LININGS FOR CANALS

by

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
PURPOSE OF LINING	2
TYPES OF LINING	13
Concrete Lining	13
Shotcrete Lining	15
Asphaltic Lining	16
Earth Material Lining	17
Plastic Lining	19
DESIGN OF LINING	20
SELECTION OF TYPE OF LINING	31
ECONOMICS OF CANAL LINING	40
CONCLUSION	48
REFERENCES	49
ACKNOWLEDGMENTS	50

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LIST OF TABLES

Table		Page
1	Estimated water losses in unlined conveyance systems.	4
2	Seepage losses for unlined canals and some typical linings.	6
3 (a & b)	Comparative dimensions of concrete-lined and unlined canals	11 & 12
4	Manning's coefficient of roughness (N) for unlined and lined canals	22
5	Tentative standards for covers using non-cohesive materials for buried asphalt membrane lined canals .	27
6	Approximate proportions for thick compacted-earth linings.	31
7	Physical properties of soils and their uses for canal linings.	32
8	Irrigation canal linings and their main features . .	34
9	Formats for cost analysis of lined and unlined canals	44

LIST OF FIGURES

Figure		Page
1	Typical canal lining joints.	14
2	Determination of thickness of hard-surface lining based on canal capacity.	25
3	Typical section of a compacted earth-lined canal . .	30
4	Comparative cross sections of an unlined and a concrete-lined canal	41

INTRODUCTION

Irrigation has been practiced from time immemorial and so has been the building of irrigation canals; but it is only since the last century that canals have been designed on a more or less scientific basis. Conveyance and distribution of water are an integral part of an irrigation project. Irrigation systems should be built in such a way that they operate at maximum efficiency. It is very important to store, transport and use the available water without undue loss through evaporation or leakage. Often, lining irrigation canals to prevent seepage losses, which average 40 percent of the water transported in unlined canals, is justified on a purely economic basis. Certainly the loss of this valuable water cannot be tolerated (7).

Approximately 3,900,000 acre-feet of 15,650,000 acre-feet of irrigation water supplied to Bureau of Reclamation projects in 1949 were lost through seepage from canals and laterals, according to records obtained from 46 operating projects. These same records indicate an average annual delivery to the farmer of 3 1/2 acre-feet of water per acre. On the basis of this average delivery, the 3,900,000 acre-feet of water lost would have been more than enough to irrigate an additional 1,000,000 acres (10).

The efficiency of the conveyance and distribution system--that is, the transport of water at minimum cost and with minimum water loss--therefore essentially affects the total economy of an irrigation project. Seepage losses may be and have been satisfactorily reduced through the installation of relatively impervious linings or by special treatment of canal section. Determination of the need to line should be based on an analysis of benefits such as water conservation, reduced water logging or lower drainage requirements, reduced excavation and right-of-way cost, lower operation and maintenance costs and structural safety.

Materials used for canal lining are of almost infinite variety, but they can be generally categorized as hard-surface, membrane and earth linings. No particular type of lining is lowest in cost or most satisfactory for use in all locations. Almost every type of lining has its specific merits. Selection should be based on a careful analysis of local conditions such as availability and cost of labor, mechanical equipment and construction materials, transport facilities, anticipated irrigation method, and canal operation, traditional lining techniques and maintenance requirements.

PURPOSE OF LINING

Lining of an irrigation canal is justified economically when its cost can be repaid in benefits during the life of the lining. Some of the more important tangible benefits resulting from lining irrigation canals--those that can be evaluated with some accuracy--are savings of water that would otherwise be lost through seepage, reclamation of water-logged lands, lower maintenance and operation costs, and reduced right-of-way requirements. Some additional benefits from lining canals, such as prevention of bank erosion and better control and more uniform distribution of water, are difficult to evaluate from a monetary standpoint, but should be given consideration when the value of a lining is being appraised. The more important reasons for lining canals which, under certain conditions, will justify the expense of constructing the lining are (10):

a. to reduce losses of water from the canal,

b. to prevent damage to lowlands by seepage from the canal,

c. to reduce operation and maintenance costs,

d. to increase the capacity of the canal,

e. to reduce construction costs,

f. to prevent failure of canal.

Consideration of any one or more of the above factors may justify the cost of lining a canal and the dominating factor may dictate the type of lining to be installed. The first two of the above reasons (the reduction of water losses and the prevention of seepage damage) are becoming increasingly important as the complete utilization of our natural water resources is approached and as the ultimate development of older projects exposes the damages of a raising groundwater surface resulting, in part, from canal water losses. Water losses in unlined conveyance systems are usually high. These are shown in Table 1, which shows estimates from various sources (5). Lining a canal will not completely eliminate losses, but it will reduce the losses. Some authors state that roughly 60 to 80 percent of the water lost in unlined canals can be saved by hard-surface lining. Table 2 shows measured or calculated seepage losses in various unlined and lined canals, demonstrating the scope of possible seepage reduction with different types of lining. The table may also serve as a guide in determining the need for lining in cases where specific figures on seepage losses cannot be obtained by tests, calculations or comparisons (5).

The value of the water lost is not the only monetary loss that can be charged to seepage. According to the report of the Bureau of Reclamation, the value of water saved through the installation of canal linings

Table 1

Estimated Water Losses in Unlined Conveyances Systems(5)

Country (project)	Water losses as percent of total water diverted	Remarks
46 irrigation projects in the U.S.A.	3-86 (average 40)	Records from 46 irrigation projects, including seepage water taken up by uncontrolled vegetation in canals and evaporation losses of canals
West Pakistan	18-44	Seepage losses only
West Pakistan: Indus River Basin	35	Mean figure of total conveyance losses
West Pakistan: Bari Doab Canal	20	Canals and branches
	6	Distributaries
	21	Water courses (ditches
	47	Total losses
Mexico	26	Less pervious soils
	35-50	More pervious soils
Turkey:		
Konya Cumra Plain	40	
Menemen Plain	30	
Egypt:		
Nile Delta area	8-10	Low because of silting effect of Nile water
New canals in desert areas	50	
U.S.S.R.	20-35	Mains and distributaries
India:		
Ganges Canal	15	Main canals and branches
	7	Distributaries
	22	Water courses
	44	Total seepage losses
Pakistan:	Maximum 40	Total seepage losses
Kushita unit of the Ganges-Kobadak Irrigation Scheme	5.7	Main canals
	7.3	Secondary canals
	12.0	Tertiary canals
	25.0	Total seepage losses

Table 1 (continued)

Country (project)	Water losses as percent of total water diverted	Remarks
Iran: Garmsar Irrigation Project	40	Main and secondary canals
Huasco Valley Project	54 (ca. 2.2/km)	Canal 25 km in length having about 1 m^3/sec discharge capacity
U.S.S.R.: Kara Kum Canal, 400-km reach; 28 to 6 m; sandy soils	43	Average loss during first year of operation; losses decreased in subsequent years as water table rose
Algeria: El Arjiane	40	Average losses in channels dug in sandy soil
Punjab Province	11	Average losses in 44,000 water courses equal to 7,000 million m^3 per year

TABLE 2. — SEEPAGE LOSSES FOR UNLINED CANALS AND SOME TYPICAL LININGS (5)

SEEPAGE LOSSES CUBIC METRES PER SQUARE METRE OF WETTED PERIMETER IN 24 HOURS: 0.1 – 0.2 – 0.3 – 0.4 – 0.5

SEEPAGE LOSSES CUBIC FEET PER SQUARE FOOT OF WETTED PERIMETER IN 24 HOURS: 0.1 – 0.2 – 0.3 – 0.4 – 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1.0 – 1.1 – 1.2 – 1.3 – 1.4 – 1.5

CATEGORY	For additional information, refer to same no. in notes on p. 9	EXPLANATIONS	
UNLINED CANALS	1	0.25 – 0.35 " impervious " clay loam	
		0.35 – 0.50 medium clay loam underlaid with hardpan at 2 - 3 ft or less below bed	
		0.50 – 0.75 ordinary clay loam, silt soil or lava ash loam	
		0.75 – 1.0 gravelly clay loam or sandy loam, sand and clay	
		1.0 – 1.50 sandy loam	
		1.50 – 1.75 loose sandy soils	
		2.0 – 2.50 gravelly sandy soils	
		3.0 – 6.0 very gravelly soils	
	2	0.34 cemented gravel and hardpan with sandy loam	
		0.41 clay and clay loam	
		0.66 sandy loam	
		0.68 volcanic ash	
		0.98 volcanic ash with some sand	
		1.20 sand and volcanic ash or clay	
		1.68 sandy soil with some rock	
		2.20 sandy and gravelly soil	
	3	0.27 alluvium (yellow silty clay layers)	
	4	0.71 fine to medium sand	
	9	1.12 silty loam	
CEMENT CONCRETE LINING	5	0.03 – 0.059 average water depth 3 - 5.5 ft; 0.04 – 0.225 " " " 2.5 - 4 ft } average value of 5 ponding tests	
	6	0.231 – 0.374 3 tests, average depth: below 1 ft ; 2 in concrete	
	–	0.03 – 0.16 measured on concrete-lined canals, Lower Rhone-Languedoc irrigation scheme, France	(F7)
	–	0.07 3 ½ in concrete; Friant Kern Canal, Central Valley, California, water depth 17.2 ft	(A1)
	7	0.53 4 in thick concrete, seepage measured by inflow - outflow	
	–	0.008 reach 1; 0.09 reach 2 } Contra Costa Canal, Central Valley Project, California } design discharge 140 cusecs; reinforced concrete, design depth approx. 5 ft	(A1)
	–	0.16 - seepage tolerance used for calculations (Lower Rhone - Languedoc, France)	(F7)
CONCRETE BLOCKS	–	0.43 unlined adjacent control reach (wetted perimeter 28.4 ft); 0.20 lined reach (" " 25.1 ft) } " D " - Line Canal, Boise Project, Idaho	(A1)
SHOT-CRETE	–	0.08 immediately after installation; 0.27 15 years " " } 3 in unreinforced air-entrained concrete, Swift Current A Lateral, Canada	(B30)
	–	0.20 immediately after installation; 0.35 15 years " " large cracks } 1 ½ in. unreinforced shotcrete, no air entrainment, Swift Current A Lateral, Canada	(B30)

Table 2 (continued)

