R-89-05

COMPACTION OF SOIL ON CANAL SIDE SLOPES

June 1989

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
Research and Laboratory Services Division
Geotechnical Services Branch

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. R-89-05	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE COMPACTION OF SOIL ON CANAL SIDE SLOPES		5. REPORT DATE June 1989
		6. PERFORMING ORGANIZATION CODE D-3760
7. AUTHOR(S) Chester W. Jones		8. PERFORMING ORGANIZATION REPORT NO. R-89-05
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bureau of Reclamation Denver Office Denver CO 80225		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE DIBR

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at the Denver Office, Denver, Colorado.

16. ABSTRACT

For many years, Bureau of Reclamation researchers have perceived the need for more efficient methods of compacting soil on canal side slopes, both in situ and in layers parallel to the slope as a lining. The conventional method of placing side slope lining in horizontal layers results in overexcavation and in linings thicker than are often necessary. Factors to be considered in the use of equipment for side slope compaction are discussed and research by Reclamation is summarized. Respondents to a survey of construction equipment manufacturers and contractors believed that available conventional equipment with or without minor modifications can serve the purpose and that present demand does not justify development of special equipment. It is recommended that when an appropriate canal lining job arises, specifications could be provided for slope compaction and this might be an incentive for the development of more efficient equipment.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*-- canals/ canal lining/ compaction/ compaction equipment/ cohesive soil/ research/ construction equipment/ canal seepage

b. *IDENTIFIERS*--

c. *COSATI Field/Group* *COWRR:* *SRIM:*

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT) *UNCLASSIFIED*	21. NO. OF PAGES 39
	20. SECURITY CLASS (THIS PAGE) *UNCLASSIFIED*	22. PRICE

R-89-05

COMPACTION OF SOIL ON CANAL SIDE SLOPES

by

Chester W. Jones

Geotechnical Services Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

SI METRIC

June 1989

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

Responses to Bureau of Reclamation letters to equipment manufacturers and to contractors requesting information on current equipment that could be used for compacting soil on canal side slopes and/or interest in a proposal for further development of methods for this purpose were appreciated. A copy of this report is being sent to each company contacted. Although a Reclamation research project on this subject is not active at present, should there be any further information or comments on the subject, please contact Paul C. Knodel, Geotechnical Services Branch, code D-3762 [telephone (303) 236-5987] or Walter L. Long, Water Conveyance Branch, code D-3120 [telephone (303) 236-4203], Bureau of Reclamation, PO Box 25007, Denver CO 80225.

The work of Daniel L. Maag in compiling and summarizing the information and of Amster K. Howard in providing logistic support for publication is appreciated.

The research covered by this report was funded under the Bureau of Reclamation PRESS (Program Related Engineering and Scientific Studies) allocation No. DR-85 - Open and Closed Conduit Systems Program.

CONTENTS

FIGURES

CONTENTS - Continued

APPENDIXES

INTRODUCTION

There has been a longstanding need for improved equipment and methods for compacting soil on canal side slopes to control seepage. The prevailing current method of constructing thick compacted soil (earth) lining built up in horizontal layers by increasingly large conventional earthmoving and compaction equipment sometimes results in excessive canal excavation with more processed soil and a greater thickness of lining than are often necessary. In some cases, placement of thinner soil linings with layers parallel to the side slopes would be adequate to control seepage and be more economical than the conventional thick linings, provided equipment better adapted for this purpose was available. Also, there are many existing unlined canals worldwide where seepage has developed and compaction of soils in place could provide significant seepage reduction to conserve water and minimize damage to adjacent agricultural land. Furthermore, recent instances of sloughing of protective soil cover on plastic canal linings and on linings of soil subject to erosion indicate the possible need for compacting cover materials on side slopes.

Following a brief description of soil linings, this report presents results of a survey of representative construction equipment manufacturers and contractors to determine (1) current equipment available for canal side slope compaction and (2) the extent of interest in further development of such equipment, if needed, with the possibility of cooperative research with the Bureau of Reclamation. A summary of Reclamation research on canal side slope compaction is presented in appendix B.

CONCLUSIONS

The following conclusions are based on the survey of manufacturers and contractors on equipment for compaction of soil on canal side slopes:

1. Several respondents indicated that available conventional equipment with or without minor modifications would serve the purpose.

2. There was little interest expressed in developing specialized equipment for the purpose because the market was thought to be too small to justify the effort.

After reviewing the few field research demonstrations performed by Reclamation, it is apparent that, although conventional canal construction equipment has developed significantly, its application for canal side slope compaction of cohesive soils has not progressed much during the past 35 years.

