second layer of 2" thick tiles in 1:3 Cement Mortar is laid over $\frac{1}{4}$" thick mortar of the same ratio.

Single tile lining cosists of 2" thick tiles laid in 1:5 Cement Sand Mortar over 3/8" thick Mortar of the same ratio. $\frac{3}{4}$" thick plaster of 1:3 Cement Sand Mortar can be laid over it on the second day in Summer and third day in winter after curing, testing and repairing the first layer of tiles.

The double tile lining on sides rests on compacted embankment in case of filling reaches. Side slope $1\frac{1}{2}$:1 was adopted upto mile 18 of Rajasthan Canal. Beyond mile 18, side slopes of 2:1 have been adopted.

During the earth work excavation or construction of embankment provision for extra cover of earthwork is required over the designed formation. This extra earth is cut at the time of lining and the process is termed as lip cutting.

This extra earth cover serves the following purposes:-

1. To safe guard the sub grade from being blown away by wind.
2. In filling reaches the inner edges of banks can't be compacted to the desired density. To obtain firm sub grade it is necessary to cut loose earth.
3. It serves as protection to sub grade from rain.
4. It serves as cover required for the finishing of the sub grade.

Quality Control.

A Log Book for works is maintained by the Research staff and various data's in connection with quality of work are noted therein. Important points are described as below:-

a) Sub Grade preparation:-

After lip cutting or bed cutting, sub grade is examined carefully and loose pockets if any are filled with mud concrete. In cases of doubt D.B.D.'s of the sub grade are also observed to ensure the suitability of the same.

Anti salt treatment. is provided in the following reaches:-

a) Where the total salt content is .5 to 1.0% or Sodium Sulphate .2 to .3% the first layer of tile is laid in 1:3 C.S. Mortar.

b) Where salt content is above 1.0% or Sodium Supphate is over .36% in addition to the use of ~~brick~~ rich cement mortar 1:3, the sub grade is first covered with 1/16" thick layer of maxphalt 30/40 over crude oil sprayed at the rate of one gallon per % sft.

Soaking of Tiles:- Tiles are soaked for minimum 2 hours in the soaking tanks before use for lining work.

Mortar:- 1:5 and 1:3 Cement Sand Mortars are used. Proportioning is done on volume basis. Slump for 1:5 Cement Sand Mortar

Inspecting Officer.

5) Daily consumption of materials is same. Use of materials can thus be effectively controlled.

6) In case of Tile lining as the bed and sides are completed simultaneously construction of earthen bunds is possible. Thus better curing is ensured.

For proper planning it is essential to classify the various items of work and adjust them in such a manner so as to have a unified effect.

The lip cutting work is taken in hand before the actual start of lining. At least 100 ft. length of Canal should be dressed with proper sub grade before hand. It should be ascertained that 100 ft. length of canal is always ready in advance with proper sub grade.

Actual process of bed and side lining of Rajasthan Canal which consists of single tile and double tile lining can be sub divided into following operations:-

1. Final dressing of the sub grade, watering and construction of 'Dhumalies' (Profiles) for 1st layer.
2. Laying 2" thick layer of tiles 1:5 cement sand mortar on 3/8" thick 1:5 cement sand mortar.
3. Raking curing, testing and repairing of joints.
4. Laying sand witched plaster 5/8" thick with 1:3 cement sand mortar.
5. Curing of sand witched plaster and construction of 'Dhumalies' for the second layer.
6. Laying of second layer of 2" thick tiles in 1:3 Cement Sand Mortar on $\frac{1}{4}$" thick 1:3 Cement Sand Mortar.

is kept at 1½" and that for 1:3 mortar as ¾". Tests for Fineness modulus of Bikaner Bajri and sand are usually conducted at site Briquettes of 1:5 and 1:3 Cement Sand Mortars are casted every day and tested after 7 days. The strength of 1:5 and 1:3 Cement Sand Mortars should not be normally below 90 lbs/sq in and 140 lbs/sq in respectively.

Testing of joints, thickness of mortar etc.

Joints of lining are tested on the second day after curing the layer of tiles and refilled where ever found empty. Each and every tile is tested by Research staff. Assistant Engineers and Executive Engineer also check the joints as far as possible. Checking of the thickness of mortar is very important. Mortar should be laid with the help of L. shaped wooden frames to ensure correct thickness. This should be invariably checked.

Curing of Lining:- Curing of lining plays on important rol for strength. 28 days curing is normally done after the finished portion of Canal is ready. Bed which consists of single tile lining is always to be kept filled with 3" depth of water (Adequacy of 3" depth of water is discussed in a saperate chapter).

Necessity of Planning.

It has been observed that the work of lining is some times done haphazardly due to one reason or the other. It is, therefore, very necessary to frame a programme of construction. Proper planning has the following advantages:-

1) Better and consistant quality of workmanship is achieved.
2) Minimum equipment is required.
3) Time required for completion is also less as the labour is trained for a particular specialised job resulting in greater efficiency.
4) Quality of all the items of work can be checked by any

7) Curing, testing and repairing of joints, concreting work on top and construction of curing drain.

8) Dressing of bed and construction of Dhumalies.

9) Laying 2" thick layer of tiles in 1:5 Cement Sand Mortar on 3/8" thick Cement Sand Mortar.

10) Raking, curing, testing and repairing of 1st layer.

11) Laying $\frac{3}{4}$" thick 1:3 Cement Sand Plaster.

Daily requirement of material and labour for lining heading.

For completing 12.5 ft. of canal daily the following material labour and T&P are required:-

A) Materials.

i)	Tiles	8000 Nos.
ii)	Cement.	90 Bags.
iii)	Bajri.	110 cft.
iv)	Sand.	250 cft.

B) Labour.

For lip cutting	50 to 60 donkeys & 20 Donkey Men.
For Dressing.	3 to 4 Dressers.
For lining.	50 Mazdoors.

C) T&P Articles.

Soaking Tanks.	6 Nos. for soaking.
	2 Nos. for curing arrangements.

D) Pumps, Hose Pipes etc. would also be required.

Lining Plan.

A lining plan in figure 2 shows the arrangements of various components and space for construction materials on any particular day. Double tile lining on sides consists of seven operations. As the work has been planned in such a way that each operation is executed on any day the work of side lining is spread in 100 ft. length for completing on an average 12.5 ft. length of canal per day. For construction of side lining space in bed is required for materials and labour. Therefore, bed lining is started from the place where side lining is just completed i.e. at a lag distance of 50 ft. as shown in the figure. The bed lining consists of four operations (8 to 11) and the work is spread in 50 to 100 ft. length at one time.

Figure No. 3 shows the out line of lining Plan. Various operations on different sections to be done and difference days are shown in different colours. Red, Green, Yellow, Blue and Red colours represent operations on Ist, 2nd, 3rd, 4th and 5th days respectively.

For any particular section of the canal if item No. 1 is executed on Ist day, the item No. 2nd, 3rd, 4th, 5th and 6th and 7th will be executed on 2nd, 3rd, 4th, 5th, 6th and 7th day respectively. The double tile lining at a particular section would be completed in 7 days. From the study of the lining plan on Ist and 3rd day it would be clear that the double lining tile has shifted by 25ft. in two days. Thus 25 ft. of double tile lining is ready on alternative days.