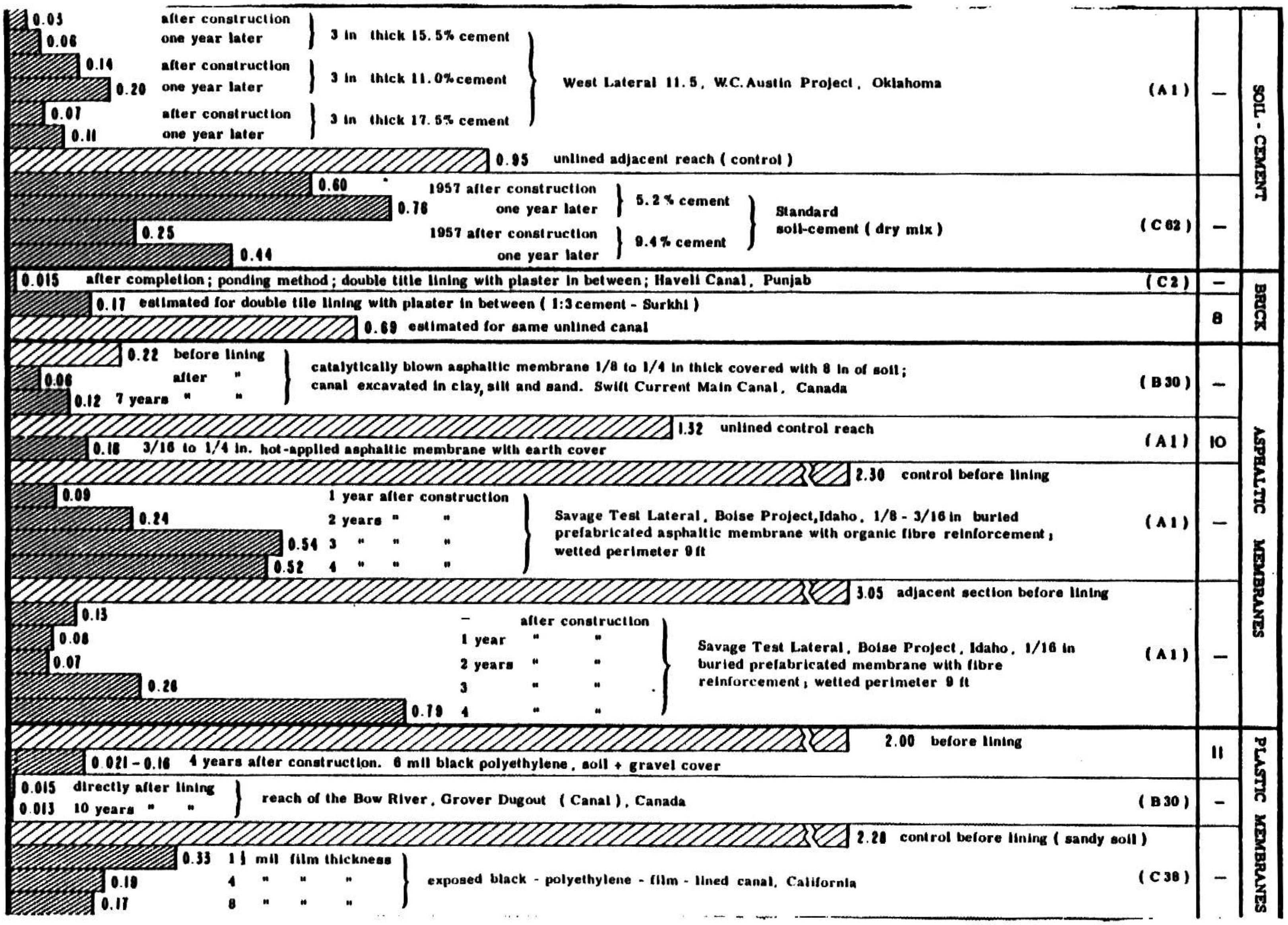
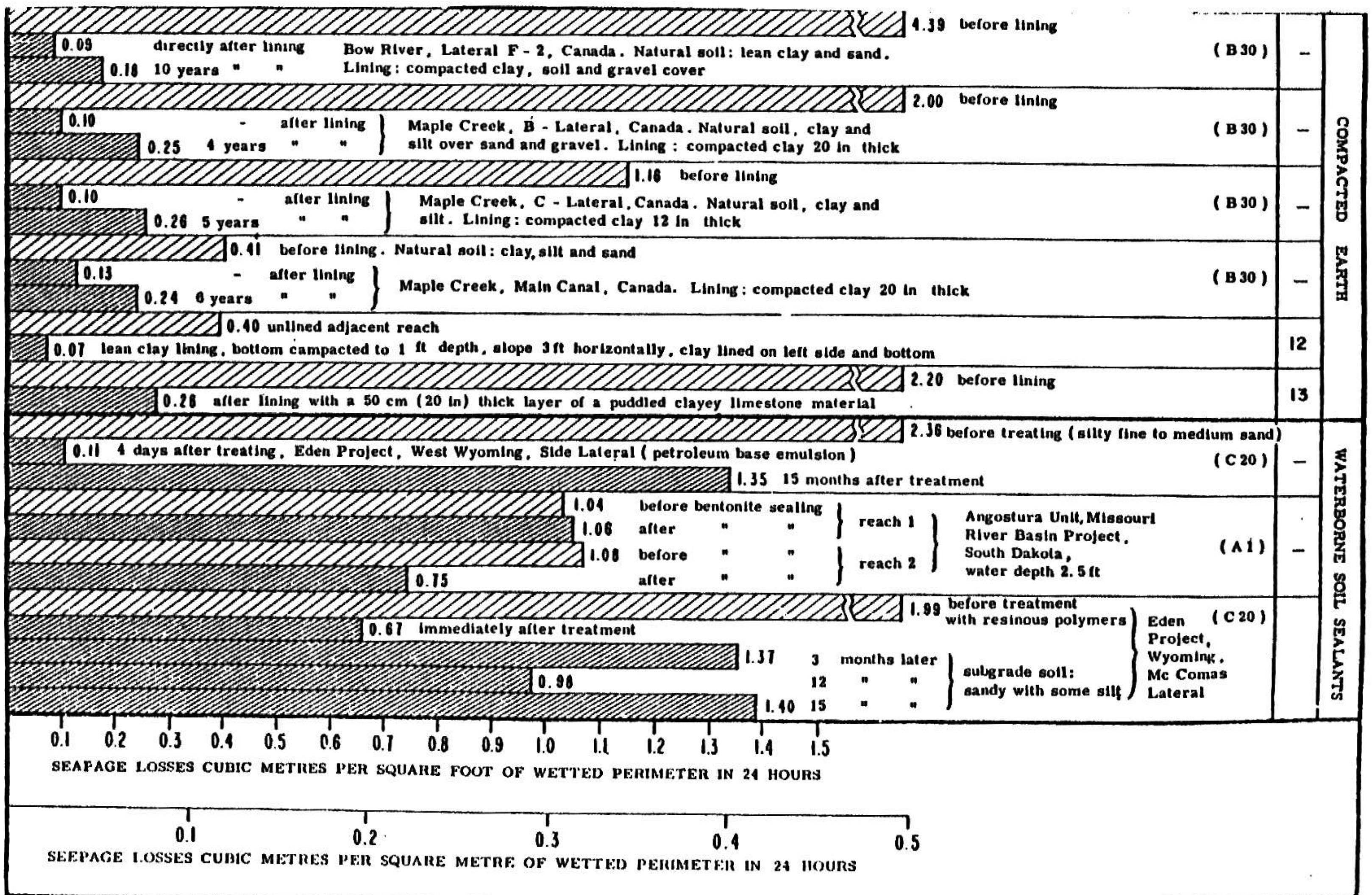


Table 2 (continued)



Notes to Table 2

1. Average conditions for canals not affected by the rise of groundwater owing to seepage. The higher values are for comparatively new canals. Seepage loss usually decreases noticeably with age, particularly if the water carries sediments (A7).

2. Data compiled by the U.S. Bureau of Reclamation on actual seepage losses in canals excavated through certain types of soil. They represent average losses from observations on eight different projects (A9).

3. Measured by ponding test in an unlined 17 000 ft (5 182 m) reach of the Right Main Canal, Chambal Commanded Area, India (B26). Water table: 3 ft (ca. 1 m) below canal bottom; mean wetted perimeter: 167 ft (51 m). Canal had been in service for eight years.

4. Average of six ponding and six seepage-meter tests on the Interstate Lateral 24A, North Platte Project, Wyoming, U.S.A. (A1).

5. East Contra Costa Canal, basin 2 + 3, U.S.A. (A9).

6. E-W Farm Lateral, Fort Collins, Colorado, U.S.A. (A9).

7. West Canal, Rio Grande Project, New Mexico-Texas, U.S.A. Average figure from three test reaches (A1).

8. Bhakra Main Canal, India (C2). Bed width: 52-63 ft (16-19 m); water depth: ca. 20 ft (6 m).

9. Mean seepage rate on main canal: approximately 110 m^3/sec; capacity: 4-5 m deep. Mexico (A3).

10. Lateral R-4-S, Shoshone Project, Wyoming, U.S.A. (A1). Design capacity: approximately 85 ft^3/sec (2.4 m^3/sec); water depth: 2.1-2.2 ft (0.64-0.67 m).

11. Two reaches of the Bow River—F-5 Lateral, Canada, excavated into loam on sand and gravel. No information on canal size (B30).

12. Conchas Canal, Tucumcari Project, New Mexico, U.S.A. (A1). Canal capacity: 700 ft^3/sec (19.8 m^3/sec); water depth as tested: 7 ft (ca. 2 m).

13. Supply canal, Abda Donkkala, Morocco. Canal capacity: 16 m^3/sec. Losses before lining refer to sandy regions "where the land was very porous" (A3).

from 1946 to 1952 was approximately $1.6 million. The value of adjacent farmland that was saved from waterlogging was over $2.2 million. The savings made by the canal linings in the Gering-Fort Laramie Irrigation District of the North Platte Project in Nebraska are typical. About 6,800 ft. of a lateral canal were lined with concrete in 1950. Seepage loss measurements made before and after the lining was placed indicate that at least 440 acre-feet of water, value $900, are now saved each year. More important is the fact that 740 acres of land that had been waterlogged have been reclaimed and are back in production, while an estimated 300 additional acres that were threatened with waterlogging have been saved. The value of this land is about $185,000, while the cost of the lining was only $32,500. The economic justification in this case is obvious (7).

In canals lined with exposed hard-surface materials, greater velocities are permissible than are normally possible in earth canals. The maximum non-erosive velocities for different soils are (13):

Fine sand under quicksand condition	- 0.20-0.30 m/sec
Sandy soil	- 0.30-0.75 m/sec
Sandy loam	- 0.75-0.90 m/sec
Loam to clay loam	- 0.85-1.10 m/sec
Stiff clay	- 1.10-1.50 m/sec

They range roughly from 0.3 to 1.8 m/sec, while the flow velocities for concrete and brick linings range from 1.5 to 2.5 m/sec. Table 3 shows the relative quantities of water which can be transported through a concrete-lined canal and an unlined canal of the same size (5).