RECOMMENDATIONS

In the absence of up-to-date research, any further improvement in methods to compact soil on canal side slopes either in place or in layers parallel to the slope could best be accomplished under the marketplace "law of supply and demand." When an appropriate specific need arises, Reclamation could issue a performance-type specification for soil compaction on canal side slopes, either as a single bid item or as an alternative. The contractor could then provide equipment required for necessary performance. Any such work should be contingent upon approval by Reclamation after thorough evaluation and testing at the beginning of lining compaction.

Research should be performed to determine seepage through soil layers for canal lining with water flowing generally perpendicular to layers compacted parallel to side slopes, compared to water flowing parallel with horizontal layers as compacted in conventional canal lining.

LINING DESIGN AND CONSTRUCTION

Soils

Figure 1 lists the important physical properties of soils and their relation to canal linings for adequate erosion resistance and low permeability. The plasticity index of the soil should be between 10 and 45 (Bureau of Reclamation, 1980).

Thick Linings

Thick canal linings are constructed with both the bottom and side slope lining compacted by sheepsfoot rollers in successive horizontal layers not more than 6 inches (150 mm) thick after compaction (fig. 2).

The usual 2- to 8-foot (0.6- to 2.4-m) wide horizontal layers on the side slopes can be overbuilt as necessary to accommodate conventional, large earthmoving and compaction equipment, which may be up to 12 feet (3.7 m) wide, then trimmed to required cross-sectional lines, where necessary. Thus, the actual thickness of lining is usually 2 to 3 feet (610 to 915 mm) or more, measured normal to the slope. For large canals, where ample lining material is readily available, the widest lifts are generally used because large quantities of soil can be moved economically and compacted with large equipment. The actual thickness of the lining is usually more than is necessary, but the economics of using conventional large-scale equipment, the reduced maintenance costs, and the elimination of the need for a protective soil cover to allow for soil erosion make this the currently preferred canal lining.

Thin Linings

Thin compacted earth linings ordinarily consist of one or two 6-inch (150-mm) layers of cohesive soil thoroughly compacted and often protected against degradation by a 6- to 12-inch (150- to 305-mm) cover of coarse-grained soil. Lining and cover thickness requirements vary with the types of soil used, the velocity of the water to be conveyed, and other specific conditions. Thin linings may be expensive because of the difficulty with operating compaction equipment on a 2H to 1V slope to obtain the specified soil unit weight, which is usually at least 95 percent of the laboratory maximum. For this purpose, rollers have been operated either up and down the slope or traveling on the slope longitudinal with the canal. In either case, it has been necessary to tie the roller to a dragline or other mobile equipment traveling along the top of the canal slope.

For small canals and laterals, thin linings can be constructed on side slopes by building up successive horizontal layers 3 to 4 feet (0.9 to 1.2 m) in width. Compaction may be accomplished with a small single-drum sheepsfoot roller towed by a small tractor. Sometimes for a small canal or lateral, the canal is overexcavated, the excavation is completely filled with compacted soil, and the canal prism is then excavated to specified dimensions. By this method, a relatively thin compacted lining remains.

One reason that thin linings have not been used more is because of the risk of reduction in lining thickness from erosion by water or by excavation during canal cleaning operations. Thin linings that require repair of damage can result in much higher maintenance costs than thick linings, and the difference in maintenance costs can exceed the initial cost difference for construction.

COMPARISON BETWEEN LININGS WITH SOIL LAYERS HORIZONTAL AND ON SLOPE

Sometimes it is economical to conserve soil lining because (1) nearby borrow is limited, (2) a more distant source requires extra expense for overhaul, or (3) extra expense is incurred to blend fine and coarse soils for a suitable mixture. Figure 3 illustrates the usual thick compacted lining (method A) and a thinner lining compacted in layers parallel to the canal side slope (method B). For a typical thick lining placed on a 2H to 1V side slope, a lining would be constructed to the approximate dimensions shown for method A using 6-inch (150-mm) thick, compacted horizontal layers. If the soil were compacted in layers parallel to the slope, a thinner lining as shown in method B could be used. A 2-foot (610-mm) thick lining with four 6-inch (150-mm) thick layers of the proper type of soil would often be adequate to control seepage and still allow enough thickness for a moderate amount of degradation.

In calculating the volumes of soil required for methods A and B, the difference is in the thickness of the lining. The ratio of the thickness of method A, 3.6 feet (1100 mm), to the thickness of method B, 2 feet (610 mm), indicates that method A requires about 80 percent more compacted lining than method B. If the costs of placing and compacting soil lining by methods A and B were the same, the cost savings would be proportional to the respective volumes of soil in the linings with the corresponding amounts of excavation required for each.