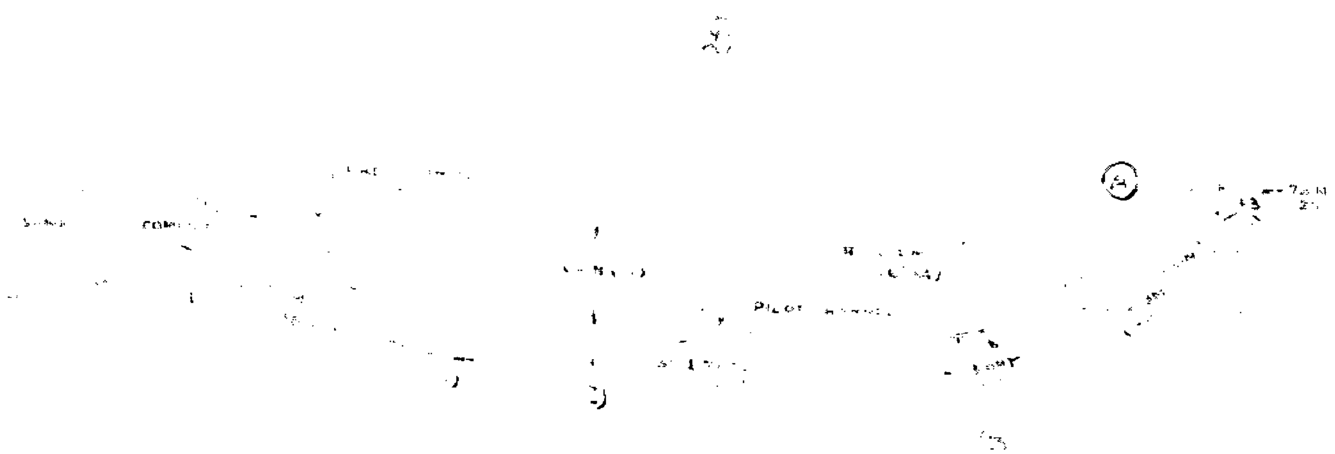
From the comparision of position of different items of bed and side lining on Ist and 5th day it is observed that the entire lining heading has shifted by a distance of 50 ft. In other words 50 ft. length of canal is ready in four days (average 12.5 ft. per day). As bed lining is started at a lag distance of 100 ft. from the operation position of item No. 1 of double tile lining it takes 8 days to start the bed lining on that section. In other workd 12 days are required for any canal section to be lined (bed as well as side slopes).

Planning of the lining as detailed above is based on the ideal conditions such as completion of earthwork in reach before start of lining, no break down in labour and supply of materials etc. It shows an approach to idealistic planning to ensure good quality of work. On site the planning may be modified according to the availability of labour and constructional materials etc. It may, however, be emphasized that any unscientific deviation might deteriorate the quality of lining work.

A CROSS SECTION OF RAJASTHAN CANAL SHOWING

SCALE 1" = 40 FT

(122)



11

9

7 6

5 4

3 2

1

CHAPTER - 8

SPECIAL PROBLEMS

(a) INSULATION TO TEMPERATURE VARIATIONS ON TILE LININGS

(b) TILE LINING ON SANDY SUBGRADES

CHAPTER 8(a)

INSULATION TO TEMPERATURE VARIATION ON TILE LININGS

In case of Double tile lining, the top layer of tiles serves as a insulating material to the Sand-witched layer of plaster. In case of single tile lining, 2" to 3" depth of water is provided to serve for insulation. Jatinder Singh and Gulbir Singh Dillon (10) state that in a 12 hours day the top layer of tile will not let the temperature of the plaster surface rise by more than 11°C while in case x of single tile lining the rise in temperature even after providing 2" depth of water would be about 59°C. On the other hand investigations conducted in Amritsar Research Station (11) reveal that although the top layer of tile has significant effect in reducing the x temperature variations in the sand witched plaster due to abrupt changes in the atmospheric temperature, the maximum temperature attained by the plaster was only 1.5°C and 3.5°C less than the maximum temperatures attained by top layer of tile in Summer and winter respectively. In case of single tile lining the reduction in temperature due to 3" depth of water is very much more as compared to top layer of tiles.

It appears that the results are contrary to each other. A theoritical nanalysis of the problem by applying heat theory of conduction into semi infinite solid to find out which of the above results/opinions are correct is given below. Probable erors involved in their assumptions/ experiments are brought out.

THEORY OF HEAT CONDUCTION IN A SEMI INFINITE BODY

If a temperature θ_o is applied to the face of a semi-infinite body intially at temperature 0 thoughout, it will propogate into the body. The rate at which the propagation takes place is given by

$$\frac{\alpha t}{x^2} = \phi \left(1 - \frac{\theta}{\theta_0}\right)$$

Where α = Thermel diffusivity $\left(\frac{L^2}{T}\right)$

t = Time required for a temperature $(\theta_0 - \theta)$ to penetrate into the body to a depth x.

The temperature distribution in semi infinite body is given in table No.1 (Taken from 22)

TABLE NO.1

$\frac{\alpha t}{x^2}$	$1 - \frac{\theta}{\theta_0}$
0	0.0
.0278	.001
.04	.001
.0625	.005
.111	.034
0.174	.090
0.25	.158
0.277	.180
.309	.203
.333	.229
.391	.258
.444	.289
.510	.322
.590	.358
.694	.396
.826	.437
1.00	.479
1.99	.500
1.23	.525
1.56	.572
2.04	.621
2.78	.671
4.00	.724

6.25	.777
11.10	.832
25.00	.888
100.00	.9436
625.00	.9774
2500.00	.9987
∞	1.00

APPLICATION OF THEORY TO DOUBLE TILE LINING

The physical properties of Bricks, soil and water are given in table No.2 below

TABLE NO.2

Material	K	C	ρ	α
Bricks	.47	.2	106	.022
Soil	.90	.45	100	.02
Water	.346	.998	62.4	.0056

Double tile lining resting on earth can be treated as semi infinite solid receiving solar radiation on the top due to reasons mentioned below.

1) The surface of tiles gets the heat from solar radiation for 10 to 12 hours a day. In 10 hours period 10% effect reaches hardly to a depth of 1 ft. The thickness of double tile lining is 0.44 ft. hence penetration of heat into soil is of small magnitude.

2) The rate of propagation depends upon the value of α, which is nearly same for brick and soil.

Due to the above mentioned reasons it is fairly correct to treat the double tile lining resting on earth as a semi infinite solid receiving solar radiation on the top.

Experiments were conducted in Amritsar Research station to find out the damping effect of upper layer of tiles in sandwiched linings the details of which are given below.

The investigations were carried out on portable blocks 6'x6"x5-1/8" of sand witched type of lining. Horizontal bore holes approximately ¼" dia meter and 3" in length were made on a vertical side 6'x5-1/8" of the blocks at known depths from the top. Cotton was used to for plugging the-rmometers and hessain cloth to cover sides. The results as available in Canal linings (11) are given in figure No. 1 and are shown in table No.3 below

TABLE NO.3

Time in hours.	Temperature of tile surface in Deg.Centg.	Temp.at top of plaster in Deg.Centg.
1	2	3
7	30	30
8	36	32
9	41	36
10	48	41
11	56	45
12	60	52
13	58.5	56
14	58.5	57.5
15	57	58
16	54	56.5
17	50	56
18	46	54

At the time t 0, when both top of tile surface and inter pased plaster are at 30°C. 30°C would be assumed as Zero temperature and the rise or fall will be calculated accordingly. Temperature at the top of tile surface would be assumed as given in column 2 and temperature at various intervals at top of plaster would be calculated by conduction theory treating the body as semi infinite.

