Construction of Compacted Soil Linings for Canals

Construction de revêtements en sol compacté pour canaux

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Summary

The control of seepage from irrigation canals for conserving water and protecting arable lands from seep waters has become an important consideration in the western part of the United States, as it has in many other areas throughout the world. To obtain maximum seepage control benefits for minimum costs, our Bureau has initiated a program to develop lower-cost linings. Our Earth Laboratory has studied silting methods, bentonite linings, admixture stabilized soils, and compacted earth linings. The lining that appears to hold the greatest promise from economic and operation standpoints is the "heavy compacted earth lining". This lining is made by compacting stable, impervious soils in 6-inch horizontal layers to provide a 3-foot normal thickness. Gravelly and sandy soils with clay binder provide the most suitable materials, although others may be used. The cost of these linings is about 25 percent of conventional concrete linings, and tests have shown that seepage losses are comparable to the losses of concrete linings.

Sommaire

Le contrôle de la filtration de l'eau hors des canaux d'irrigation dans le but de conserver l'eau et de sauvegarder le terrain arable de l'action des eaux de fuite est devenu une question importante dans l'ouest des Etats-Unis ainsi que dans les autres parties du monde. Pour obtenir le contrôle de la filtration, et en même temps limiter les dépenses, notre Bureau a conçu un projet permettant la construction de revêtements à bas prix.

Notre laboratoire des sols a étudié les méthodes d'alluvionnement, les revêtements en bentonite, les sols stabilisés par diverses additions ainsi que les revêtements en sol compacté. Le revêtement qui donne les plus grandes espérances tant du point de vue économique que de celui de la performance, est le «revêtement épais en sol compact». Ce revêtement est construit en compactant des sols imperméables et stables en couches horizontales de 6 pouces jusqu'à ce qu'une épaisseur moyenne de trois pieds soit obtenue. Les matériaux graveleux et sableux avec liants d'argile sont les plus appropriés bien que d'autres sols puissent être utilisés. Le prix de ces revêtements est approximativement le quart du prix des revêtements habituels en béton. Les essais ont démontré que les pertes d'eau par filtration dans les canaux ainsi revêtus sont comparables aux pertes dans les canaux revêtus de béton.

Introduction

It has been found that about 25 percent of water entering unlined canals and laterals is lost by seepage before it reaches the farmer's fields. Uncontrolled seepage from unlined irrigation systems not only wastes valuable water but also may cause seeped conditions which make nearby lands unproductive or necessitate expensive drainage systems. Similar conditions exist on irrigation projects throughout the world. Approximately 3,900,000 acre feet of the 15,650,000 acre feet of irrigation water supplied by the Bureau of Reclamation in 1949 was lost in this manner. It has been estimated that the water thus lost would have irrigated an additional 1,000,000 acres of farm land (Ref.). Because of the importance of the problem, our Bureau initiated a program in 1946 to develop lower-cost linings for the purpose of securing maximum seepage control benefits for a minimum cost. Since that time, it is estimated that from this program, about $15,000,000 has been saved as a result of the lining installations, through the saving of water, reclaiming water-logged land, preventing water-logging, and reducing maintenance costs. The over-all program includes laboratory studies and full-scale field investigations in which many types of materials are tested, various construction methods are tried, and service records are analyzed. As a part of the over-all work, our Earth Laboratory has studied various uses of soils for seepage control purposes.

Types of Earth Linings

Silting is the most simple method of treating canals to reduce water losses and has been used for a long time. This is a method of treatment in which fine-grained soils are dispersed into the water, by hydraulic or mechanical means, and deposited over the canal perimeter. While silting often reduces seepage appreciably, it is not considered a permanent seal because of its susceptibility to destruction. Thin, loose earth blankets of fine-grained soils are often used. While such linings are quite cheap and many times effective, they may erode quite easily unless protected with gravel cover material. Bentonite has been used successfully as a membrane or when admixed with permeable soils to provide an impermeable barrier. Gravel cover materials are necessary, however, to prevent erosion. Linings made with soils treated with cement and chemicals have been constructed on a small scale. The soil-cement lining appears to have possibilities, although construction is difficult, with the equipment now available, and the amount of cement required increases the lining cost in excess of other types of earth linings.