EQUIPMENT FOR COMPACTING BACKFILL FOR CONCRETE LINING

Various equipment has been used successfully for compacting backfill (predominantly granular soil of relatively high permeability) behind concrete lining on canal side slopes. Figure 4 shows a pneumatic, tamping-type compactor used to place this type of material on the large Friant-Kern Canal in the mid-1940's (Benson et al., 1946). This equipment was reported to have compacted a 2-foot (610-mm) thickness of backfill to an average unit weight of 93 percent of the maximum laboratory unit weight. A respondent to the Reclamation survey believed that the equipment their company currently uses for compacting backfill for concrete linings might be used to compact soil linings, but to our knowledge this type of equipment has not been used for Reclamation soil linings. Such equipment appears to be more applicable to granular soil for concrete backfill than for multiple layers of cohesive soils normally used for canal lining. Figure 5 shows a vibrating smooth-drum roller attached to an excavator being used to compact sand and gravel on a reservoir slope (Bureau of Reclamation, 1976).

SEEPAGE TEST SECTIONS

It has been demonstrated that a compacted soil canal lining can be placed on a 3H to 1V side slope by a roller without being attached to other equipment on the canal bank. In 1955, a reach of Franklin Canal in Nebraska was lined with an 18-inch (460-mm) thick lining of silty loess constructed in this manner (Jones and Lowitz, 1960). The lining was then covered with loose soil to form 1-1/2H to 1V side slopes. In 1958, a ponding-type seepage test on this lining was performed and the seepage rate was 0.03 $ft^3/ft^2/d$ (9 $L/m^2/d$) (Jones, 1987). Another ponding test performed simultaneously on Franklin Canal lining of similar soil placed in horizontal layers 6 feet (1.8 m) wide had a seepage rate of 0.09 $ft^3/ft^2/d$ (27 $L/m^2/d$); this lining had a thickness normal to the 1-1/2H to 1V side slopes of about 3.3 feet (1 m).

SURVEY OF MANUFACTURERS AND CONTRACTORS

A letter dated August 31, 1984, was sent to 34 equipment manufacturers and earthwork contractors to determine (1) information on equipment available to efficiently compact soil linings on canal side slopes and (2) interest in further development of such equipment with possible cooperative research with Reclamation. A copy of this letter and a list of recipients are included as item 1 in appendix A. A brief statement soliciting the same information was published in the CBD (Commerce Business Daily) on Monday, September 24, 1984. The CBD notice is included as item 2 in appendix A. On April 19, 1985, a letter similar to the the one above was sent to another company doing canal lining work.

There were 11 replies to the first letter, 5 responses to the notice in the CBD, and a response to the April 1985 letter; a list of those responding is included as item 3 in appendix A. Of the five responses to the CBD notice, three simply sent brochures or catalogs of their equipment and two asked for more detailed information. The response to the April 1985 letter contained only a brochure showing equipment manufactured by the company, without comment. Letters with the requested information were sent to the latter two, and one replied.

Responses to the August 1984 letter of indicated that five companies had no equipment that would be appropriate and were not interested in the development of any. They believe that the potential market does not warrant any special effort. One respondent indicated an interest in a joint research activity. Four companies addressed the problem, although one of these misunderstood the application and the comments were not relevant. Of the other three, one described how their current equipment could be used, one discussed a possible equipment modification, and one discussed the economics of the problem.

There was apparently very little interest in developing equipment for canal side slope compaction. One letter provided the best comments on the current situation as the company understood it. These comments are quoted as follows:

> "1. The market for compacted embankment is really not very well defined, even in the canal building area. At present we do not see it as a large market.
>
> "2. It is possible to develop a special machine to do compaction faster and better than it is presently being done.

"3. It doesn't appear that there have been serious complaints about the systems presently being used to accomplish this work. Even though apparently slow and inefficient, the costs do not appear to be too bad.

"4. The development of a specialized machine to do this work seems questionable, considering that contractors are presently doing an acceptable job with equipment they now possess.

"5. A contractor buying new machinery for future work would probably write the new machines off on a single job and this would not be economically sound in the bidding process.

"6. The use of a winched roller may appear slow and inefficient, but the basic economics of this operation have never appeared to warrant anything better."

DISCUSSION

The applicability of equipment to compact soil on canal side slopes depends on conditions at each specific site. The following factors need to be considered:

1. Size of the canal or lateral. - A particular compaction method may be economical for a large canal but not for a small one, or vice versa.