As the temperature is not uniform and varies contiaously it would be assumed that the same is uniform for 1 hour intervals and the temperature at interposed plaster would be calculated by the method of superimposition.~~xxxxxxxxxxxxxxxxxxxxxxxx~~.

Thickness of tile layer = .17 ft.

$$\alpha = .022$$

$\therefore \frac{\alpha t}{x^2}$ at 1 hour time = $\frac{.022 \times 1}{.17^2}$ = .75

$\frac{\alpha t}{x^2}$ for various time intervals have calculated and values of $1-\frac{\theta}{\theta_0}$ computed from the table No.1 are shown in the table No.4 given below.

T A B L E NO.4

Time	$\frac{\alpha t}{x^2}$	$1-\frac{\theta}{\theta_0}$ from Table No.2
½	.37	.25
1½	1.1	.50
2½	1.9	.61
3½	2.6	.66
4½	3.4	.70
5½	4.1	.73
6½	4.9	.75
7½	5.6	.76
8½	6.4	.77
9½	7.1	.78
10½	7.9	.79

T A B L E NO.5

SUPERIMPOSITION OF RESULTS

Time in Hrs.	Temperature of tile surface.	Temp-rise.	Rise or fall in Temperature at plaster over 30^0C	Calculated temp. of plaster	Actual observed temp.
1	2	3	4	5	6
7	30	-	-	-	30^0
8	36	6	6x.25 =1.5	31.5	32^0

1	2	3	4	5	6
9	41	5	5x.25+6x.50 = 4.25	34.25	36^{0}
10	48	7	(7x25)+(5x.50)+(6x.61) =7.8	37.8	41^{0}
11	56	8	(8x.25)+(7x.5)+(5x.61) +(6x.66)= 12.5	42.5	45^{0}
12	60	4	(4x.25)+(8x.5)+(7x.61) +(6x.66)+(7x.70)=16.8	46.8	52^{0}
13	58.5	(-)1.5	-(1.5x.25)+(4x.5)+ (8x.61)+(7x.66)+(5x.70) +(6x.73) = 19	49	56
14	58.5	0.0	(0x.25)-(1.5x.5)+(4x.61) +(8x.66)+(7x.70)+(5x.73) +(6x.75) = 20	50	57.5
15	57	- 1.5	-(1.5x.25)-(1.5X.61)+ (4x.66)+(8x.70)+(7x.73) +(5x.75)+(6x.76) = 20.5	50.5	58
16	54	-3.0	-(3x.25)-(1.5x5)-(1.5x.66) +(4x.70)+(8x.73)+(7x.75)+ (5x.76)+(6x.70) = 20	50	56.5
17	50	-4.0	-(4x.25)-(3x.5)-(1.5x.61) -(1.5x.70)+(4x.73)+(8x.75) +(7x.76)+(5x.77)+(6x.78) = 18.3	48.3	56
18	46	-4.0	-4(.25+.50)-(3x.61)-(1.5x .66)-(1.5x.73)+(4x.75)+ (8x.76)+(7x.77) +(5x.78)+(6x.79) = 16.2	46.2	54

From the above table it is clear that due to upper layer of tiles the insulation effect on the sand witched plaster would be 60-50.5 = 9.5^{0}C which is nearer to the figure of 11^{0}C suggested by Jatinder singh & Dillon and not 1.5^{0}C as observed in Amritsar Research station.

Anticipated experimental error that might have caused the difference is due to the fact that insulation can not be done properly and therefore the results are on the higher side.

INSULATION EFFECT OF A COLUMN OF WATER ON THE TEMPERATURE VARIATIONS OF THE SUBMERGED LINING

The investigation were conducted in the Amritsar Research Laboratory to find out the insulation effect of 3",6" & 9" depth of water. Three Bricks masonry blocks having $\frac{1}{2}$" C.sand plaster were kept in a cylindfrical masonry container 7 ft. in dia and 1'-6" deep fitted with water in such a way that depth of water over the plaster surface was 3",6" and 9" for first, second & third block respectively. The temperature at the top of block, under water and on the top of block placed out side and that of air were noted by thermometers. The results are shown in figure 2.

It has been explained by them that propagation of heat takes place as under.

1) By convection from 0^oC to 4^oC

2) By conduction from 4^oC to θ^oC

3) By convection from θ^oC to 4^oC.

4) By conduction from 4^oC to 0^oC.

Theoritically speaking it is obsolutely correct to assume that the propagation would take place as explained above In actual practice due to wind velocity the progagation by convection would also be there alongwith conduction and therefore theoritical analysis is not possible. However, assuming that the propagation would take place by conduction results are analysed theoritically and compared with the results obtained from experiments.

Physical properties of water.

α = .0056

k = .47

c = .2

ρ = 62.4

Assuming that the rise in temperature at the top of the surface of water is same as for top of tile surface.(The assumption is not correct as the temperature of the water surface is mostly different than that of tile surface as the pro-

propagation takes place by both conduction as well as convection, the temperature at a depth of.25 ft, .5 ft and .75ft. would be calculated at different time intervals. The results are given in table No.6 below

TABLE NO 6

Time	Value for x =.25		Values for x=.5		Values for x =.75	
	$\frac{\alpha t}{x^2}$	$1-\frac{\theta}{\theta_0}$	$\frac{\alpha t}{x^2}$	$1-\frac{\theta}{\theta_0}$	$\frac{\alpha t}{x^2}$	$1-\frac{\theta}{\theta_0}$
$\frac{1}{2}$	.045	.001	.01	-	.005	-
$1\frac{1}{2}$	.135	.055	.035	.001	.015	.001
$2\frac{1}{2}$	.225	.132	.055	.004	.025	.001
$3\frac{1}{2}$	.315	.21	.08	.015	.035	.001
$4\frac{1}{2}$	.405	.265	.1	.025	.045	.002
$5\frac{1}{2}$	.495	.312	.125	.05	.055	.004
$6\frac{1}{2}$	.585	.354	.146	.07	.065	.005

As is clear from the above table there is continuous rise of temperature upto 12 hours. After wards the temperature falls and therefore the propagation would take place by convection. The maximum rise in temperature of the water at 12 hours at .25,.5 and .75 ft. depth would therefore be as below.

a) Maximum rise in temperature at .25 ft. depth.

=(6x.001)+(5x.005)+(7x.132)+(8x.21)+(4x.265)

= .006+.275 +.924+1.68+1.060

= 3.945 °C Say 4 °C

b) MAximum rise in temperature at .5 ft.depth.

=(6x0)+5x(.001)+(7X.004)+(8x.015)+(4x.025)

= .005+.028+.120+.10

= .253° Say 1/4 °C

c) Maximum rise in temperature at .75 ft.depth.

=(5+7+8)x.001+.002x4

=.02+008 = .028 °C negligible.