Both thin and heavy compacted earth linings have been constructed with impervious soils. Thin linings of 6- to 12-inch thickness, which are constructed of impervious soils, provide an adequate water barrier. However, they usually require a gravel cover for erosion protection. Construction costs for this type of lining are relatively high for the amount of soil compacted because conventional construction equipment and methods cannot be used for compacting the slopes. The heavy

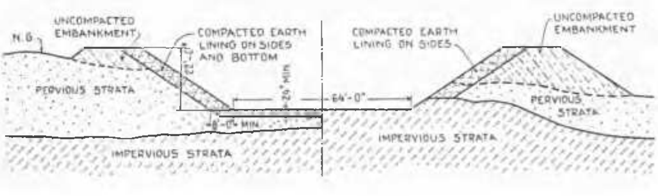

Fig. 1 Typical Cross Section of Heavy Compacted Earth Lining
Coupe typique du revêtement épais en sol compacté

compacted earth lining has proved to be the best type of earth lining, because it overcomes many difficulties encountered with the thinner soil linings. The detailed discussion contained in this paper is, therefore, devoted to this type of earth lining. In the construction of the heavy compacted earth lining, conventional construction equipment and methods may be used, thus providing lower unit costs; a wider range of soils may be used without erosion protection because of the lining thickness; the lining is not susceptible to destruction by cleaning operations, if reasonable care is exercised; and excellent seepage control is obtained. The heavy compacted earth lining is placed in 6-inch compacted layers to a depth of 2 to 3 feet in the canal bottom and to a horizontal construction width of about 10 feet on the slopes as shown on Fig. 1. This width allows the use of conventional sheepsfoot rollers and other construction equipment operating on a horizontal surface. About 2 feet of partially compacted soil on the outer surface of the slope can be removed or left in place. This construction procedure provides about 3 feet of fully compacted soil when approximately 2 : 1 side slopes are used. When impervious soils exist in the bottom of the canal, but not on the sides, the sides only can be lined as shown in Fig. 1.

Materials

Fig. 2 has been prepared to show the soils which may be used in constructing heavy compacted earth linings. The important soil properties (permeability, stability, and density) are shown by a numbering system, which indicates the order of increasing values for the property named. Thus in constructing heavy earth linings where impermeability and high stability are desirable, a soil which will provide a low order of permeability and a high order of stability is desirable. These requirements are considered in the last two columns of the table "Relative Suitability for Canal Sections", which indicate materials suitable from an erosion control standpoint (natural or cover materials) and materials for compacted earth linings. The numbering system used in these columns indicates relative suitability in decreasing order; thus, No. 1, represents the first or best material.

As indicated by the chart, a well-graded gravel with sand-clay binder (a borderline GW-GC soil) is the most suitable material for compacted earth linings, because it provides a dense, impervious, stable lining with good erosion-resistance qualities. This material has good cohesion and friction qualities. When large-size gravel particles are available, rather high velocities may be used. The clayey gravels are of next quality, because erosion resistance and stability are decreased as the clay content is increased. Next in order are the sand with clay binder and clayey sands, respectively. These materials, which are quite stable and have considerable cohesion, may be used with moderate velocities. Lean clays have been used successfully for the heavy linings. The silty soils are not too desirable because of their poor erosion qualities. If they contain sufficient gravel or coarse sand, but are still impermeable, they may be satisfactory; otherwise, a blanket of coarse material may be required even though the velocities are low. Fat clay (CH) soils have been used. However, they must be regarded with caution if shrinkage and expansion properties are high.

The effect of wind-wave action must be considered in addition to designed velocities in selecting soils from the standpoint of erosion. Fine soils without adequate cohesion will beach considerably from wave action, particularly on the larger canals and in locations where severe wind action occurs.