2. Access to the canal for supporting equipment. - The terrain beside the canal may not be suitable for mobile equipment for attachment of compactors on the side slopes. A canal usually has a roadway along one side, but it may veer away from the canal for some distance or be high above the waterline through a deep cut. On a side-hill canal, uphill side access may be impractical. This would eliminate methods described in this report where rollers are tied to equipment at the top of the slope. The equipment would need to operate from the canal bottom. Possibly a roller could be pushed up a slope by a bulldozer, which by itself may not adequately compact cohesive soil for canal lining, because of low unit tread pressure.

3. Steepness of the side slope. - Most canal side slopes are 2H to 1V or 1-1/2H to 1V, although at least one large canal had 2-1/2H to 1V slopes. The steeper the slope, the smaller the component of effective force normal to the slope for compacting the soil. Some existing canals may have a portion of the slopes almost vertical due to sediment deposits or erosion, and would need reshaping before compaction.

4. Presence of canal structures. - Compaction equipment should have the capability of being readily removed from the canal at one end of a structure and repositioned in the canal at the other end.

5. Soil type. - Some types of soil are easier to compact to a specified unit weight (usually 95 percent of maximum laboratory unit weight) on the side slope than others. A sheepsfoot roller in silt, particularly for in-place compaction, would not "walk out" but would

leave a significant depth of loose soil near the surface. This could be compacted by a rubber-tired roller following the sheepsfoot roller as was done in the Courtland Canal field test (app. B). However, it may be possible to develop a suitable roller that will "walk out." For a lining built up in layers, it would be preferable to have roller feet that would compact the soil to provide some degree of bonding between layers to avoid "planes of weakness" where water might tend to separate layers.

6. Soil subgrade. - To obtain an adequate degree of compaction in the bottom layer of a lining, the subgrade has to be relatively firm and unyielding. In the case of the 5-inch (130-mm) thick soil-cement lining on lateral W20F on the Columbia Basin Project (app. B), the subgrade was a medium to coarse sand and there was no problem in obtaining the specified unit weight in the lining. For a less firm subgrade, it would have to be compacted before starting lining placement.

One of the respondents to the survey stated that a roller could be developed specifically to operate on canal slopes, and such equipment can be visualized. A possible version of the proposed equipment illustrated in figure B-3 could be two unmanned, self-propelled rollers with a rigid attachment between them and both operated by one person with an electrical control system. Although it would be possible to develop a roller that could operate up and down a 2H to 1V slope, this requires continual starting, stopping, and reversal of direction; equipment operating parallel to the canal would be faster. A roller for this purpose could be constructed with feet that were adjustable so they would tamp the soil vertically and utilize the full mass of the roller. A ballast that could be shifted could provide a uniform pressure on the feet.

STUDIES NEEDED

The relative amount of seepage through a lining placed parallel to the canal side slope and one placed in horizontal layers should be investigated. There is some evidence from laboratory permeability tests on undisturbed soil samples from earth dams that permeability parallel to compacted layers may be significantly higher than permeability perpendicular to the layers. Laboratory permeability tests performed on undisturbed specimens from Navajo Dam showed horizontal permeabilities ranging from 2.3 to 30 times as high as vertical permeabilities (Ellis, 1959). The soil was a lean clay with a plasticity index of 10 and was compacted by a vibratory roller.

For the seepage tests previously mentioned on Franklin Canal, seepage through the lining placed parallel to the 3 to 1 slope was about one-third of the horizontally placed lining.

APPLICATION

This investigation brought a Reclamation concern about soil compaction on canal side slopes to the attention of private industry and elicited up-to-date responses. Although there was no immediate positive reaction, raising of the issue together with a summary of Reclamation experience with soil compaction on canal side slopes may aid in future canal lining developments.

BIBLIOGRAPHY

Benson, J. R., W. G. Holtz, and M. C. Lipp, "Lower-Cost Canal Lining Program--Regions II, III, and IV," Field trip report to Chief Engineer, Bureau of Reclamation, Denver, Colorado, December 3, 1946.

Bureau of Reclamation, "Construction Progress Report," San Luis Unit, Central Valley Project for Period of May 21, 1976, to June 20, 1976, Denver, Colorado.

____________, *Earth Manual*, 2d edition, U.S. Department of the Interior, Bureau of Reclamation, U.S. Government Printing Office, Washington, D.C., reprint 1980.

____________, *Linings for Irrigation Canals*, U.S. Department of the Interior, Office of the Chief Engineer, Denver, Colorado, July 1952.

____________, *Linings for Irrigation Canals*, 1st edition, U.S. Department of the Interior, U.S. Government Printing Office, Washington, D.C., reprint 1976.