The maximum rise intemperatures at depths of 0.25 ft, 0.5 ft. and 0.75 ft. as calculated above are $4^{0}C$, $\frac{1}{4}{}^{0}C$ and $1/40^{0}C$. The actual observed maximum temperatures are $14^{0}C$, $9^{0}C$ and $9^{0}C$ at depths 0.25 ft, 0.5 ft. and .75 ft. respectively. It is, therefore very clear that propagation of heat in water takes placed due to conduction as well as convection. In case the propagation would have been due to conduction there would have been no rise in temperature at 6" and 9" depths and rise at .25 ft. depth would have been only $4^{0}C$. It appears that there is a increase of $9^{0}C$ entirely due to convection. This increase should be for the entire column of 1.5 ft. contained by the masonry chamber. It can be argued from here that in case the depth of water in the container is 2", the rise intemperature due to convection alone (assuming that there is no loss of heat due to conduction by lining) would be $\frac{9 \times 18}{2} = 81^{o}C$ even more than figure of $58^{0}C$ suggested by Jatinder singh & Dillon.

Actually there would be losses due to conduction of heat by the lining and also due to low temperature of atmosphere, therefore, the expected rise in temperature may be ~~½ to 1/3 i.e. 25° to 40°C~~ 20° to 25°c. In other words the damping effect of 2" depth of water over the lining ~~is very much doubtful~~ would be just equivalent to that of top layer of tiles in case lining is always covered with water.

Incase the depth of water is increased to 6" to 9" the rise intemperature would be considerably reduced in proportion to the depth of water.

The reasons why the results obtained by Amritsar Laboratory are not practical are.

1) It appears that all the three samples were placed in the container with 1½ ft. water depth. It was presumed that propagation takes place by conduction (This view could have been corrected had the results been analysed theoritically) In fact rise intemperature was mostly due to convection and therefore

temperature of entire column ofwater had risen to nearly $9^{o}C$.

2) Masonry tanks with lined bottom should be constructed and depth of water in each tanks should be varied to 3", 6" & 9" depth to find out the effect correctly.

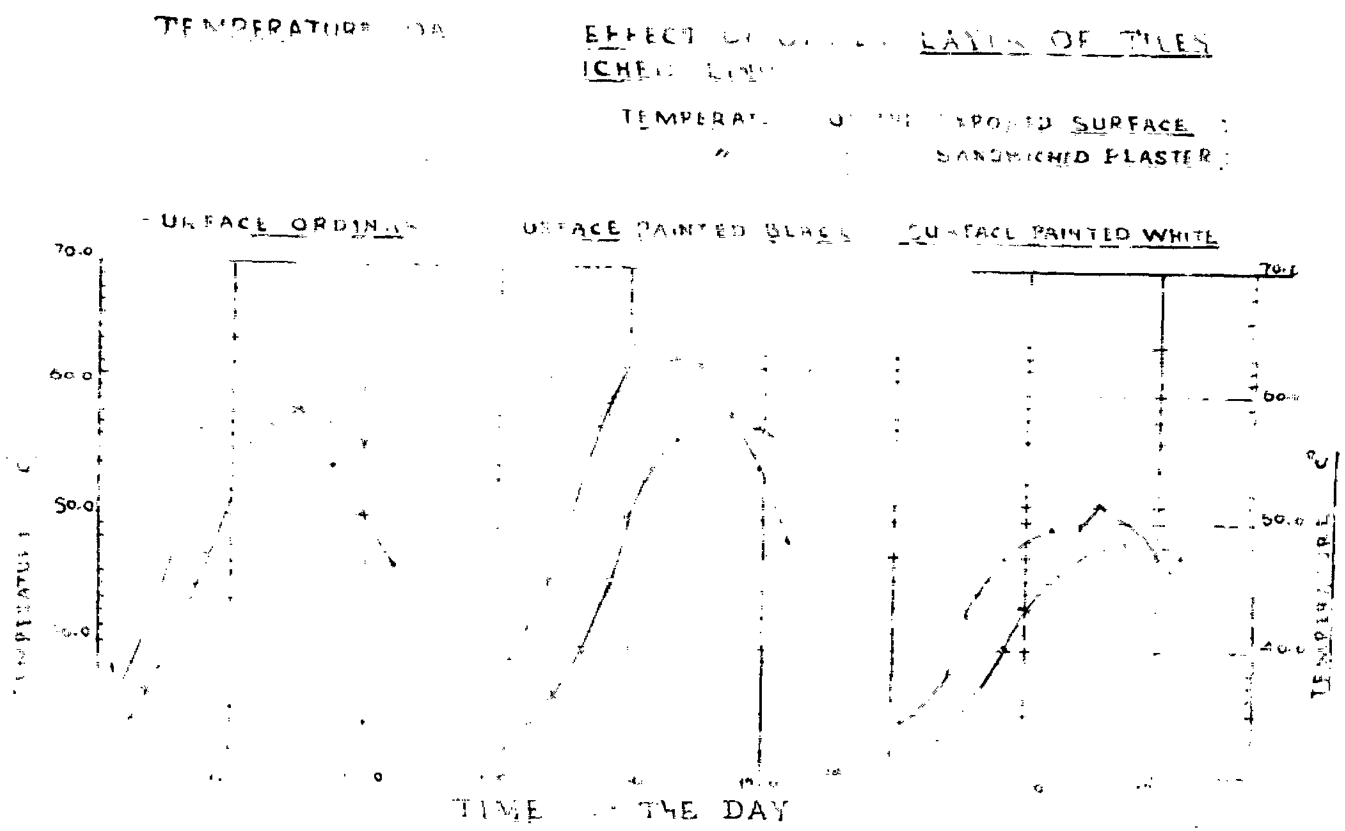
Difficulties in the field.

While executing the work of lining of Rajasthan Canal from mile 14 to 18 during the years 1962-64, the following difficulties were observed.

1) In certain reaches the losses due to absorption and evaporation were 1" to 2" per day. Due to irregular supply of water it was observed that bed filled with 2" depth of water remained dry most of the time in a month and the plaster in the bed was found to be cracked.

2) In reaches where the bed was depressed the water was filled automatically to depths varying from 1 ft. to 2.5 ft, practically no cracks were observed when the bed was emptied.

From the above discussions it is clear that the damping effect of the tile on the top of lining is substential. The damping effect of 2" depth of water over the lining is practically less and can't be relied upon. Therefore it is suggested that plaster of the lining should be covered by atleast 9" to 1 ft. depth of water to minimise the cracking of plaster.



TEMPERATURE
EFFECT
LAYER OF TILES
TEMPERAT
SURFACE
SANDWICHED PLASTER
SURFACE ORDINARY
SURFACE PAINTED BLACK
SURFACE PAINTED WHITE
70.0
60.0
50.0
TEMPERATURE °C
TIME THE DAY

CHAPTER 8 (b)

TILE LINING ON SANDY SUB GRADES

In most of the partial a cutting and heavy cutting reaches on Rajasthan Main Canal the soil forming the sub-grade for lining is sandy. The co-efficient of permeability of sand varies from 1000 to 3000 ft/year. Due to this high co-efficient of permeability, the sub-grade absorbs the moisture from the mortar so rapidly that it becomes unworkable immediatelyafter placing on the sub-grade. The problem of laying tile lining on sandy sub-grade, on Rajasthan Canal is not given due attention with the result that the first layer of tile lining behaves no better than tile pitching.Special treatement required on sandy sub-grade has been discussed.

As would be clear from chapter 2, the seepage losses corresponding to co-efficient of permeability are 40 cusecs per million square feet of wetted area.

= 40 inches per day

= 5/3 inches per hour.

$\doteq$ 1" in 30 minutes.