Materials for heavy earth linings are selected on the basis of several laboratory tests. These are tests for gradation, liquid and plastic limits, compaction, and permeability; shear tests may be desirable in specific cases. The gradation data provide information as to the suitability under various design conditions of canal size and velocity from an erosion standpoint. The liquid and plastic limits provide information as to the plastic characteristics of the fines. Upper limits for the plasticity index and liquid limit are established as required so that detrimental expansion and shrinkage will not occur. On the other hand, silty soils containing fines with a P.I. of less than 5 do not contain enough binder for good serviceability. The compaction test provides information on the expected density of the lining material and is used as a control for placing the laboratory permeability specimens and as a guide for field compaction requirements. The permeability test is used to determine if adequate seepage control can be obtained. We attempt to control canal seepage losses to 0.1 cubic foot per square foot per day when lining is required. Materials having laboratory permeability rates of 1 foot per year or slightly greater (gradient of 1) are generally suitable from a permeability standpoint.

Construction

The first heavy compacted earth lining was constructed on the Tucumcari Project, New Mexico, in 1944. The material used was a sandy clay (*SC*) and the lining was 3 feet thick normal to the slope and 1 foot thick in the bottom. The average cost of this lining was $1 per square yard of surface lined. The

Major divisions of soils			Typical names of soil groups	Group symbols	Relative values of important physical properties: Permeability	Shearing strength	Compacted density	Relative suitability for canal sections: Erosion resistance	Compacted earth linings
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to the naked eye.)	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size (For visual classifications, the ¼" size may be used as equivalent to the 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	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	8	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	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 silts, 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)	

Fig. 2 Important Physical Properties and Use of Soils for Canal Linings
Propriétés physiques importantes et emplois des sols pour le revêtement des canaux

lined section was ½ mile long and involved some 23,000 square yards of surface area. The performance of this lining was watched closely and its good service record provided confidence in the use of the heavy linings. Since 1946 some 3,800,000 square yards of canal surface area has been lined in this manner. Three major installations are discussed below.

About 25 miles of lining was constructed on the Friant-Kern Canal System during 1947–48. Selected clay soils from required excavation were placed in layers on the sides and bottom of the canal by carry-all scrapers and compacted by sheepsfoot rollers as shown in Fig. 3. The typical hydraulic properties of this canal were: Q (capacity) = 5,000 cu.ft./sec; v (velocity) = 3.2 ft./sec; d (depth) = 17 feet; b (base width) = 64 feet; and the side slopes $S = 1\frac{1}{2}:1$. Lean (CL) to slightly fat (CH) clays were used in this lining. The lining was placed to a depth of 2 feet in the bottom and with a horizontal width of 10 feet on the slopes. The approximate 2 feet of uncompacted fluff on the outer slopes was removed, giving a compacted thickness 8 feet horizontally. Fig. 4 shows the canal shortly after completion.

About 18 miles of the Delta-Mendota Canal System was lined during 1949–51 with heavy compacted earth. Although the lining material was obtained from required excavation, a high ground-water condition made it necessary to excavate the canal by dragline and stockpile the materials to drain. They were then re-excavated and placed in the lining by carry-all scraper or by dozing from the stockpiles to the canal section and compacted by sheepsfoot and pneumatic rollers. The typical hydraulic properties of this canal were: Q = 3,300 cu.ft./sec; v = 2.5 ft./sec; d = 13.9 ft.; b = 62 ft.; $S = 2\frac{1}{2}:1$. Lean clays

(*CL*) to slightly fat (*CH*) clays were used in this lining. The lining was constructed with a minimum depth of 2 feet in the bottom and a horizontal width of 10 feet on the slopes. This provided approximately 8 feet (horizontally) of fully compacted soil in the slope lining. In this case, the remaining 2 feet of partially compacted material on the outside of the slopes was left in place and smoothed by dragging. This outside layer provided some protection against drying out of the compacted lining below prior to the time water was placed in the canal.