Concrete-lined $n=0.014$								Unlined $n=0.025$				
Side slopes, $h:v$	b, ft.	d, ft.	Hp, ft.	Hc, ft.	W, ft.	Approximate capacity, Q, cfs	Grade, s	Side slopes, $h:v$	b, ft.	d, ft.	Hc, ft.	W, ft.
1:1	1.0	1.5	1.9	3.0	8.7	10	0.0010	1.75:1	2.0	1.4	2.9	12.2
1.5:1	2.0	1.8	2.3	3.3	12.4	25	0.0008	1.75:1	3.0	2.1	3.6	15.6
1.5:1	3.0	2.4	3.0	4.2	16.2	50	0.0006	1.75:1	5.0	2.6	4.4	20.4
1.5:1	4.0	3.2	3.8	5.2	20.3	100	0.0005	1.75:1	7.0	3.5	5.5	26.3
1.5:1	6.0	4.2	4.9	6.6	26.7	200	0.0004	1.75:1	10.0	4.6	7.0	34.5
1.5:1	7.0	6.7	7.9	9.6	36.7	500	0.0003	1.75:1	16.0	6.6	9.6	49.6
1.5:1	10.0	9.5	11.1	12.7	48.9	1,000	0.0002	1.75:1	24.0	9.0	12.5	67.7

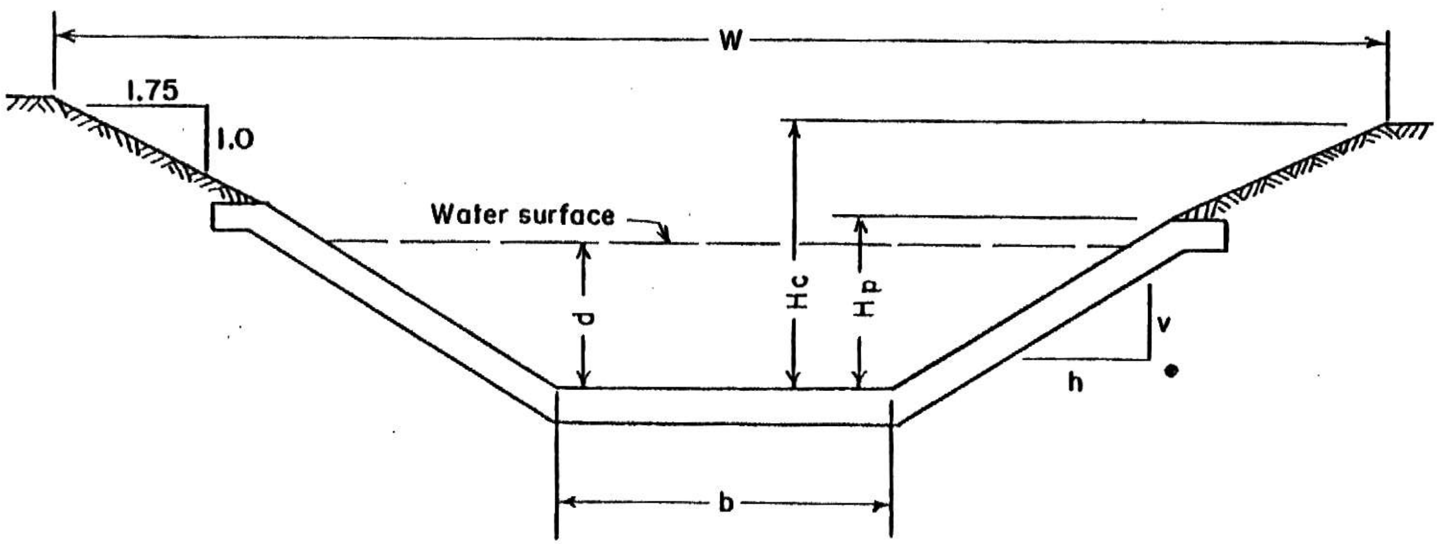


Table 3. Comparative Dimensions of Concrete-Lined and Unlined Canals (7)

Table 3 (b)

Bottom width	Flow depth	Quantity m^3/sec	
		Concrete-lined	Unlined
0.30	0.45	0.40	0.23
0.90	0.60	1.27	0.71
1.20	0.75	2.40	1.33
1.50	0.90	4.00	2.24

Table 3 (a), with the accompanying diagram, illustrates the comparative efficiency of concrete-lined and unlined irrigation canals (7).

Greater velocities in canals reduce maintenance costs when silting is a problem and resulting in increased discharges offer the advantage of shorter irrigation time.

Estimation of maintenance costs can be obtained from data for existing lined and unlined canals operating under similar climatic, geographic and agricultural conditions. The following data on maintenance costs may serve as a guide for estimating lining benefits (5).

In the United States, studies of operation and maintenance costs for 1,300 miles of lined and unlined canals in various parts of the country, based on reports covering a two-year period, showed a 75 percent reduction when hard-surface linings were used.

In India, an average of two man-days are necessary for maintaining about 40 m of unlined field canal in a year. With lined canals there is a savings of about 50 percent in labor. Wineland and Luras assumed $2 per metre of canal per year as the difference in maintenance and operation cost between a thick compacted earth-lined and a concrete-lined canal of equal capacity.

Some records in the U.S.S.R. indicate that for concrete-lined canals the saving in maintenance costs may be as much as two-thirds the cost of maintaining earth canals of similar capacity. In the lower plain of the Sequra, Spain, a study was made and concluded that lining resulted in savings equivalent to 0.34 man-days per running metre of canal per year.

Substantial savings may also be effected by reduced pumping costs due to more efficient water use. For the Ganges-Kobadak Irrigation Scheme, India, it was estimated that savings in pumping costs alone would justify canal lining.

TYPES OF LINING

Types of lining are commonly classified according to materials and methods used in their construction. The principal types are (1 to 13):

1. Concrete lining
2. Shotcrete lining
3. Asphaltic lining
4. Earth material lining
5. Plastic lining

Concrete Lining - concrete linings are the best type of lining where benefits jusitfy high lining costs. Concrete lining fulfills practically all purposes of lining. Thickness of linings usually vary from about 1 to 6 inches. Thickness depends principally on canal sizes, bank stability, amount of reinforcing and climatic conditions. Concrete lining is suitable for all sizes of canals, all topographical, climatical and operational conditions. Figure 1 shows the typical canal lining joints.

Advantages:

1. More resistant to erosion than most other lining materials.
2. Eliminates weed growth, resulting in improvement in flow characteristics.

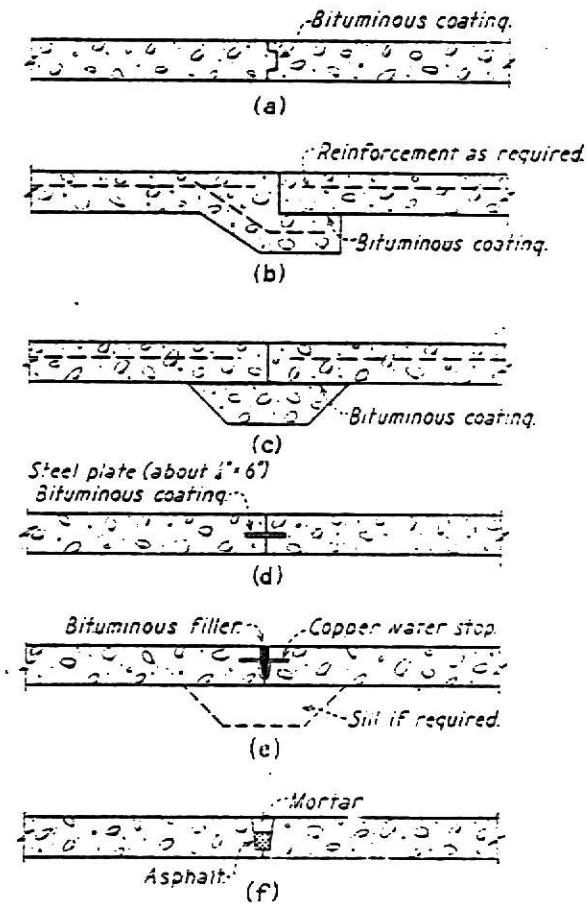


Fig:1-Typical canal-lining joints.

3. Suitable for both large and small canals; for both high and low velocities.
4. Durability is more.
5. Water losses are less.

Disadvantages:

1. Lack of extensibility, which results in frequent cracks as contraction takes place from drying, shrinkage and temperature change.
2. Cost is more.
3. Damage is caused by water pressures under the bottom or back of the sides.

The above said disadvantages can be overcome by providing weep holes in the linings and by using suitable filling compounds in the cracks.

<u>Shotcrete Lining</u> - shotcrete is a term adopted to designate pneumatically applied portland cement mortar (mortar which is shot into place by pneumatic pressure). Shotcrete is widely used for both lining and resurfacing of irrigation canals and ditches. Because of the small amount of construction equipment required and its mobility, this process is well suited to construction or repair work on small or widely scattered canal lining jobs, and also on laterals and farm ditches with frequent sharp curves. Shotcrete linings placed by the Bureau of Reclamation are usually 1 1/2 inches thick. However, shotcrete lining varies from about 1 to 3 inches in thickness. The greater thickness of lining facilitates the proper placing of reinforcement and also provides greater strength. On an average, the area of reinforcement steel, when used in shotcrete lining, is about 0.1 percent of the area of the lining. The cost of

lining is dependent on the thickness of lining, use of reinforcement, provisions for joints, size of the job, availability of materials and competitive interest (12).

Advantages:

1. Can be easily placed over a rougher subgrade than concrete linings.
2. Installation costs usually are lower than concrete linings.

Disadvantages:

1. More rapidly damaged by hydrostatic pressures and by settlement.
2. Difficulty in controlling the thickness of the shotcrete.

Asphaltic Lining - since asphalt is comparatively inexpensive and is manufactured in many types, grades, and compositions, numerous variations are possible in its application to the lining and waterproofing of canals. The Bureau of Reclamation has investigated a considerable number of methods of use and types of asphaltic linings. The two principal types are 1) hot mixed asphaltic concrete and 2) buried asphaltic membrane.

Asphaltic concrete is a combination of asphalt cement and aggregate mixed, placed and compacted in a hot and plastic state. This type of lining appears to be particularly well adapted to smaller canals. For best results, asphalt-cement should have a penetration of about 50 to 60. Aggregates should be well graded. Batches of asphaltic concrete should be mixed at a temperature of about 325°F. Linings are usually made about 2 inches thick.