Water contained in 3/8" thick layer of mortar is just equivalent to 1/16" depth. It would mean that nearly 50% of the water contained in mortar can be soaked away by the sub-grade within one minute of its laying. It has also been practically observed that the mortar becomes unworkable within one minute of its laying.

As per specifications laid down by the Rajasthan Canal Board, the mortar should not be kept in the mortar pan. It should be got emptied by the mason as soon as the same is received at the place of work. Mason should then spread the mortar by trowel and lay the tiles. The tiles are cured and tested on the next day. During the execution of work on Rajasthan Canal from mile 14 to 18 the difficulty in following the procedure was noticed. The problem was, therefore, studied as under:-

1) Laying first layer of tiles inbed in standing water 1/2" to 1" was tried but with little success.

2) A lean cement sand grout was sprinkled over the sub-grade before laying the first layer of tiles. This experiment proved to be quite successful and nearly 300 to 400 ft.length of canal was laid in that Fashion.

The matter was referred to the Research Organisation of the Project. Various tests were conducted and it was suggested to provide the cheapest of the techniques mentioned here under:-

1) 1 ft. blanket of compacted clayey earth.
2) 6" thick mud concrete.
3) 2" thick layer of stabilized soil with 2% cement and compacted with trowels to achieve density upto 1.5 gram/cc.

The cost of such applications varied from Rs. 10 to 15% sft. Therefore the proposal for treatment was dropped and it was suggested by the Director Designs to use copious watering before laying the first laying of tiles.

As already pointed out the method of ~~xxxx~~ copious watering is not effective and the first laying of tile lining behaves no better than pitching. It is necessary to provide some sort of treatement before the laying of first layers of tiles.

Application of lean cement sand mortar grout is quite satisfactory. Dr.Uppal has suggested the use of linseed oil or tar paper. It is,however,necessary to know the permeability of the soil upto which such treatement would be essential/desirable.

CHAPTER - 9

E C O N O M I C S OF L I N I N G

CHAPTER - 9

ECONOMICS OF LINING

The necessity of conserving water in this arid tract alone justifies the lining of canals. For financial justification normally direct benefits such as revenue from water rate, croprate, interest on betterment levy and interest on sale of Government land are considered. Indirect benefits such as reduced drainage costs, insurance against failure of crop, saving in maintenance and revenue from extra taxes cannot be evaluated correctly and the same are not considered. It is generally assumed that the development charges will be borne by indirect benefits.

In this example financial justification for lining of Rajasthan Canal from mile 38 to 48 has been considered. To simplify, the following assumptions have been made.

(1) Extra cost in compaction of earthwork is balanced by saving in earthwork in case of lined canaldue to winding of canal and lesser bed width.

(2) As most of the land is owned by the Government, saving in cost due to less land required in case of lined canal is neglected.

(3) Saving in cost of masonry structures is compensated by extra amount required for the establishment, T&P etc.

(4) Losses in lined canal are calculated at 2 cusecs/10^6 sq.ft. of wetted area, while in unlined canal @ 8 cusecs/10^6 ft. of wetted area.

(5) One cusec of water at Branch head can provide irrigation facilities to 250 acres of C.C.A. with 78% intensity of irrigation, actual irrigation with one cusec of water at Branch head will be 200 acres. Assuming water rate and crop rate of

of Rs.9.75 per acre and working expenses at Rs.3.00 per acre, 1 cusec will earn 1350/- (200 x 6.75) annually.

(6) Time between the construction of lining and actual utilisation is assumed as 10 years.

(7) Life of lining = 50 years

(8) Rate of interest = 4% .

Section of Lined canal and losses :-

The designed discharge in reach mile 38-48 of Rajasthan Canal is 15726cusecs. The particulars of canal as worked out from Mannings formula assuming N = .017, S = 1 in 12000 and side slopes = 2:1 are as under:-

Bed width = 99 ft. + 10 ft. curved portion
F.S.D. = 21 ft.
Wetted perimeter = 109 + 94 = 203 ft.
Losses in reach mile 38-48 = $\frac{2x203x10x500}{10^6}$ = 20 cusecs.

Section of unlined canal and losses:-

For the same discharge of 15726 cusecs (actual discharge would be more in case a the entire main canal was unlined) & bed slopes of 1 in 12000 the unlined section will have the following dimensions:-

Bed width = 300 ft.
F.S.D. = 13 ft.
Wetted perimeter = 300 + 2 x 1.12 = 13
= 300 + 29 = 329 ft.
Losses in reach mile 38 to 48

= $\frac{8 \times 329 \times 10 \times 500}{10^6}$ = 131.6 cusecs. Say 130 cusecs.

Total annual revenue:-

Saving in water due to lining = 130 - 20 = 110 cusecs.

Value of water saved per year = 110 x 1350 = 1,48,500

Assuming 8600 acres as private land and 20,000 acres as Government land, the income from Betterment charges and ~~side~~ sale preceeds would be as under:-

On 8,600 acres private land, betterment charges @ Rs.3.00 per acres	=25,80,000
Sale proceeds of 20,000 acres of land at Rs.1000/- per acre	=2,00,00,000
Total:-	2,25,80,000
Annual revenue earned as interest charges @ 4% on Rs.2,25,80,000/-	9,03,200
Revenue earned from water rate	1,48,500
Total annual revenue	10,51,700

<u>Total annual expenditure:-</u>

Cost of lining of Rajasthan Canal from mile 38 to 48 at Rs.8 lacs per mile	80,00,000
Interest charges for 10 years lag period $(1.04)^{10} - 1 = 48$ i.e. 48% say 50%	40,00,000
Total:-	1,20,00,000
Cost of construction of Branches and Disty System for 110 cusecs at Rs 2500/- per cusec	= 27,50,000
Depriciation charges ~~Cost of construction~~ at 2% per year i.e. 2% of 1,20,00,000	2,40,000
Average interest charges at $\frac{0+4}{2}=2\%$ per year on 1,20,00,000	2,40,000
Interest charges at 4% on 27,50,000	1,10,000
Total annual expenditure	5,90,000

Extra revenue earned per year =

Total annual revenue - Annual expenditure

= 1=,50,000 - 5,90,000 = 4,60,000

Thus nearly 4,60,000 would be earned annually by lining 10 miles length of canal i.e. Rs.46,000 per mile. Total annual revenue of the Project would be increased by 425x46000 = 2 crores with the lining of the main canal.

On similar lines it can also be proved that lining of Branches, distributaries and water courses is also a sound proposition.

Alternative justification on Lining:-

Capital investment per cusec of water delivered at Branch head is comparatively high in case of Rajasthan Canal due to the following reasons:-

1) construction of storage works was essential to utilise the river supplies to full extent.

2) Construction of 134 miles of Feeder channel was necessary.

3) Rajasthan canal is a contour canal and irrigates lands mostly on one side.

It is clear from the above reasons that the lining of canal is justified to save dearly water. For comparing the economy of lining of main canal, capital investment per cusec of water delivered at branch head and capital investment per cusec of water, saved due to lining of main canal, are compared

a) Capital investment per cusec of water delivered at Branch head:-

i) Capital cost of construction of works upto Branch head would be the sum total of the following:-

1)	Share of Rajasthan Canal cost of Beas Dam =	4500 lakh Rs.
2)	Share of cost of Madhopur Beas link =	500 " "
		~~5000 lakh~~ Rs.
3)	Cost of Rajasthan Feeder in Punjab	2300 lakh Rs.
4)	Cost of Lining feeder in Rajasthan	460 " "
5)	Cost of Main canal lined from mile 0 to 291.8 (tail)	6340 " "
	Total capital cost	14,100 lakh Rs.
	Cost of lining of Feeder & Main canal	3,300 " "
	Cost of unlined canal	10,800 Lakh Rs.