Ellis, W., "Laboratory Studies of Undisturbed Soil Samples From a Test Embankment Compacted by a Triple-Drum Vibrating Roller - Navajo Dam - Colorado River Storage Project, New Mexico," Report No. EM-570, Bureau of Reclamation, Denver, Colorado, October 23, 1959.

Holtz, W. G., "Construction of Compacted Soil Linings for Canals," Report No. EM-383, Bureau of Reclamation, Denver, Colorado, October 19, 1954.

____________, "Thick Compacted Earth Linings for Canals," Report No. EM-462, Bureau of Reclamation, Denver, Colorado, August 15, 1956.

Jones, Chester W., "Compaction of Soils by Rolling in Place - Station 448+00 to 458+00 - Courtland Canal - Bostwick Division - Missouri Basin Project," Field Trip Report to Chief Engineer, Bureau of Reclamation, Denver, Colorado, April 28, 1953.

____________, "Long-Term Changes in the Properties of Soil Linings for Canal Seepage Control," Report No. REC-ERC-87-1, Bureau of Reclamation, Denver, Colorado, July 1987.

____________, "Soil-Cement Lining - Lateral W2OF - Specifications No. DC-4590 - Lower-Cost Canal Lining Program, and Examination of Surge Tank Site at Station 45+00 of Sublateral W77C - Columbia Basin Project," Field Trip Report to Assistant Commissioner and Chief Engineer, Bureau of Reclamation, Denver, Colorado, December 13, 1956.

Jones, Chester W., and Clemith A. Lowitz, "Performance of Compacted Loessial-Soil Canal Linings," Report No. EM-575, Bureau of Reclamation, Denver, Colorado, July 1960.

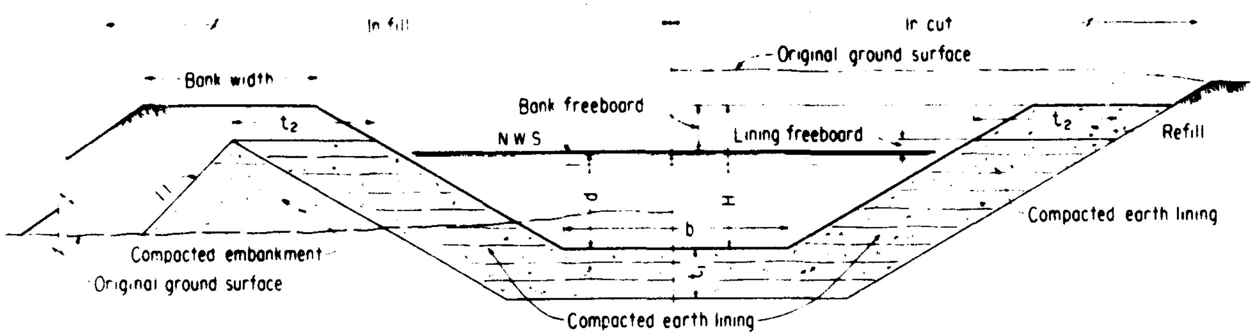
Merriman, J., and D. A. Tiedemann, "Vibratory Compaction of In Situ Canal Soils, Lower Cost Canal Lining Program," Report No. EM-744, Bureau of Reclamation, Denver, Colorado, January 20, 1967.

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 (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 classification, 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	5	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	9	—
			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)

LCCL-T10

Figure 1. - Important physical properties of soils and their uses for canal linings.



TYPICAL EARTH LINED SECTION

TABLE FOR EARTH LINING

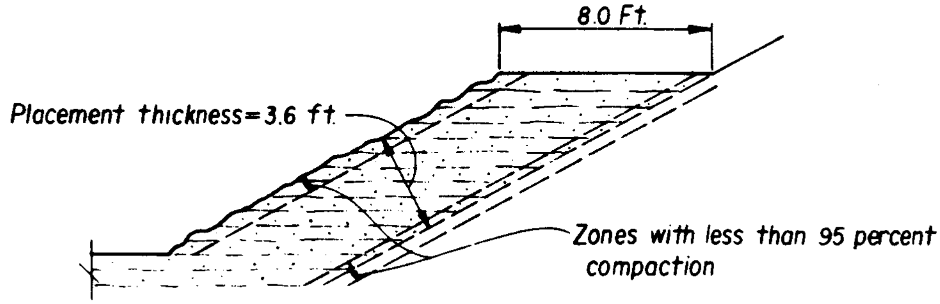
d	t_1	t_2
2.0' or less	1.0'	3.0'
>2.0' to 4.0'	1.5'	4.0'
>4.0' to 6.0'	2.0'	6.0'
Over 6.0'	2.0'	8.0'

NOTE

If lining material requires a protective cover of gravel or riprap to prevent scour or erosion, excavation shall be extended to provide for the designated thickness of lining plus the gravel or riprap cover.