Buried asphalt membrane lining is a membrane (approximately 3/8 of an inch thick) of a special asphalt sprayed in place at a high temperature (400°F) to form a waterproof barrier which is held in place and protected against injury and weathering (buried) by a layer of earth and gravel.

In the second type, a prefabricated asphalt membrane is laid on the subgrade and covered with earth or gravel in the same manner as the hot placed membrane (12).

Advantages:

1. Greater ability of the lining to adjust itself to subgrade changes.
2. Can be placed in cold weather or any season with a minimum protection.
3. Cost advantage over concrete lining.

Disadvantages:

1. Inability to carry high velocities.
2. Shorter service life.
3. Low resistance to weed growth.
4. Insufficient resistance to external hydrostatic or soil pressures.

Earth-material Lining - canal linings of natural or processed soils often prove economical for the reduction of seepage and stabilization of banks if suitable materials are available from the canal excavation or from nearby borrow areas. The principal earth-type linings include loose-earth blankets, compacted earth linings, buried bentonite membranes, soil-cement lining. Thick compacted earth linings of selected materials are the satisfactory type of lining. Most types are comparatively inexpensive but require high expenditure for maintenance.

Loose-earth blankets are constructed by dumping fine-grained soils on the sub-grades and spreading to thickness of from 6 to 12 inches. This is of limited use.

Compacted earth lining is the lowest cost permanent type of lining where suitable materials are available at job site. Soils suitable for compacted earth linings include sand and gravel type, containing enough fine particles to insure impermeability when compacted. Gravel covers are desired for thin linings. Compacted earth lining includes two types--thin compacted and thick compacted. Thin types are usually about 6 to 18 inches thick along the entire perimeter and thick types are about 2 feet to 3 feet. Actual thickness for both types are varied in accordance with characteristics of lining material. The soil must be homogeneous when placed, of proper thickness and compacted at proper moisture content to the prescribed density.

Buried bentonite linings are constructed by spreading soil-bentonite mixtures over the subgrade and covered with from 6 to 12 inches of gravel or compacted earth. Membranes of sandy soil mixed with from 5 to 25 percent of bentonite and compacted to a thickness of 2 or 3 inches are generally tougher and more permanent than thin bentonite membranes. Fine-ground bentonites are preferred for membrane construction. Soil-cement linings are constructed with mixtures of cement with the soil of the canal subgrade and water. The lining is made by mixing cement and soil in a 4 to 6 inch thick layer at a ratio of 1:4 to 1:6. Mixing is done by two methods: 1) by mixing in place and compacting at optimum moisture content, or 2) by machine-mixing with water to about the consistency of concrete and placing with slip-form equipment. The first method is called dry mixed soil-cement and the second, plastic-soil cement. Soil used in mixing soil-cement should not contain more than about 35 percent of silt and clay particles.

Advantages:

1. Cost is less.
2. It can withstand considerable hydrostatic pressure without loss of effectiveness.
3. Ease of constructing partially lined sections or reaches, as required to cut off permeable strata or areas.

Disadvantages:

1. Most earth-type linings do not prevent weed growth.
2. Do not withstand higher velocities.
3. Soil-cement lining is costly to construct.

<u>Plastic Lining</u> - The most suitable plastic lining material proved to be polyethelene, vinyl and PVC. Vinyl is costly though it is best. Both exposed and buried plastic linings have been used and buried plastic membranes have proved to be considerably more durable than exposed linings. Plastic lining must be covered with a minimum of 1 foot of earth material for protection against the elements and physical damage. Plastic lining is restricted to canals where 1) earth cover is not objectionable, 2) velocity flow is low enough to prevent erosion of earth cover, and 3) flat slope canal banks can be constructed to provide a stable earth cover condition.

Normally, maintenance of plastic linings is limited to repair of the cover material. According to field tests, polyvinyl-chloride plastic lining is more resistant to puncture, more readily available in larger fabricated pieces and more easily repaired. But the principal advantage of polyethylene lining over PVC plastic lining is its lower cost. Also polyethylene is not as susceptible to stiffening or loss of elongation on aging under buried conditions as is PVC lining.

DESIGN OF LININGS

Hard-surface Linings - this category includes all exposed linings constructed of cement concrete, soil-cement, asphaltic materials, brick and stone.

General Design Considerations (5):

Cross-section

Since the cost of hard-surface linings is usually high, the section with the smallest perimeter for a given area is the most economical. From experience, the steepest satisfactory side slopes for most canals from both construction and maintenance viewpoints is 1.5 to 1. Canals provided with a hard-surface lining are usually designed with a finished bed-width to water-depth ratio of 1 to 2.

Sub-grade

A primary prerequisite to the success of most hard-surface linings is a firm foundation in order to reduce the amount of cracking and the danger of failure due to settlement of the sub-grade.

Embankments

For most hard-surface linings, the canal embankment must be compacted at least to the height of the lining. The embankment material should be placed at a specified moisture content and compacted to a specified density in layers not more than 6 inches thick after compaction.

Drainage

Where the groundwater is likely to rise above the bottom of the lining, drains must be provided underneath or alongside the canal to relieve any hydrostatic pressure which might cause uplift of the lining when the canal is empty.

Water Velocities

Hard-surface linings permit higher velocities, but velocities in unreinforced concrete linings should not exceed 2.5 m/sec (8 ft/sec) to avoid the possibility of lifting.

Coefficient of Roughness

The coefficient of roughness used in the design of canals represents an evaluation of the degree of roughness of the lining surface and its retarding effect on the flow of water. Coefficient of roughness should not be based on the degree of original surface finish applied to the lining, but rather on the surface that will exist after a few years of operation. Coefficient of roughness, according to Manning's formula for the design of different types of linings adopted in different countries, is given in Table 4.

Manning's formula:

$$v = \frac{1}{n} \times R^{2/3} \times s^{1/2}$$

where

v = velocity

n = coefficient of roughness

R = hydraulic radius

s = longitudinal bed or water surface slope.

Rate of flow is inversely proportional to the roughness of the lining surface.

Design of Cement Concrete Lining

Thickness of Lining - no general rule has been given for establishing the thickness of concrete linings. Figure 2 shows the thickness normally used for several hard-surface linings in

Table 4

Manning's Coefficient of Roughness (N) for Unlined and Lined Canals [5]

Surface conditions	Value of n	Reference
Unlined canals		
Smooth natural earth canals, free from weed growth, little curvature	0.020	(F4)
Small canals in good condition	0.025	(F4)
Earth canals with considerable aquatic weed growth	0.030-0.035	(F4)
Earth canals with thick aquatic weed growth	0.040-0.050	(F4)
Rock canals - main canals	0.030-0.035	France (A16)
- small canals	0.035-0.040	France (A16)
- smooth and uniform	0.025-0.040	Pakistan (A16)
- jagged and irregular	0.035-0.050	Pakistan (A16)
Lined canals		
CEMENT CONCRETE		
- exceptionally good finish (rare)	0.011	India (A16)
- very well-finished linings	0.013	U.S.S.R. and other countries (A16)
- well-finished for straight canal reaches	0.013	France (A16)

Table 4 (continued)

Surface conditions	Value of n	Reference
- worldwide adopted value for well-finished linings	0.014	(A1, A16 and others)
- worldwide adopted value for average finished linings	0.015	(A16 and others)
- widely adopted value for poor finish or for curved reaches (France)	0.017	(A16 and others)
- poorly finished, badly maintained canals	0.018	India, Pakistan (A16)
ASPHALTIC CONCRETE		
- machine placed	0.014	United States (A1)
- smooth	0.014	Japan, U.S.S.R. (A16)
- rough	0.017	Japan, U.S.S.R. (A16)
SOIL-CEMENT		
- well-finished	0.015	(A3)
- rough	0.016	(A3)
CEMENT MORTAR (hand finished)		
- normal	0.013	Pakistan (A16)
- maximum	0.015	Pakistan (A16)

Table 4 (continued)

Surface conditions	Value of n	Reference
SHOTCRETE (Gunite)		
- normal	0.017 0.018	United States (A1) Australia (A16)
- maximum	0.019 0.023	Pakistan (A16) Pakistan (A16)
PRECAST CONCRETE BLOCKS (slabs)	0.015-0.017	Japan (A3)
PRECAST CONCRETE FLUMES	0.012-0.016	Japan (A16)
BRICK		
- brickwork in cement mortar	0.013-0.017	India (A16)
- exposed brick surface (design figure)	0.0146	India (A3)
- exposed brick surface (actual measured value)	0.018	India (A3)
STONEWORK	0.018-0.0225	India (A16)
DRY RUBBLE MASONRY	0.023-0.035	Japan (A16)
EXPOSED PREFABRICATED ASPHALT MATERIALS	0.015	United States (A1)
BURIED MEMBRANE AND COMPACTED EARTH LINING		
- small canals	0.025	United States, Japan (A16)
- large canals	0.020-0.0225	United States (A1)