Total discharges at head of Main canal (at Harike head works) is 18,500 cusecs. The losses in Feeder and Main canal lined are 5%. The losses in unlined canal are $6\frac{1}{2}$ times ($\frac{130}{20}$) more than lined canal. Therefore, anticipated losses in unlined canal would have been 6.5 x 5 = 33%.

The available discharge at branch head in case of lined canal = .95 x 18,500 = 17,600 cusecs.

Discharge available at branch head in case of unlined canal = 18,500 x .67 = 12,400 cusecs.

Capital investment per cusec of water delivered at Branch head in case of unlined canal	$= \frac{10,800}{12400}$ =0.87 lakh Rs.
Discharge available at branch head due to saving in losses by lining of main canal	=17600-12400 =5,200 Cs.
Therefore, capital investment per cusec of water by lining of main canal	$= \frac{3300}{5200}$ =0.64 lakh Rs.

Capital investment per cusec of water delivered at branch head by unlined canal is .87 lakh rupees. Capital investment per cusec of water saved and delivered at branch head by lining of Main canal is o.64 lakh rupees. The lining of Main canal is thus an economical proposition.

CHAPTER- 10

ECONOMICAL BED SLOPE FOR LINED RAJASTHAN CANAL.

CHAPTER 10

ECONOMICAL GRADIENT FOR RAJASTHAN CANAL

In arid regions canals are lined to save absorption losses. Generally speaking gradients (bed slops) on lined canals are kept sufficiently steep so that the channel becomes economical due to lesser cross-section but the maximum velocity is limited from 6 to 8 ft./sec. In case of Rajasthan Canal, which is a contour Canal a bed slope of 1 in 12000 (suficiently flatter) has been provided for the total length of 426 miles. The flat slope has been kept to enable irrigation of most of the lands by flow irrigation. After completion Rajasthan Canal will provide irrigation facilities to 36.5 lac acres C.C.A.(30 lac acres by flow and 6.5 lac acres by lift upto 150 ft.)

The annual expenditure on the lift channels would be more as compared to flow channels.This would, however, depend upon the cost of power which varies considerably depending upon the source of generation and length of transmission lines. The expenditure on lift channels can be reduced by providing flatter bed slope in the main canal.This would, however,increase the cost of lining,earthwork and masonry works. The problem of silting of Rajasthan Canal with flatter slopes has already been considered in chapter No.4. For the purpose of this study it has been assumed that silting would not be a problem as Rajasthan Canal would carry desilted water after the construction of Pong Dam.

The problem has been studied from two different angles.

1) To find out economical gradient for Rajasthan Canal

for different costs of unit power to provide lift irrigation facilities to 6.5 lac acres as envisaged in the project.

2) To find out culturable commanded area to receive lift irrigation facilities with different bed slopes at different cost of unit power.

DESIGN FEATURE OF RAJASTHAN CANAL

As already mentioned a bed slope of 1 in 12000 has been provided on Rajasthan Canal side slopes 1.5:1 has been provided upto mile 152 (from Harike) and there after 2:1 as the canal traverses desert area where the soil is mostly sandy. In the upper reaches mile 0-3 the canal is unlined with water depth as ~~1.4~~ 14.0 ft. From mile 3-36 the depth of water has been kept as 14.4 ft. to safe gaurd against high sub soil area. From mile 36 to 300 , 21 ft depth has been provided and from mile 300 to 426 depth would vary from 21 to 15 ft. The details of design are shown in Table No.1 below. Index plan at Figure 1 shows the various details of the project area.

TABLE No.1

Reach in miles. (from Harike)	Discharge in cusecs	Bed width including curved portion (in ft.)	Depth in ft.	Side slope	Bed slope	Remarks
1	2	3	4	5	6	7
0-3	18500	332	14.0	$1\frac{1}{2}$:1	1 in 12000	Unlined.
3-36	"	260	14.4	"		3.4 ft. fall
36-111	"	138	21.0	"		2.83 ft. fall
111-134	"	138	"	"		
134-148	17400	128	"	"		
148-152	16000	118	"	"		
152-167	15900	110	"	2:1		

1	2	3	4	5	6	7
167-182	15700	109	21.0	2:1	in	
182-256	12700	85	"	"	12000	
256-275	10850	68	"	"		
275-300	10350	64	"	"		
300-319	9100	63	20.5	"		
319-342	8000	59	19.0	"		
342-399	6850	58	17.5	"		
399-411	6060	58	16.5	"		
411-426	5000	57	15.0	"		

COMPARATIVE STUDY.

The capital investment and annual maintenance cost on the civil works on lift channels would be the same as for flow channels. The additional works required for the lifts channels would be detention reservoirs, pump houses, installation of pumps and motors, pipe lines etc. The additional annual cost would therefore comprise of the following:-

1) Depreciation charges on account of additional works.

2) Cost of Electrical power.

Due to adoption of flatter slopes than 1 in 12000 there would be saving in annual cost due to above two items.

It is estimated that the cost of installation of additional works (including cost of pumps mortors) would be Rs. 1600/- per cusec for an average head of 40 ft. i.e. Rs. 40 per cusec ft. Therefore, the depreciation charges at 10% per year, would be Rs. 4 per cusec ft.

At the time of preparation of 1963 revised project estimate it was anticipated that the cost of unit power would be Rs. 3.75 paisa. For the purpose of this study different rates at 4,6,8,10 and 12 paisa per unit (K.W.H)or Rs.350, 525,700,875 and 1050 per K.W.year would be considered.

Due to adoption of flatter gradients than 1 in 12000, there would be increase in cost of Earth work,lining and masonry works.The expenditure on these works shall have to incurred Say 10 years before utilisation of irrigation water. Assuming rate of interest at 4% per year the actual cost of civil works would be 50% higher than the actual execution cost This facter would betaken into consideration while arriving at the costs.

Increase in the annual charges due toextra works due to adoption of flatter slopes would therefore be as under:-

1) Depreciation cost of lining at 2% per year and masonry works at 1% per year.

2) Maintenance charges at ½% for lining and masonry works and 2% for earthwork.

3) The average cost of lining and earth work would be as under:-

Item	Costs. At present	After 10 years.
Single tile lining in bed.	Rs. 60 per % sft.	Rs. 90 per % sft.
Earth work.	Rs. 50 per %o cft.	Rs. 75 per %o cft.

Note:- The above rates are average and include over head charges also.

1) Annual charges would, therefore,work out as under:-

Single tile lining per % sft in bed.

Depreciationat 2% of 90 = 1.80

B.F 1.80

Maintenance at ½% of 90	= 0.45	
Interest charges at 4% of 90	= 3.60	
	5.35	Say Rs.6/- per % sft.

2) Earthwork per %o Cft.

Maintenance charges at 2% of Rs 75	= 1.5	
Interest charges at 4%of 75	= 3.0	
	4.5	Say Rs. 5/- per %o cft.

3) Masonry works.

Depreciation charges.	1%	
Maintenance Charges.	½%	
Interest charges	4%	
	5½%	Say 5% of the increased cost of masonry works.