Figure 2. - Typical canal section for thick compacted soil lining.

METHOD A-Conventional Thick Soil Lining
(6-Inch-Thick Horizontal Layers)



METHOD B-Proposed Thinner Soil Lining
(6-Inch-Thick Layers Parallel to Side Slope)

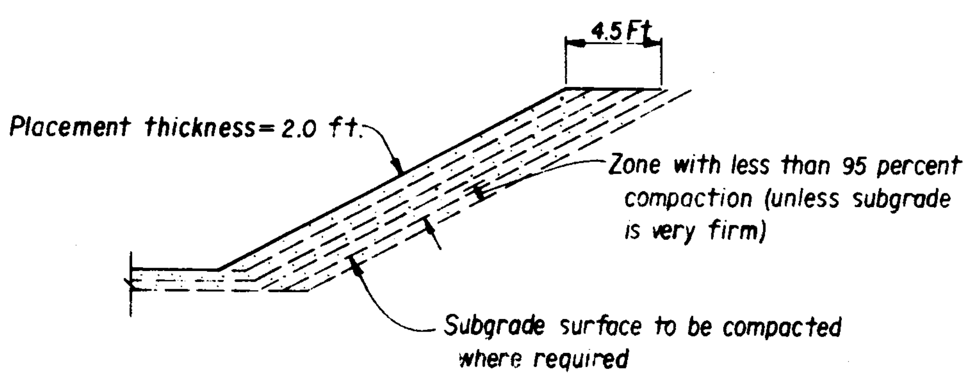


Figure 3. - Two methods of placing soil lining on 2H to 1V canal side slopes.

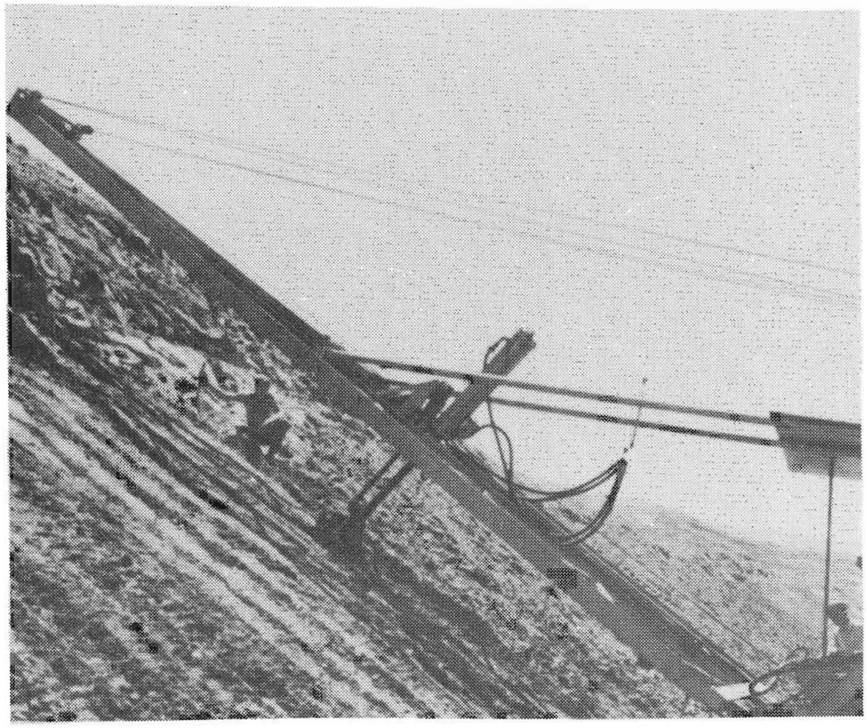


Figure 4. - Pneumatic tamping-type compactor for compacting backfill for concrete canal lining.