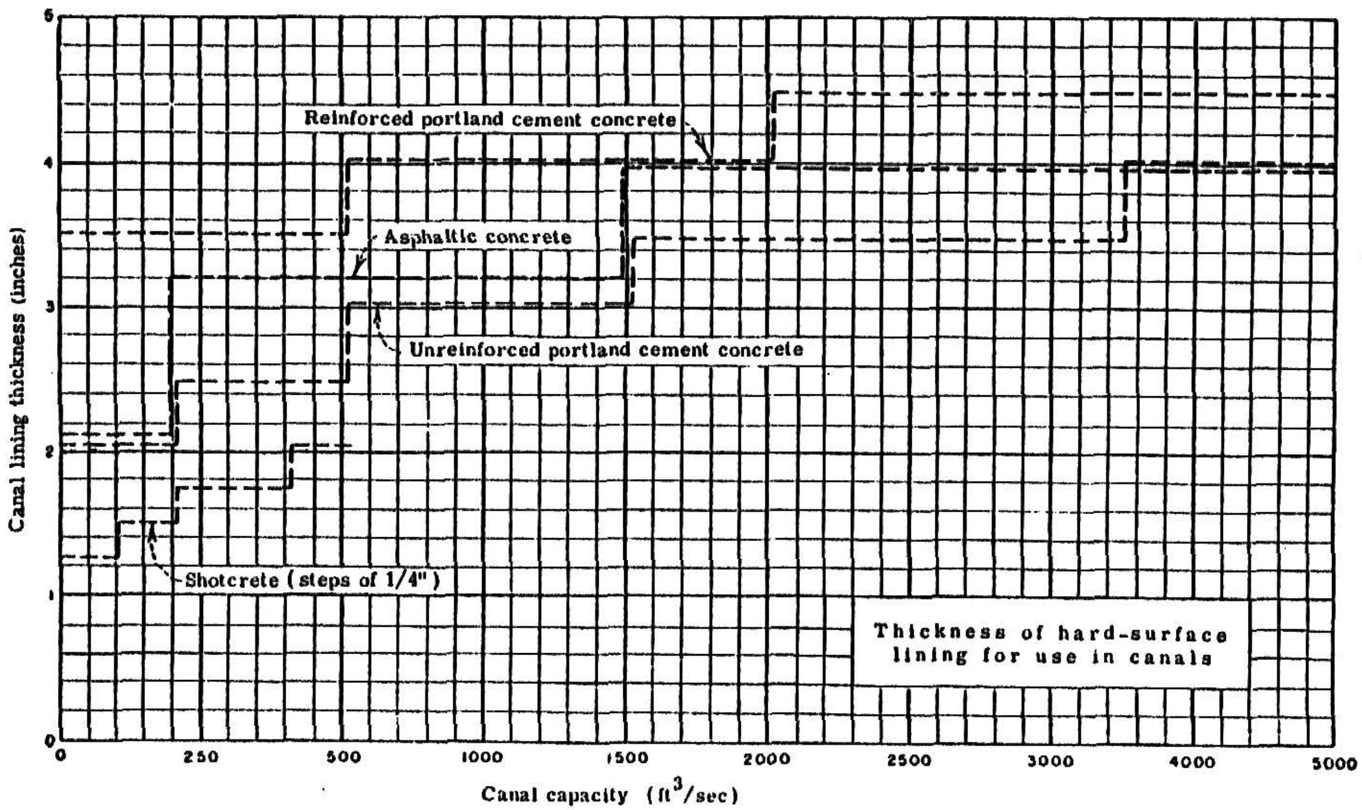


Fig. 2: Determination of thickness of hard-surface lining based on canal capacity (USBR)-(8)

relation to canal capacity as recommended by the U. S. Bureau of Reclamation. If surface deterioration in a freezing climate is expected, these thicknesses should be increased and an allowance made for the increased roughness resulting from the deteriorated surface (5). Table 5 shows the tentative standards for covers using non-cohesive materials for buried asphalt membrane lining, as recommended by the U. S. Bureau of Reclamation (12).

Reinforcement - during recent years, reinforcement has been omitted wherever possible to reduce construction costs. The use of reinforcement steel is of no material benefit if transverse joints are provided at sufficiently frequent intervals to control immediate cracking. The necessary area of reinforcement can be found with the following formula:

$$A = \frac{L \times f \times w}{25}$$

where

A = the area in square inches of steel per foot of width in the direction in which L is measured

L = distance in feet between free transverse joints in computing longitudinal steel or between free longitudinal steel or between free longitudinal joints or edges in figuring transverse steel

f = coefficient of friction between slab and sub-grade (varies from 0.5 to 3.0, depending upon sub-grade material)

w = weight of the concrete slab in pounds per square foot

s = allowable working stress in steel in pounds force per square inch (usually assumed to be about one-half the ultimate strength of the steel).

The amounts of steel generally vary from about 0.10 to 0.4 percent of the area in the longitudinal direction and from about 0.10 to 0.20 percent of the area in the transverse direction (4,6).

Table 5
Buried Asphalt Membrane Lined Canals-Tentative Standards For Covers Using Non-cohesive Materials (12)

Water Depth - d (feet)	Membrane Freeboard Fb (feet)	Beach Belt (1) Min. Thickness (in.)	Beach Belt (1) Screen Size (inches)	Earth Cover (2) Allowable Tractive Force = .040 Thickness (inches) Slopes	Earth Cover (2) Thickness (inches) Bottom	Earth Cover (2) Max. Velocity (ft/sec)	Gravelly Material (3) .060 Thickness (inches) Slopes	Gravelly Material (3) Thickness (inches) Bottom	Gravelly Material (3) Max. Velocity (ft/sec)	Earth or Gravelly Material with Gravel Topping (2 or 3 with 4) .075 Slopes Total Thickness (inches)	Slopes Gravel Thickness (inches)	Bottom Total Thickness (inches)	Bottom Gravel Thickness (inches)	Max. Velocity (ft/sec)	Earth or Gravelly Material with Screened Gravel Topping (2 or 3 with 5) .085 Slopes Total Thickness (inches)	Slopes Gravel Thickness (inches)	Bottom Total Thickness (inches)	Bottom Gravel Thickness (inches)	Max. Velocity (ft/sec)
1.0	0.5	0		12	12	1.22	10	10	1.59	9	4	9	4	1.80	8	3	8	3	1.92
1.5	0.6	0		12	12	1.33	10	10	1.68	9	4	9	4	1.90	8	3	8	3	2.02
2.0	0.6	0		12	12	1.42	10	10	1.80	9	4	9	4	2.01	8	3	8	3	2.13
2.1	0.7	0		13	12	1.44	11	10	1.81	9	4	9	4	2.03	8	3	8	3	2.15
2.3	0.7	0		13	12	1.47	11	10	1.85	9	4	9	4	2.07	8	3	8	3	2.19
2.5	0.7	0		13	12	1.50	11	10	1.88	9	4	9	4	2.11	8	3	8	3	2.23
2.6	0.8	0		14	13	1.51	12	11	1.90	9	4	9	4	2.12	8	3	8	3	2.25
2.8	0.8	3	1½	14	13	1.54	12	11	1.92	9	4	9	4	2.16	8	3	8	3	2.28
3.0	0.8	3	1½	14	13	1.56	12	11	1.95	9	4	9	4	2.19	8	3	8	3	2.32
3.1	0.9	4	2	15	13	1.57	13	11	1.97	11	5	10	4	2.20	10	4	9	3	2.34
3.3	0.9	4	2	15	13	1.59	13	11	1.99	11	5	10	4	2.23	10	4	9	3	2.36
3.5	0.9	4	2	15	13	1.62	13	11	2.01	11	5	10	4	2.26	10	4	9	3	2.39
3.6	1.0	4	2	16	14	1.63	13	11	2.03	11	5	10	4	2.27	10	4	9	3	2.41
3.8	1.0	4	2	16	14	1.65	13	11	2.05	11	5	10	4	2.29	10	4	9	3	2.43
4.0	1.0	4	2	16	14	1.67	13	11	2.07	11	5	10	4	2.31	10	4	9	3	2.45
4.1	1.1	4	2½	17	14	1.68	14	11	2.08	12	5	11	5	2.33	11	4	10	3	2.46
4.3	1.1	4	2½	17	14	1.70	14	11	2.10	12	5	11	5	2.35	11	4	10	3	2.48
4.5	1.1	4	2½	17	14	1.71	14	11	2.11	12	5	11	5	2.37	11	4	10	3	2.51
4.6	1.2	5	2½	18	15	1.72	15	12	2.12	13	6	11	5	2.38	12	5	11	4	2.52
4.8	1.2	5	2½	18	15	1.74	15	12	2.14	13	6	11	5	2.39	12	5	11	4	2.54
5.0	1.2	5	2½	18	15	1.75	15	12	2.16	13	6	11	5	2.41	12	5	11	4	2.56
5.1	1.3	5	3	19	15	1.76	15	12	2.16	14	6	12	5	2.42	13	5	12	4	2.57
5.3	1.3	5	3	19	15	1.77	15	12	2.18	14	6	12	5	2.44	13	5	12	4	2.58
5.5	1.3	5	3	19	15	1.79	15	12	2.19	14	6	12	5	2.45	13	5	12	4	2.60
5.6	1.4	5	3	19	15	1.80	15	12	2.20	14	6	12	5	2.46	13	5	12	4	2.61
5.7	1.4	5	3	20	16	1.81	16	13	2.21	15	7	12	5	2.47	13	5	12	4	2.62
5.9	1.4	5	3	20	16	1.82	16	13	2.23	15	7	12	5	2.48	13	5	12	4	2.64
6.1	1.5	6	3½	20	16	1.83	16	13	2.24	15	7	13	6	2.50	13	5	12	4	2.65
6.2	1.5	6	3½	21	16	1.84	17	13	2.25	15	7	13	6	2.51	13	5	12	4	2.66
6.4	1.5	6	3½	21	16	1.85	17	13	2.26	15	7	13	6	2.52	13	5	12	4	2.68
6.6	1.5	6	3½	21	16	1.86	17	13	2.27	15	7	13	6	2.53	13	5	12	4	2.69
6.7	1.5	6	3½	22	17	1.87	17	13	2.28	16	7	13	6	2.54	14	5	12	4	2.70
6.9	1.5	6	3½	22	17	1.88	17	13	2.29	16	7	13	6	2.55	14	5	12	4	2.71
7.1	1.5	7	4	22	17	1.89	17	13	2.31	16	7	13	6	2.56	14	5	12	4	2.73
7.2	1.5	7	4	23	17	1.89	18	14	2.31	16	7	13	6	2.57	14	5	12	4	2.74
7.4	1.5	7	4	23	17	1.90	18	14	2.32	16	7	13	6	2.58	14	5	12	4	2.75
7.6	1.5	7	4	23	17	1.91	18	14	2.34	16	7	14	6	2.59	14	5	12	4	2.76
7.7	1.5	7	4	23	17	1.92	18	14	2.34	17	7	14	6	2.60	14	5	12	4	2.77
7.8	1.5	7	4	24	18	1.93	19	14	2.35	17	7	14	6	2.61	16	6	13	5	2.78
8.0	1.5	7	4	24	18	1.94	19	14	2.36	17	7	14	6	2.62	16	6	13	5	2.79
8.1	1.5	8	4½	24	18	1.94	19	15	2.37	18	8	14	6	2.63	16	6	13	5	2.80
9.0	1.5	8	4½	24	18	1.99	19	15	2.42	18	8	14	6	2.68	16	6	13	5	2.86