During 1949, 6.5 miles of lining was placed on the Wellton-Mohawk Canal, Arizona. The typical hydraulic properties of this canal were: $Q = 1{,}300$ cu.ft./sec; $v = 2.4$ ft./sec; $d = 8.8$ ft.; $b = 44$ ft.; and $S = 2:1$. The material used in this lining was a well-graded gravel-sand mixture with clay binder, available from a nearby borrow area. The bottom lining was constructed to a 2-foot minimum thickness. The slope lining was constructed to a horizontal width of 8 feet. This included 6 feet of fully compacted soil plus 2 feet of partially compacted soil on the outside of the slope. The soil was excavated in the borrow area by power shovel and transported to the canal in bottom dump trucks. The soil was then spread by graders and

Fig. 3 Construction of Heavy Compacted Earth Lining—Friant-Kern Canal, California
Revêtement épais en sol compacté – Canal de Friant-Kern, Californie

compacted with sheepsfoot rollers. The looser soils at the edge of the slopes were shaped prior to acceptance of the lining. Fig. 5 shows the construction of this lining.

In addition to the large canal systems discussed above, there is a need for constructing earth linings on smaller systems. To date, our work in this respect has been limited. Single drum rollers and smaller equipment can be adapted to heavy compacted earth linings of lesser thickness than described for the large canals. A lesser thickness of lining is usually adequate on smaller systems as the water velocity and depths are less. On one project, the contractor found it economical to construct the compacted banks of a lateral by building a complete fill and then excavating out the canal section. This scheme is shown on Fig. 6. More work of this type can be expected in the future.

Rigid construction control, similar to that required on earth dam construction work, is required for the placing of all heavy earth linings. The density and optimum moisture control is based on U.S.B.R. laboratory standard compaction tests which is comparable to the compaction standard of the American

Fig. 4 Completed Heavy Compacted Earth Lining—Friant-Kern Canal, California
Revêtement épais en sol compacté – ouvrage achevé – Canal de Friant-Kern, Californie

Society for Testing Materials. Densities which will provide adequate stability and impermeability are specified; this has been obtained with densities of from 95 to 98 percent of laboratory maximum. Several in-place density tests are taken daily during construction to check the quality of the work, and the material is rerolled if the specified density is not obtained. A density equal to 95 percent of laboratory maximum was specified for the Delta-Mendota Canal lining. The average density obtained was 96.5 percent. A check on the permeability is also obtained by frequent laboratory permeability tests on soils taken from the lining. These soils are remolded in the laboratory to their in-place density conditions. Field permeability tests are also made to check the in-place permeability. These tests are made in the slope lining by measuring the outflow from test wells augered in the linings and subjected to a constant head of water. In the bottom lining, the tests are made by measuring the flow of water under constant head through a cylinder of soil formed by forcing a casing through the lining to the more pervious soils below.

Fig. 5 Construction of Heavy Compacted Earth Lining—Wellton-Mohawk Canal, Arizona
Construction de revêtements épais en sol compacté – Canal de Wellton-Mohawk, Arizona

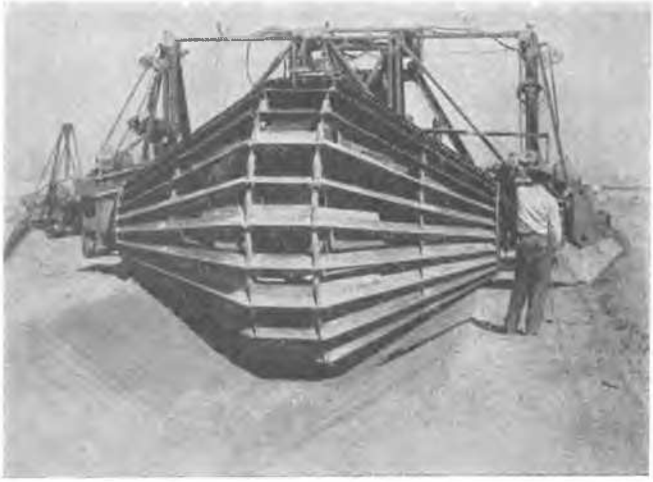

Fig. 6 Construction of Compacted Earth Lateral—Gila Project, Arizona
Construction des canaux latéraux en sol compacté – Projet de Gila, Arizona