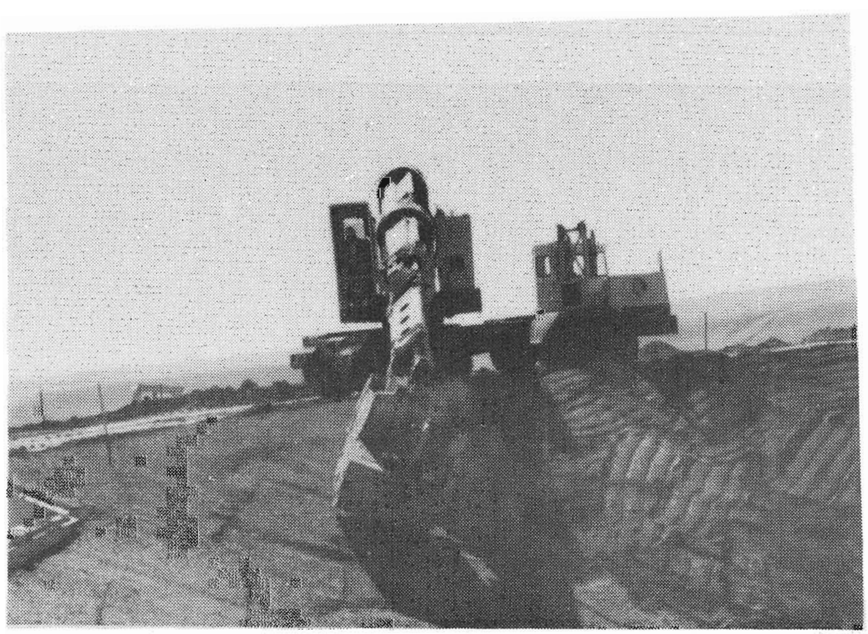


Figure 5. - Vibrating smooth-drum roller used to compact cohesionless soil on side of reservoir.

APPENDIX A

Supporting documents for survey

ITEM 1

Quoted letter dated August 31, 1984 (sent to 34 equipment manufacturers and earthwork contractors)

Gentlemen:

There is a need for equipment capable of efficiently compacting soil for lining on canal side slopes. This letter is an inquiry to determine (1) the latest equipment available or planned for this purpose and (2) interest in further development of such equipment if it is not now available. We are sending the letter to various companies which manufacture or assemble construction equipment for earthwork and to the Commerce Business Daily.

The conventional method of constructing soil linings for seepage control has been to overexcavate the canal prism and then build the lining up the usual 2 horizontal to 1 vertical side slopes in 6-inch horizontally placed and compacted layers, using large hauling equipment and rollers for compaction. Considering the present width of conventional equipment, this results in large volumes of overexcavation for lining and replacement and compaction of excessive volumes of selected, moisture-conditioned, compacted soil lining. This causes a thicker, more expensive lining than necessary to control seepage. Also, there are many unlined canals in operation where seepage occurs in certain areas and remedial measures are required, but the cost of the thick compacted soil linings placed conventionally is prohibitive. Canal dimensions vary widely, but generally would have bottom widths of 5 to 75 feet and water depths from 2 to 15 feet.

Equipment is needed to effectively and economically place and compact a few thin soil layers parallel to the slopes. In cases where existing soils in unlined canals would be of low permeability when compacted, the soil could be compacted in place after shaping or reshaping the side slopes.

In the past, a limited amount of soil compaction has been accomplished on canal side slopes using a roller on the slope attached to equipment traveling on the top of the canal bank, where there is a roadway. In this case, the roller is usually winched up and down the slope. However, this method is slow and inefficient. A more rapid method by a single unit capable of compacting soil on the slope, or possibly the simultaneous compaction of both slopes by two pieces of equipment joined together, is needed.

If a survey reveals that there is no equipment now available to efficiently compact thinner linings on canal slopes, the Bureau of Reclamation may consider a cooperative research program with another organization to develop such equipment. The Bureau could specify the soil compaction requirements and designate a canal reach where the equipment could be tried and the performance evaluated by testing.

We would like to receive any information you may have on equipment which could be used for compacting thin soil linings on side slopes and/or a proposal for further development for this purpose.

Sincerely,

/s/ Larry B. Harrell

Larry B. Harrell, Chief, Procurement and Contracts Branch

Identical letter to:

R. A. Hanson Company, Inc.
Attn Gordon Hawkins
PO Box 7400
Spokane WA 99207

Guntert and Zimmerman
Construction Division, Inc.
Attn Hans Schiesser
222 East Fourth Street
Ripon CA 95366

Shaw Sales & Service Company
PO Box 2275
La Puente CA 91746

Essick/Hadco Manufacturing Co.
1950 Santa Fe Avenue
Los Angeles CA 90021

Hyster Company
Equipment Div.
PO Box PO Box 289
Kewwanee IL 61443

Wichita Steel Fabricators, Inc.
PO Box 4009
Wichita KS 67204

Bros Road Machinery, Inc.
Dept. TR
7216 Boone Avenue North
Brooklyn Park MN 55428