For the purpose of comparative study increase in annual cost on the main Canal and saving in annual cost on lift scheme due to adoption of flatter gradient than 1 in 12000 would be considered at the rates mentioned above.

Increase in annual cost on main canal V/S bed slope.

For working out the increase in cost on main canal following assumptions are made:

1) Increase inx the cost on the basis of average, discharge of 12700 cusecs would be reasonably accurate.
2) F.S.Depth in canal with different slopes would be kept as 21 ft. and only the bed width would vary.
3) It is assumed that the canal would tranverse through a similiar type of terrain for different aligaments with different bed slopes e.g. there x would be heavy cutting and bed fillings in the same length of canal for different alignments.

Channel dimensions with different bed slopes.

Keeping the depth as 21 ft. bed widths required for discharge of 12700 cusecs have been worked out with different bed slopes by Manning's formula as shown in the table No.2 below

TABLE NO.2

Bed slope	Discharge in cusecs	N	Bed width in ft.	Depth in ft.	R in ft.	side slope	Velocity in ft./Sec.
1 in 12000	12700	.017	85	21	14.95	2:1	4.77
1 in 15000	"	"	95	"	15.25	"	4.39
1 in 18000	"	"	105	"	15.50	"	4.08
1 in 21000	"	"	115	"	15.75	"	3.81
1 in 24000	"	"	125	"	16.0	"	3.57
1 in 27000	"	"	135	"	16.25	"	3.41
1 in 30000	"	"	145	"	16.45	"	3.26

Increase in annual cost on main canal due to lining.

The total length of main Canal is 426 miles or 2.1×10^6 ft. Increase in cost would be due to bed lining as F.S.D. is kept same. The increase in annual cost at Rs. 6/- per % sft for single tile lining in bed has been worked out in table No. 3

TABLE NO 3

Bed slope	Length of canal in 10^6 ft.	Reqd. bed width.	Increase in bed width thanwith 1/12000	Increase in lining face in 10^6 sft.	Increase in annual cost of lining in 10^6 RS @ Rs.6/- per Sft.
1	2	3	4	5	6
1 in 12000	2.0	85	-	-	-
1 in 15000	"	95	10	20	1.2
1 in 18000	"	105	20	40	2.4
1 in 21000	"	115	30	60	3.6

1	2	3	4	5	6
1 in 24000	2.0	125	40	80	4.8
1 in 27000	"	135	50	100	6.0
1 in 30000	"	145	60	120	7.2

Increase in annual cost due to earthwork.

As the depth of the canal has been kept the same in all the cases, the increase in the cost of earth in cutting reaches where the depth of cutting is less than balancing depth of cutting would be negligible. In reaches where bed filling exists or depth of cutting is more than balancing depth, there would be an increase in the quantity of earth work. It has been estimated that the Rajasthan Canal passes through reaches in 40 miles length where average bed filling is 10 ft and in 200 miles length where average ~~bedxfillingxis~~ depth of cutting (more than balancing depth) is 30 ft.

Increase in earth work due to one ft.increase in bed width $= (200x30+40x10)x5000 = 32 \times 10^6$ cft.

Increase in annual cost of earth work at Rs. 5/- per ~~x~~ %o cft works to Rs. $16x10^6$ per ft.increase inbed width. The total increase in annual cost is worked out in the table No.4 given ~~x~~ below:-

TABLE NO 4

Bed slope	Increase in bed width than with 1 in 12000 gradient	Increase in annual cost due to earth work in 10^6 Rs.
1	2	3
1 in 12000	-	-
1 in 15000	10	1.6
1 in 18000	20	3.2

1	2	3
1 in 21000	30	4.8
1 in 24000	40	6.4
1 in 27000	50	8.0
1 in 30000	60	9.6

Increase in cost due to Masonry works.

The estimated costof masonry works on Rajasthan Main Canal is Rs. 4.3 Crores. The actual cost after 10 years would work out to Rs. 6.5 Crores. Increase in cost of masonry works would be in proporation to increase in water surface width Annual cost at 5% per unit water surface width for bed slope of 1 in 12000 is Rs. $\frac{6,50,000 \times 5}{100 \times 170}$ = 19,100 Say 20,000/- The increase in annual cost is worked out in the table No.5 given below:-

TABLE NO 5

Bed slope	Reqd. bed width	Water surface width=Bed width + 84 say 85 ft.	Annual maintenance cost in 10^6 Rs.	Increase in annual maintenance cost in 10^6 Rs.
1 in 12000	85	170	3.4	-
1 in 15000	95	180	3.6	0.2
1 in 18000	105	190	3.8	0.4
1 in 21000	115	200	4.0	0.6
1 in 24000	125	210	4.2	0.8
1 in 27000	135	220	4.4	1.0
1 in 30000	145	230	4.6	1.2

Total increase in annual costs.

The total increase in annual costs will the sum total of the increase in annual costs due to lining, Earth work and masonry works. Total increase in annual costs for gradients flatter than 1 in 12000 is shown in the table No.6 given below. These costs show increase in annaul costs due to increased sections required for flatter slope as compared 1 in 12000 gradient.

TABLE NO 6

Bed slope	Annual increase in cost due to flatter sopes			
	Lining	Earthwork	Masonty works	Total
	Amount in 10^6 Rs.			
1 in 12000	-	-	-	-
1 in 15000	1.2	1.6	0.2	3.0
1 in 18000	2.4	3.2	0.4	6.0
1 in 21000	3.6	4.8	0.6	9.0
1 in 24000	4.8	6.4	0.8	12.0
1 in 27000	6.0	8.0	1.0	15.0
1 in 30000	7.2	9.6	1.2	18.0

A graph showing increase in annual cost V/S bed slope is in fig 2 ~~figure 2~~

Saving in annual expenditure on lift channels due to different bed slopes.

The details of lift channels proposed on the Rajasthan Canal are shown in table No 7 below

TABLE NO 7

Name of lift channel.	Mileage of off taken from ~~bricks~~ Harike	Length of channel in miles.	Height of lift (Max.)	Gross Lift	C.C.A. in a lac. acres.	Discharge at x head. cusecs
1	181	107	134.5	260	2.5	1000
2	319	80	146	226	2.5	1000
3	399	60	70	130	1.5	750

For the purpose of study it is assumed that one lift channel takes off at mile 300 and the lifts for various discharges would be as shown in Table No.8(a)below:-

TABLE NO 8(a)

Lift in ft.	Discharge in cusecs.	Discharge x head.	Commulative Dis. x head
30	2500	75000	75000
60	2000	60000	1,35,000
90	1500	45000	1,80,000
120	1000	30000	2,10,000
150	500	15000	2,25,000

Due to adoption of flatter gradients, there would be saving in head loss. The head loss so saved at mile 300 of Rajasthan Canal has been calculated in the table No.8(b)

For lifting of one cusec of water by one ft.head at 0.7 capacity factor. 1 KWH$\left(\frac{1x1x7}{14x.5}\right)$ energy would be required.The annual saving in cost for one cusec ft.would work to Rs. 35,53,70,88 & 105 respectively

When the cost of power is 4,6,8,10 and 12 paisa per K.W.H.The total annual saving per cusec ft. would therefore work out to Rs. 39,57,74 92 and 109 say Rs. 40,60,80,100 and 120 resp.when the cost of power is 4,6,8,10 and 12 paisa per K.W.H.