Gravel (4) .100 Thickness (inches) Slopes	Gravel (4) .100 Thickness (inches) Bottom	Gravel (4) .100 Max. Velocity (ft/sec)	Screened Gravel (5) .130 Thickness (inches) Slopes	Screened Gravel (5) .130 Thickness (inches) Bottom	Screened Gravel (5) .130 Max. Velocity (ft/sec)
7	7	2.12	7	7	2.43
7	7	2.22	7	7	2.54
7	7	2.33	7	7	2.64
7	7	2.35	7	7	2.66
7	7	2.39	7	7	2.70
7	7	2.43	7	7	2.75
8	7	2.46	7	7	2.77
8	7	2.49	7	7	2.81
8	7	2.53	7	7	2.86
8	7	2.54	8	7	2.88
8	7	2.57	8	7	2.91
8	7	2.60	8	7	2.95
9	8	2.62	8	7	2.97
9	8	2.64	8	7	2.99
9	8	2.67	8	7	3.03
9	8	2.68	8	7	3.04
9	8	2.70	8	7	3.07
9	8	2.72	8	7	3.09
10	8	2.73	9	8	3.11
10	8	2.75	9	8	3.13
10	8	2.78	9	8	3.15
10	8	2.79	9	8	3.16
10	8	2.80	9	8	3.19
10	8	2.82	9	8	3.21
11	9	2.83	9	8	3.22
11	9	2.84	9	8	3.23
11	9	2.85	9	8	3.25
11	9	2.87	9	8	3.27
12	10	2.88	10	8	3.28
12	10	2.90	10	8	3.30
12	10	2.91	10	8	3.32
12	10	2.92	10	8	3.33
12	10	2.94	10	8	3.35
12	10	2.95	10	8	3.37
13	11	2.96	11	9	3.38
13	11	2.97	11	9	3.39
13	11	2.99	11	9	3.41
13	11	3.00	11	9	3.42
13	11	3.00	11	9	3.43
13	11	3.02	11	9	3.45
14	12	3.02	12	10	3.45
14	12	3.03	12	10	3.53

NOTES

The cover materials shall have hard dense durable rock fragments in the percentages by weight shown in the following tabulation:

MATERIAL	MINIMUM % RETAINED (By Weight)	SCREEN SIZE
1. Gravel Beach Belt	50	See table
2. Earth Material	—	—
3. Gravelly Material	25	No. 4
4. Gravel	50	No. 4
	25	¾ inch
5. Screened Gravel	90	No. 4
	45	¾ inch
	10	3 inch

Side slopes of canals with water depths greater than 2.5 ft. to be 1¾:1 if gravels of cover materials are angular or subangular, and 2:1 if they are well rounded.

The velocities of the table are shown to hundredths of a foot per second to make a smoothly graded table. In the determination of slopes it is desirable, for the convenience of survey work, to select each slope so that it is:

(a) One for which velocities have been tabulated in the Hydraulic and Excavation Tables, or

(b) An interpolation between such slopes as is a fifth or a tenth of the tabular difference of slopes.

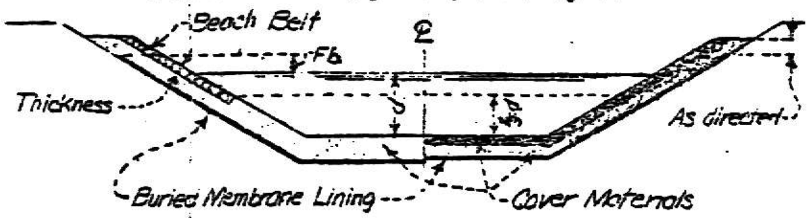
In consequence, velocities may vary from those given in the table.

Any allowable tractive force shown is the product of (62.5)(s)(d) where d = water depth and s = the canal slope to give the particular velocity listed in the table at the given tractive force and water depth. It is an approximation of the true tractive force. The slopes are such as would be obtained by the use of Kutter's formula with a hydraulic radius corresponding to a section with 1¾:1 side slopes and a bottom width 4 times the water depth.

Unless otherwise shown, the beach belt should extend from ⅔ d to the elevation of the top of the lining.

Values for cover thickness given are minimums and greater thicknesses may be used.

*The use of crushed or angular gravel should never be permitted where such material is placed directly on the membrane because of the danger of puncturing it.



This drawing approved July 19, 1951 by Chief Engineer as part of Field Trip Report dated May 9, 1951 by Engineers J.R. Benson and I.B. Hosig.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

BURIED ASPHALT MEMBRANE LINED CANALS

TENTATIVE STANDARDS FOR COVERS USING NON-COHESIVE MATERIALS

Joints - four kinds of joints or grooves are used in concrete canal lining--construction joints, transverse contraction joints, lontitudinal contraction joints, and expansion joints.

A construction joint is placed at any location where it is suitable during construction. Usually it later performs the function of a transverse, longitudinal or expansion joint.

Transverse contraction joints are installed to control transverse cracking, which results from shrinkage during volume change caused by drops in temperature or moisture loss, as well as by moisture loss in curing.

The U. S. Bureau of Reclamation recommends the following spacing of joints in unreinforced concrete (4).

Thickness of lining	Approximate joint spacing
5 to 6.5 cm (2 to 2.5 in.)	3 m (10 ft.)
7.5 to 10 cm (3 to 4 in.)	3.5 to 4.5 m (12 to 15 ft.)

Average spacing is 50 times the thickness of the slab. In reinforced concrete linings, joint spacing should be limited to 6 m (approximately 20 ft.) to prevent large cracks which may make it difficult to keep joints watertight. Longitudinal joints are spaced 2.5 to 4.5 m apart where perimeter of the lining is 9 m (about 30 ft.). Expansion joints are ordinarily not required.

Design of Earth Linings - a typical section of a compacted earth-lined canal is shown in Figure 3. Side slopes in earth canals are 1.5 to 1 or flatter, depending on the size of canal and materials available for lining, as well as the type of lining to be used. The permissible velocities also

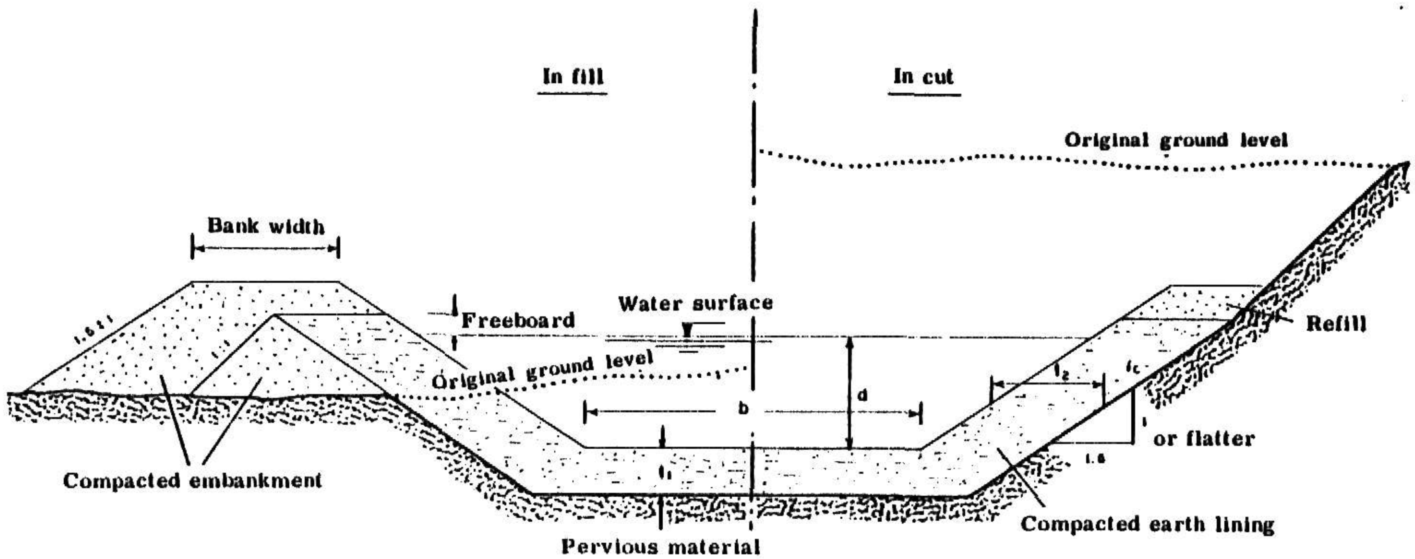


Fig-3: Typical section of a compacted earth lined canal.(5)

vary with the type of lining material and usually range from 1 to 4 ft/sec. Manning's roughness coefficient of 0.025 is used for canals with capacities less than 3 m^3/sec (100 cusecs) and 0.020 for larger canals.

The proportions indicated in Table 6 apply to all types of earth linings (4).

Table 6

Depth (d)	Bottom Thickness (t_1)	Side Thickness (t_2)	Bed width to depth (b/d)	Slope s
60 cm (2 ft)	30 cm (1 ft)	90 cm (3 ft)	2	1.5:1
120 cm (4 ft)	45 cm (1.5 ft)	120 cm (4 ft)	3	1.5:1 or 1.75:1
250 cm (8 ft)	60 cm (2 ft)	180 cm (6 ft)	3.5	2:1
250 cm (over 8 ft)	60 cm (2 ft)	250 cm (8 ft)	4 to 7	2:1

For placing of all compacted earth linings, rigid control of the density and optimum moisture is required. A density from 95 to 98% of the laboratory maximum, as determined by the Proctor compaction method, will normally provide adequate stability and impermeability. Table 7 will assist in selecting materials for linings and gravel protection if needed (8).

SELECTION OF TYPE OF LINING

Although canal linings are very simple structures from an engineering point of view, the fact that normally large investments of labor and materials are involved necessitates very careful selection and design of the lining to be used. Lining needs attention from the very beginning of project planning. If linings are constructed at the time of original

Major Divisions of Soils			Typical Names of Soil Groups	Group Symbols	Soil Properties: Permeability	Soil Properties: Shearing Strength	Soil Properties: Compacted Density	Suitability for Canals: Erosion Resistance	Suitability for Canals: Compacted Earth Linings
COARSE-GRAINED SOILS More than half of material is larger than No. 200 sieve size	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size	CLEAN GRAVELS (Little or no fines)	Well-graded gravels, gravel-sand mixtures, little or no fines	GW	14	16	15	2	—
			Poorly graded gravels, gravel-sand mixtures, little or no fines	GP	16	14	8	3	—
		GRAVELS WITH FINES (Appreciable amount of fines)	Silty gravels, poorly graded gravel-sand-silt mixtures	GM	12	10	12	5	6
			Clayey gravels, poorly graded gravel-sand-clay mixtures	GC	6	8	11	4	2
			Gravel with sand-clay binder	GW-GC	8	13	16	1	1
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size (For visual classifications, the 1/4" size may be used as equivalent to the No. 4 sieve size)	CLEAN SANDS (Little or no fines)	Well-graded sands, gravelly sands, little or no fines	SW	13	15	13	8	—
			Poorly graded sands, gravelly sands, little or no fines	SP	15	11	7	9 coarse	—
		SANDS WITH FINES (Appreciable amount of fines)	Silty sands, poorly graded sand-silt mixtures	SM	11	9	10	10 coarse	7 Erosion Critical
			Clayey sands, poorly graded sand-clay mixtures	SC	5	7	9	7	4
			Sand with clay binder	SW-SC	7	12	14	6	3
FINE-GRAINED SOILS More than half of material is smaller than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to the naked eye)	SILTS AND CLAYS Liquid limit less than 50		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	10	5	5	—	8 Erosion Critical
			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	CL	3	6	6	11	5
			Organic silts and organic silt-clays of low plasticity	OL	4	2	3	—	9 Erosion Critical
	SILTS AND CLAYS Liquid limit greater than 50		Inorganic silt, micaceous or diatomaceous fine sandy or silty soils, elastic silts	MH	9	3	2	—	—
			Inorganic clays of high plasticity, fat clays	CH	1	4	4	12	10 Volume Change Critical
			Organic clays of medium to high plasticity	OH	2	1	1	—	—
HIGHLY ORGANIC SOILS			Peat and other highly organic soils	Pt	*			**	

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

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

Table 7. Important physical properties of soils and their uses for canal linings (identification based on Unified soil classification system)- (8)

construction of a project, and loss of water from the canals and laterals is thereby greatly reduced, the sizes of the associated dams, reservoirs, canals and laterals also can be reduced. The resultant savings would pay, in part, at least, for lining of the smaller irrigation system which would deliver the same amount of water, in some cases, without extensive drainage construction. The advantages of lining at the time of canal construction include (5):

1. Less right-of-way cost and better utilization of land due to smaller canal cross section.
2. For a given area, the possibility of canal structures; diversion and storage facilities and pumping installations of smaller capacity.
3. Shorter bridges and other crossings.
4. Appropriate location and gradient of canal and the avoidance of certain drop structures.
5. Reduced excavation, except for earth lining.
6. Saving in drainage investment for prevention of water logging.
7. No interruption of irrigation water supply.
8. Saving of additional cost for by-passes during lining of existing canal.