General Considerations

Favorable service records and low initial construction costs make heavy compacted earth linings attractive for lower-cost seepage control. All heavy earth linings placed to date have performed satisfactorily with the exception of some slide failures on the Friant-Kern Canal. These slides were the result of drying and cracking of the fat clays and a poor foundation soil condition. Troubles of this nature can be avoided through the use of proper soils if available, or through special design considerations. Erosion is not a problem as long as the materials used are compatible with the velocities and other hydraulic properties of the canal. Figs. 7 and 8 show completed earth linings in operation. The beaching of fines from the uncompacted outer layer is minor in nature. Although it is believed that maintenance cost of earth linings will be greater over a long period of time than for concrete linings, there is no indication that these costs will be excessive. To date weed growth has been of no consequence, even though most of the heavy compacted earth linings have been constructed in areas which have warm climates and long growing seasons.

Seepage losses from canals lined with heavy compacted earth are comparable to losses from canals lined with concrete. Ponding tests were made on the Friant-Kern Canal to measure the actual seepage losses from adjacent earth-lined and concrete-lined sections. Sections about 3,000 feet long were isolated by earthen dikes and the ponds so formed were filled with water. The water loss was measured by staff gages, corrections being made for evaporation losses. The final rates of seepage losses after 25 days were 0.067 cu.ft./sq.ft./day for the earth-lined section and 0.070 cu.ft./sq.ft./day for the concrete-lined section. Other tests will be made as the opportunity arises.

The cost of heavy compacted earth linings averaged $0.52 sq.yd. or roughly 25 percent of the cost of conventional unreinforced concrete linings on three recent projects where adjacent reaches of concrete and earth linings could be compared. These particular jobs involved large units of concrete and earthwork. Favorable unit prices can now be obtained for such large-scale earthwork because of improvements in equipment and methods of earth construction in the last 10 years.

There are considerations, other than cost, that may make earth the most desirable lining material. Where expansive clays are encountered, as in Arizona, California, and other places, concrete linings have been ruptured by the expansive forces of subgrade clays. Heavy earth linings usually have sufficient weight to resist major uplift or are sufficiently flexible to withstand the uplift that does occur. In high ground-water areas, rigid linings must be protected against hydraulic uplift by extensive drainage systems. Heavy earth linings, because of their weight, can resist such forces without damage.

Service records are being obtained at frequent intervals on all heavy compacted earth linings we have constructed and will be obtained on future installations. From these service records we hope to establish better correlations between serviceability and soil properties, designs, and constructions techniques.

References

United States Department of the Interior, Bureau of Reclamation (1952): Canal Linings and Methods of Reducing Costs, p. 1.

Fig. 7 Heavy Compacted Earth Lining in Operation—Wellton-Mohawk Canal, Arizona
Revêtement épais en sol compacté en opération – Canal de Wellton-Mohawk, Arizona

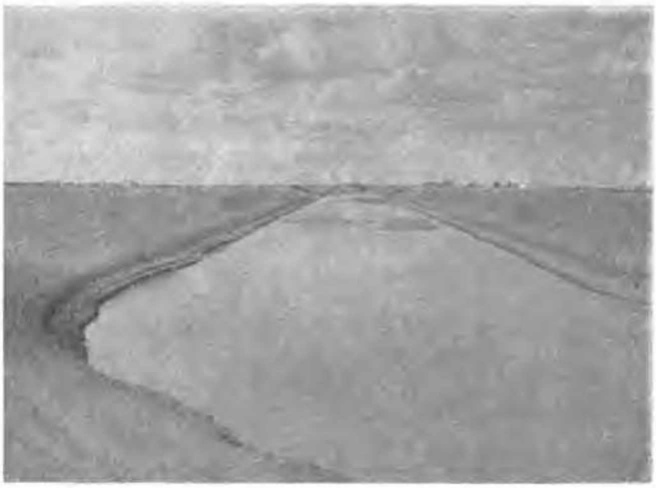

Fig. 8 Heavy Compacted Earth Lining in Operation—Delta-Mendota Canal, California
Revêtement épais en sol compacté en opération – Canal de Delta-Mendota, Californie