Annual saving in cost due to adoption of flatter gradeients is shown in table No.8b given below:-

TABLE 8 (b)

Bed slope	Bed slope ft./ mile.	Saving in head per mile.	Total saving in head.	Saving in head x Dis. (cusec. ft.)	Annual saving in cost in 10^6 Rs. cost of power per unit is Paisa 4	6	8	10	12
1 in 12000	.417	-	-	-	-	-	-	-	-
1 in 15000	.333	.084	25	62000	2.50	3.75	5.0	6.2	7.5
1 in 18000	.278	.139	41	100000	4.00	6.00	8.0	10.0	12.0
1 in 21000	.238	.179	53	122000	4.88	7.32	9.76	12.2	14.64
1 in 24000	.209	.208	62	140000	5.60	8.40	11.2	14.0	16.8
1 in 27000	.185	.232	70	150000	6.00	9.00	12.0	15.0	18.0
1 in 30000	.167	.250	75	160000	6.40	9.60	12.8	16.0	19.2

Graphs showing saving in annual expenditure on lift channels V/S bed slopes for different unit cost of power are also drawn in figure No.2. The points where this curve intersects the curves determines the economical gradients for different unit cost of power. It would be seen that 1 in 15000 gradient for main canal is economical when the unti cost of power is 6 paisa.

From the above results a curve showing relation between economical gradient and unit cost of power is shown in figure 3(case I)

~~S.C.A to receive lift irrigation facilities economically~~

C.C.A to receive lift irrigation facilities economically with different bed slopes for different cost of unit power.

The above study was conducted keeping in view that the total area as envisaged in the Project report would receive irrigation facilities. Similar studies are conducted to cover the C.C.A. for lifts upto 120 ft, 90 ft, 60 ft. and 30 ft. only. Table No. 9,10,11,and 12 show the calculations for cummulative head x Discharge for various lifts.

TABLE NO 9

Case II Lift upto 120 ft.

Height of lift.	Discharge in cusec.	Head x Discharge.	Cummulative Head x Discharge.
30 ft.	2000	60,000	60,000
60 ft.	1500	45,000	1,05,000
90 ft.	1000	30,000	1,35,000
120 ft.	500	15,000	1,50,000

TABLE NO 10

Case III Lift upto 90 ft.

Height of lift	Discharge in cusec.	Head x Discharge.	Cummulative Head x discharge.
30	1500	45000	45000
60	1000	30000	75000
90	500	15000	90000

TABLE NO 11

Case IV Lift upto 60 ft.

Height of lift	Discharge in cusec.	Head x discharge	Cumulative head x dis.
30	1000	30,000	30,000
60	500	15,000	45,000

TABLE NO 12

Case V Lift upto 30 ft.

Height of lift	Discharge in cusec.	Head x discharge.
30	500	15000

Curves showing relation between head loss and saving in head and discharge are drawn in the figure 4 for the cases I, II, III, IV and V.

From these curves saving in head and discharge for any particular loss of head can be read the corresponding unit cost of power can also be calculated so that the saving due to reduction in lift is equal to the increase in cost due to inder section. The calculations are given in Table 13

A set of curves showing the relation between Height of economical lift V/S Unit cost of Power for various gradients say 1 in 15,000, 1 in 18,000, 1 in 21,000, 1 in 24,000, 1 in 27,000 and 1 in 30000 are drawn in figure 5. Anticipated curve for gradient of 1 in 12000 has also been drawn.

TABLE NO 13

Bed slope	Increase in annual cost due to flatter slope in 10^6 Rs.	Saving in head loss.	Saving in discharge x head. in 10^3 cusec-ft Case I	Case II	Case III	Case IV	CASE V.	Rate of unit power in paisa for which gradient is economical. Case I.	Case II.	Case III	Case IV	Case V.
1 in 12000	-	-	-	-	-	-	-	-	-	-	-	-
~~1 in 15000 3.0 25 62000 50000 37500~~												
1 in 15000	3.0	25	62	50	37	25	12	4.8	6	8	12	24
1 in 18000	6.0	41	100	76	56	35	15	6.0	7.8	11.7	16.9	40
1 in 21000	9.0	53	122	94	68	41	15	7.4	9.5	13.2	21.7	60
1 in 24000	12.0	62	140	108	76	45	15	8.6	11.1	15.8	26.7	75
1 in 27000	15.0	70	150	115	80	45	15	10	13	18.7	33.3	100
1 in 30000	18.0	75	160	120	82	45	15	11.2	15	21.8	40	120

The curves show that if the cost of power is 4 paisa per K.W.H it would be economical to provide lift irrigation facilities for areas upto 150 ft. lift as envisaged in the project. If the cost of power is 6 paisa, it be would economical to provide lift irrigation facilities for areas upto 90 ft. lift with exisiting gradient of 1 in 12000. On the other hand with 1 in 18000 gradient of canal lift irrigation facilities could have been provided to areas upto 150 ft. at the unit cost of power as 6 paisa per K.W.H.

At low cost of power flatter gradients are costlier than providing lift irrigation on the other hand at higher cost of power flatter gradients are economical as compared to lift irrigation. However, for a particular gradient there is certain area which can be irrigated by reasonable lift. From set of curves in figure 5 economical lifts for different slopes can be read directly. Similiar economical gradients should be calculated for Branches, distributaties and minors on lift channels to arrive at the most economical proposition.

C H A P T E R - 11

SCOPE FOR RESEARCH.

CHAPTER 11

SCOPE FOR RESEARCH.

Although a lot of work has been done during recent past on the various problems in connection with lining such as design considerations, constructional procedures etc. but the literature available is mostly empirical. According to Professor Danel "Empirical knowledge, however, glorious it may be at times suffers from the disadvantage of being very different to convey readily to other people or to discuss in a meeting. Further more it suffers from something worse, it can never prove its case completely in that although it may produce working solutions it cannot prove they are the most economical and most efficient. The change that they even are generally remote2.

Techniques for the determination of seepage losses of a canal prior to its construction or even after are either very costly or not reliable. Therefore need for improved techniques that are accurate as well economical is felt to determine the actual losses in the field.

Reliable estimates for the determination of life of different types of linings are not available. It has however been established that the life of concrete or tile lining is more than 40 to 50 years. For other types of linings results for a life span of 10 to 15 years are available. For the present the economics of lining is determined from the figures of initial cost of construction as the cost of maintenance are not available. For the purpose of determination of most economical type of lining, its maintenance costs are also necessary. It is also necessary to know the various forces acting on the lining and cheap means to counteract these forces without adding much to the cost of lining.

Research work on the development of new materials or on the improvement of known materials is still in the stage of development. It is just possible that the new materials to be developed may change the techniques of construction. In case of old unlined canals it is not possible to adopt the present methods for their lining. This is because of the fact that period of construction required for conventional type of lining is great as normally closures are not possible. In addition to this the cost of construction in lining these canals is also high.

Lacey's or Kennedy's theories for design, canals free from trouble of silting are applicable for unlined canal or at the most can be made applicable for small lined canal. For big lined canals studies on models or prototype structures are necessary to find out the gradient/section of the canal that will be free silt trouble.

The cost of generation of power is high with the result the expenditure on lifting of water is very heavy. By provi flattest possible slopes (that may not endanger the canal wit silting problem) the height of lift can be reduced considerab there by the cost also.

The need for standralisation of canal section is being felt. This would simplfy the various construction procedures.

CHAPTER - 12

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