The more common types of lining and their main features are summarized in Table 8.

Factors governing the selection of lining (5):

Soil Properties - It is important to examine the soils along or near the line of a proposed or existing canal for possible use as lining materials. Also, test results will help to decide whether to by-pass areas with unsuitable subsoils by changing the canal alignment.

Table 8

Irrigation Canal Linings and Their Main Features (5)

Type of lining and thickness	Durability (service life)	Water losses ($m^3/m^2/24$ h)	Other important features
A. Hard-surface linings			
Portland cement concrete, unreinforced, 5 cm As above, but 7.6 cm As above, but 10 cm and reinforced	Commonly estimated to last 50 years	Below 0.03 if well constructed and maintained, but values up to 0.15 have been measured	Suitable for all sizes of canals, all topographical, climatical and operational conditions; firm subsoil required; susceptible to swelling clays; availability of aggregates near the job is essential; construction either by hand methods or slipform.
Pneumatically applied mortar, unreinforced, 5 cm	In mild climate and stable subgrade same as concrete (30 years have been reported)	0.03-0.06	As above, but no need for coarse aggregates; special equipment necessary; generally not economical for large jobs; suitable on subgrades of weathered rock.
Precast concrete blocks, 7 cm	About the same as above if properly maintained	If joints are well sealed, about 0.03 can be achieved	Advantageous where concrete lining is suitable, but remote precasting is more economical (lack of aggregates at site, transport facilities for precast material available).
Soil-cement (dry-mix), 13 cm Soil-cement (plastic), 7.6 cm	Largely dependent on cement content; 23 years have been recorded	0.03-0.06	Although less durable than portland cement concrete, low initial costs make this an economic lining where suitable sandy soils are available from canal excavation or nearby.

Table 8 (continued)

Type of lining and thickness	Durability (service life)	Water losses ($m^3/m^2/24$ h)	Other important features
Asphaltic concrete, in place, 5 cm Asphaltic concrete, prefabricated slabs, 3.8 cm	Seldom more than 15 to 20 years	About 0.03, but will increase considerably if weed infested	For the in-place type, availability of aggregates at site is essential; because of shorter service life, asphaltic concrete does not offer any advantage over cement concrete except on less stable subgrades (swelling clays); offers better resistance against certain chemical deterioration; susceptible to weed penetration.
Brick and stone	May be as high as cement concrete if properly constructed and maintained	Brick with cement plaster: around 0.03. Stone: relatively permeable unless carefully mortared	Labour-intensive methods; availability of construction material at or near the site is essential.
B. Exposed membranes			
Asphaltic materials Polyvinyl (0.19 mm; 8 mil)	Only a few irrigation seasons	Vary widely depending on weed penetration and other	Suitable only as temporary lining for seepage control.

Table 8 (continued)

Type of lining and thickness	Durability (service life)	Water losses ($m^3/m^2/24$ h)	Other important features
C. Buried membranes			Suitability of excavated soil as cover material is important for economic reasons.
Sprayed-in-place asphalt	Depends largely on erosion resistance of cover material, maintenance (weed hazard, beaching, burrowing animals), and operation (drawdown); records show a serviceable life of at least 15 years, but rubber membrane is likely to last much longer	Below 0.06	Heater and spray equipment must move along canal; skilled personnel are required.
Prefabricated asphaltic membrane		Below 0.08	Easily transported and placed materials, but slippage of cover material caused particularly by drawdowns has sometimes been a problem.
Polyethylene (0.24 mm; 10 mil)		Below 0.06	
Polyvinyl (0.24 mm; 10 mil)		As above	
Synthetic rubber (0.77 mm; 32 mil)		Below 0.03	
Bentonite layer (4-5 cm)	Not reported	--	--
Bentonite layer (1.3 cm)	Less than 6 years	--	After 7 years, water losses equal to unlined conditions.
Sublining of plastic sheeting or sprayed-in-place asphalt under precast concrete	Determined by service life of concrete lining	Practically water-tight if properly constructed	Very effective in preventing seepage. Concrete joints and cracks need not be sealed but eventually filled with some material to protect the underlying membrane.

Table 8 (continued)

Type of lining and thickness	Durability (service life)	Water losses ($m^3/m^2/24$ h)	Other important features
D. Earth linings			
Thick compacted (approx. 90 cm thick) Thin compacted (30 cm and less)	For economy evaluations 20 years have been assumed	Below 0.08 (0.02 has been measured)	Suitable soil from canal excavation or nearby borrow pit area is essential for economy. Freezing-thawing and alternate wetting-drying are hazards to all compacted-earth linings because they loosen the compaction and increase the permeability.
Loosely placed earth (loam, clay)	--	--	Low initial cost, but with little effectiveness as to seepage control; little advantage against unlined canals; low durability.
E. Soil sealants			
Waterbone bentonite Sodium carbonate Resinous polymers, petroleum, asphalt emulsions and other chemicals sprayed on the subgrade	One or two irrigation seasons	May average around 0.30 after treatment but varies widely	Means of temporarily controlling seepage in unlined canals. Sealing effect is high just after treatment but may be reduced to less than half after only one or two irrigation seasons. Because of low cost, repeated treatment may be an economical alternative to more durable types of lining.

Table 8 (continued)

Type of lining and thickness	Durability (service life)	Water losses ($m^3/m^2/24$ h)	Other important features
F. Flumes and pipes			
Concrete flumes	Approx. 50 years	Negligible if joints are well sealed	Relatively independent of soil and topographic conditions; ratio of cost to carrying capacity is high; economical only when value of water is very high.
Concrete pipes (precast, cast in place)	More than 50 years	Negligible if joints are properly sealed	Particularly suitable for areas with irregular or rolling topography and intensive cultivation.
Lay-flat tubing	Not yet known	Practically nil	As above.

Water Table - If the water table is above the bed level of a canal, emptying the canal can be expected to cause external hydrostatic pressure on the linings. Failures have been reported where linings are too light and too rigid to resist the pressure. Heavy compacted earth linings have always proved satisfactory in this respect.

Land Use and Irrigation Systems - In areas of high land value and when improvements of traditional irrigation systems and patterns are to be undertaken, hard-surface lined canals with steep side slopes are recommended.

Water Tightness - If the value of water is high and measurement of seepage shows high losses, then a relatively watertight lining has to be adopted. Probably the most impermeable lining is a thin plastic, rubber membrane placed under a concrete lining.

Operation and Maintenance - If the operation of a canal system requires frequent filling and emptying or causes frequent water level changes, a hard-surface lining will perform best. With earth linings, such process would speed up the deterioration process considerably and would require more maintenance.

Durability - The durability assigned to a lining will essentially influence the benefit-cost calculation and should therefore be determined carefully. Durability of linings depends on type of lining and quality of lining materials used.

Availability of Construction Materials - Generally the most economical lining is that which makes the best use of locally available materials.

Availability of Labor and Machinery - Some linings are suitable for manual labor and other, like concrete, for machine installation. The choice, therefore, is often governed by the relative supply of labor and machinery.

Cost and Financial Aspects - Costs of a given lining have to be weighed against obtainable benefits. The amount of water saved will be the determining factor in the cost-benefit confrontation.

ECONOMICS OF CANAL LINING

The true cost of a lining is not its first but its annual cost. The annual cost includes annual depreciation and interest charges during the life of the lining. The annual benefits accruing from lining a canal must be greater than its annual cost if its construction is to be justified. The annual cost of lining will vary with the type of lining. Form A of Table 9 will be helpful in determining which of two types of lining has the lower annual cost and therefore is more economical. In the case of original construction, it is necessary to compare the additional annual cost of a lined over an unlined canal with the annual benefits derived from lining. Form B of Table 9 can be used for this purpose. If a lining is being considered for an existing canal. Form C of Table 9 should be used. Form D of Table 9 is suggested as a guide in computing annual benefits (7).

The following example illustrates how to calculate and compare annual costs and benefits (derived from Ref. 1). Cross-sections for lined and unlined are shown in Figure .

1. Required canal capacity: 28.3 m^3/sec
2. Loose sandy soil, economic cut permissible
3. Permissible velocity, unlined: 0.50 m/sec
4. Permissible velocity, lined: 1.50 m/sec
5. Maximum water depth: 3.10 m
6. Bank slopes, unlined: 2:1

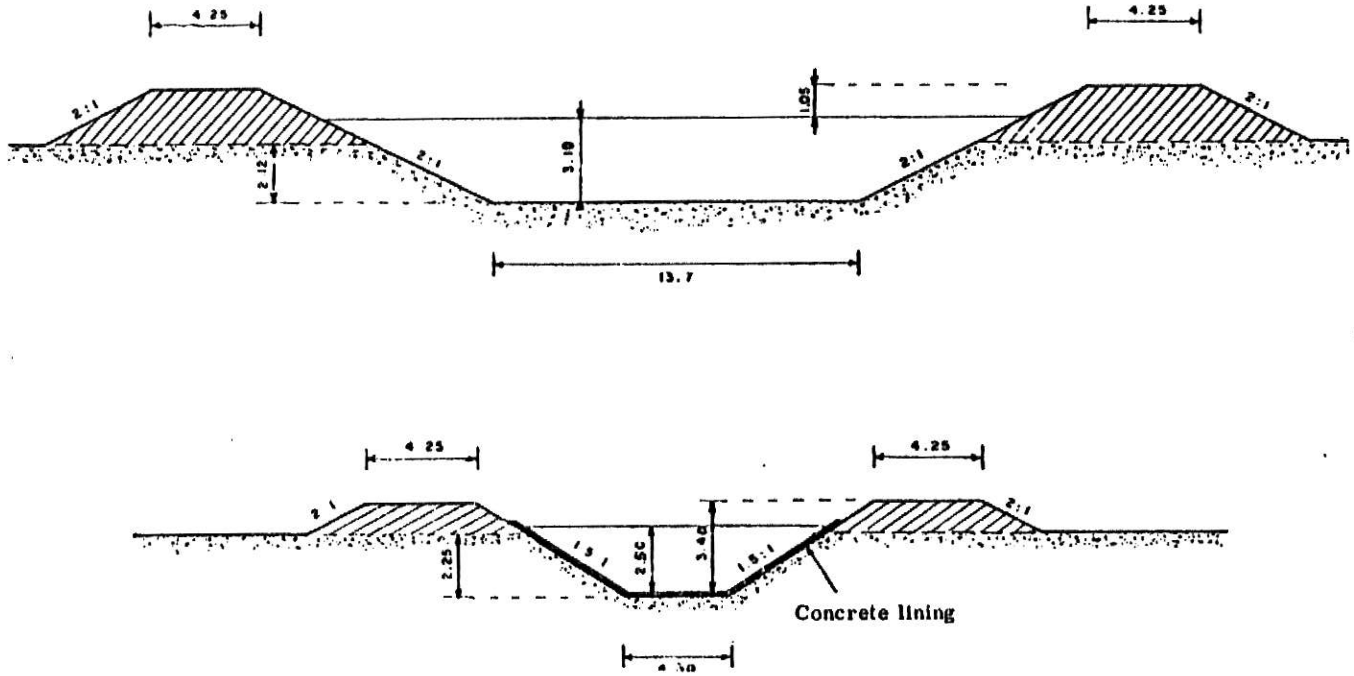


Fig. 4: Comparative cross sections of an unlined and a concrete-lined canal (5)

7. Bank slopes, lined: 1.5:1

8. Portland cement concrete lining, unreinforced: 7.6 cm (3 in) thick

9. Top width of banks: 4.25 m

10. Shrinkage allowance: 10 percent

11. Seepage loss, unlined canal: 0.46 m^3/m^2/day

12. Seepage loss, lined canal: 0.015 m^3/m^2/day

13. Manning's n, unlined canal: 0.0225

14. Manning's n, lined canal: 0.013

15. Available slope: 0.0002

16. Cost of excavation, including placing in embankments: \$0.65 per m^3

17. Cost of lining: \$4.30 per m^3

18. Annual maintenance cost, unlined canal: \$1.15 per m

19. Annual maintenance cost, lined canal: \$0.50 per m

20. Value of water: 0.33 cent per m^3

21. Life of lining: 40 years

22. Interest rate: 5 percent per annum

23. Variable operation over 8-month period equivalent to about 6 months continuous full flow

24. Land area lost to the unlined canal: 47 m^2 per meter of canal

25. Land area lost to the lined canal: 31 m^2 per meter of canal

26. Annual right-of-way costs: \$180 per ha.

Annual cost per meter of unlined canal:

a. Capital cost

excavation: 38 m^3 at \$0.65 = \$24.7

$$\text{interest} = \frac{24.7 \times 0.05}{2} = \qquad \$\ 0.62$$

b. Value of annually lost water:

$2300\ m^3$ at 0.33 cents per m^3 = $ 7.60

c. Maintenance = $ 1.15

d. Right-of-way cost $\frac{180 \times 47}{10,000}$ = $ 0.85

Total annual cost $10.22

Annual cost per meter of lined canal:

a. Capital cost

excavation: $17.3\ m^3$ at $0.65 = $11.25

concrete lining: $15.4\ m^2$ at $4.30 = $66.22

$77.47

interest = $\frac{77.47 \times 0.05}{2}$ = $ 1.93

depreciation of lining $\frac{66.22}{40}$ = $ 1.65

b. Value of annually lost water:

$36\ m^3$ at 0.33 cent per m^3 = $ 0.12

c. Maintenance = $ 0.50

d. Right-of-way cost $\frac{180 \times 31}{10,000}$ = $ 0.56

Total annual cost $ 4.76

Annual saving per meter of lined canal:

$10.22 - $4.76 = $5.46.

On the basis of assumed data, the lined canal saves $5.46 per meter per year. In this case, other benefits such as savings on canal structures and increased safety, may justify the concrete lining even further.

Table 9(7)

Form A

For Comparing Estimated Annual Costs of Two Different Types of Linings

		Type I	Type II
1.	Excavating, filling, compacting and trimming	$________	$________
2.	Lining	$________	$________
3.	Checks, turnouts, bridges and other necessary structures	$________	$________
4.	Incidental construction	$________	$________
5.	Total construction cost: (1) + (2) + (3) + (4)	$________	$________
6.	Life expectancy: Type I _______ years Type II _______ years		
7.	Salvage value at life expectancy	$________	$________
8.	Total depreciation during life: (5) - (7)	$________	$________
9.	Annual depreciation charge: (8) ÷ (6)	$________	$________
10.	Annual interest charge: $\frac{(5) + (7)}{2}$ x interest rate	$________	$________
11.	Annual maintenance charge	$________	$________
12.	Total annual cost: (9) + (10) + (11)	$________	$________

Table 9 (continued)

<u>Form B</u>

For Estimating the Additional Annual Cost of a Lined Over an Unlined Canal (Original Construction) and Net Annual Savings

		a. Lined	b. Unlined
1.	Excavating, filling, compacting and trimming	$________	$________
2.	Lining	$________	
3.	Checks, turnouts, bridges and other necessary structures	$________	$________
4.	Incidental construction	$________	$________
5.	Total construction cost: (1) + (2) + (3) + (4)	$________	$________
6.	Difference in construction cost: (5a) - (5b)	$________	
7.	Life expectancy: ______ years		
8.	Salvage value at life expectancy	$________	
9.	Total depreciation during life: (6) - (8)	$________	
10.	Annual depreciation charge: (9) ÷ (7)	$________	
11.	Annual interest charge: $\frac{(6) + (8)}{2}$ x interest rate	$________	
12.	Total annual cost: (10) + (11)	$________	
<u>Net Annual Savings</u>			
13.	Total annual benefits: (20), Form D	$________	
14.	Total annual cost: (12) above	$________	
15.	Net annual savings: (13) - (14)	$________	

Table 9 (continued)

Form C

For Estimating Annual Cost of Lining an Existing Canal and Net Annual Savings

1. Excavating, filling, compacting, reshaping and trimming $________

2. Lining $________

3. Checks, turnouts, bridges and other necessary structures $________

4. Incidental construction $________

5. Total construction cost: (1) + (2) + (3) + (4) $________

6. Life expectancy: ______ years

7. Salvage value at life expectancy $________

8. Total depreciation during life: (5) - (7) $________

9. Annual depreciation charge: (8) ÷ (6) $________

10. Annual interest charge: $\frac{(5) + (7)}{2}$ x interest rate $________

11. Total annual cost: (9) + (10) $________

Net Annual Savings

12. Total annual benefits: (20), Form D $________

13. Total annual cost: (11) above $________

14. Net annual savings: (12) - (13) $________

Table 9 (continued)

Form D

For Estimating Annual Benefits from Lined Canal

Land Saved

1. Right-of-way, unlined canal __________acres
2. Right-of-way, lined canal __________acres
3. Right-of-way, saved: (1) - (2) __________acres
4. Reclaimed waterlogged land __________acres
5. Total land saved: (3) + (4) __________acres
6. Annual value of total land saved: _______ acres at $_______(net crop value) $__________

Water Saved

7. Flow when in use: _______ cfs
8. Hours in use: _______ per year
9. Total flow per year: (7) x (8) x 0.0826 = _______ acre-ft.
10. Estimated loss from unlined canal: _______% of (9) = _______ acre-ft.
11. Annual value of water saved: _______ acre-ft. (10) at $_______ per acre-ft. $__________

Maintenance Saved (Include maintenance of necessary drainage facilities.)

12. Annual maintenance cost, unlined canal $__________
13. Annual maintenance cost, lined canal $__________
14. Annual saving in maintenance: (12) - (13) $__________

Labor Saved

15. Labor, irrigating unlined canal: _______ man-hours per year
16. Labor, irrigating lined canal: _______ man-hours per year
17. Annual saving in labor: _______ man-hours (15) - (16) at $_______ per hour $__________
18. Total annual tangible benefits: (6) + (11) + (14) + (17) $__________
19. Estimated annual intangible benefits $__________
20. Total annual benefits: (18) + (19) $__________

CONCLUSION

It is only during the planning and designing stages that full advantage can be taken of the many benefits of the installation of a canal lining. When lining is included in the original plans and designs, the cost of the lining might be justified in consideration of reduced storage and diversion requirements, smaller canal sections, smaller and possibly fewer canal structures, reduction of pumping costs where pumping is necessary, and a possible reduction in the right-of-way requirements.

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LININGS FOR CANALS

by

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B.E., Karnatak University (India), 1976

AN ABSTRACT OF A MASTER'S REPORT

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requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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ABSTRACT

The purpose of this report is to provide a compilation of some of the information on irrigation canal lining. This report tells why irrigation canals need lining and describes some of the types of lining and their design. The efficiency of the conveyance and distribution system--that is, the transport of water at minimum cost and with minimum water loss--therefore essentially affects the total economy of an irrigation project. Determination of the need to line should be based on an analysis of benefits such as water conservation, reduced waterlogging or lower drainage requirements, reduced excavation and right-of-way cost, lower operation and maintenance costs, and structural safety. There are several types of linings now generally used. The principal types that have been found satisfactory in the past are concrete linings, shotcrete lining, asphaltic lining, earth material lining and plastic lining. No particular type of lining is lowest in cost or most satisfactory for use in all locations. Almost every type of lining has its specific merits. Selection should be based on a careful analysis of local conditions such as availability and cost of labor, mechanical equipment and construction material, transport facilities, anticipated irrigation method and canal operation, traditional lining techniques, and maintenance requirements. The availability of labor, skilled and unskilled, is perhaps the most important factor causing differences in lining practices. The more common benefits derived from canal lining are 1) a saving in water, 2) reduced damage to lowlands from seepage or reduced drainage costs, 3) greater safety, and 4) reduced operation and maintenance costs.(1to13)