Wacker Corporation
PO Box 09402
Milwaukee WI 53209

RayGo, Inc.
Dept. TR
PO Box 1362
Minneapolis MN 55440

Massey-Ferguson, Inc.
1901 Bell Avenue
Des Moines IA 50315

Ingersoll-Rand Company
Ingersoll Drive
Shippensburg PA 17257

Guy F. Atkinson Company Construction
10 West Orange Avenue
South San Francisco CA 94080

Ball, Ball, & Brosamer, Inc.
300 Camille Avenue
PO Box 1007
Danville CA 94526

S. J. Groves & Sons Company
PO Box 1267
10,000 Highway 55 West
Minneapolis MN 55440

American Steel Works
2459-T Charlotte
Kansas City MO 64108

General Engines Company, Inc.
Interstate 295
Thorofare NJ

Stow Manufacturing Company
400 Bump Road
Binghamton NY 13902

Galion Manufacturing Division
Dresser Industries, Inc.
PO Box 647
Galion OH 44833

Erie-Go Manufacturing Inc.
1432 Tiffin Avenue
Sandusky OH 44870

Mauldin Manufacturing Company
Rutherford Road
PO Box 3992
Greenville SC 29608

W. E. Grace Manufacturing
Company
7000 South Lamar Street
Dallas TX 75215

Tampo Manufacturing Company
PO Box 7248
San Antonio TX 78207

Southwest Research Institute
Attn Gary Stecklein
PO Drawer 28510
San Antonio TX 78209

AMCA International Corporation
Bomag Unit
1210 Kinton Street
Springfield OH 45505

Kiewit Engineering Company
1000 Kiewit Plaza
Omaha NE 68131

Granite Construction Company
PO Box 900
Watsonville CA 95077

Holloway Construction Company
29250 Wixom Road
Wixom MI 48096

J. F. Shea Company, Inc.
655 Brea Canyon Road
Walnut CA 91789

Scott Huber
PO Drawer 10263
Charleston SC 29411

Dresser Industries, Inc.
Dresser Bldg.
1505 Elm Street at Akard
Dallas TX 75201

Ingram Manufacturing Company
PO Box 2020TR
San Antonio TX 78297

Rexworks, Inc.
PO Box 2037
Milwaukee WI 53201

CMI Corporation
PO Box 1985
Oklahoma City OK 73101

Rammax Machinery Company Koehring
PO Box 24832
Durham NC 27705

ITEM 2

Notice published in the Commerce Business Daily

COMMERCE BUSINESS DAILY

September 24, 1984

Bureau of Reclamation, Engineering and Research Center, Procurement and Contracts Branch, Contracts Branch, Contracts Section, Code D-810, Denver Federal Center, PO Box 25007, Denver CO 80225 (303/234-3051)
Contact: Richard T. Kelley

38-EQUIPMENT CAPABLE OF EFFICIENTLY COMPACTING SOIL FOR LINING ON CANAL SIDE SLOPES. The Bureau of Reclamation is requesting information from industry to ascertain the existing state of the art availability, planned availability, or interest in development of such requirement. The equipment is needed to effectively and economically place and compact a few thin soil layers parallel to the slopes. Respondents should note that the requested hereby is for use in a feasibility study. The Government does not intend to award a contract on the basis of this request or otherwise pay for the information being solicited. Firms desirous of providing information or obtaining additional information for formulating a response should write Issuing Office (263).

ITEM 3

Respondents to the letter of August 31, 1984:

1. R. A. Hanson Company, Inc.
2. Guntert and Zimmerman
   Construction Division, Inc.
3. Essick/Hadco Manufacturing Company
   Division of Figgie International, Inc.
4. Wichita Steel Fabricators, Inc.
5. Bros Road Machinery, Inc.
6. Scott Huber
7. W. E. Grace Manufacturing Company
8. Tampo Manufacturing Company
9. RayGo, Inc.
10. Ingersoll Rand Company
11. Kiewit Engineering Company

Respondents to the Commerce Business Daily Notice:

12. Intercontinental Engineering - Manufacturing Corporation, PO Box 9055,
    Kansas City MO 64168
13. Allied Steel and Tractor Products, Inc., 5800 Harper Road, Solon OH 44139
14. GEMCO Equipment Co., PO Box 36278, Houston TX 77236
15. Over-Lowe Co., 2767 S. Tejon St., Englewood CO 80110
16. Construction Rental and Sales, Inc., PO Box 549, Fort Collins CO 80522

Respondent to the letter of April 19, 1985:

17. CANA Engineering, Ltd., PO Box 5220, Station "A," Calgary, Alberta, Canada

APPENDIX B

Reclamation research on compaction of soils on canal side slopes

INTRODUCTION

The need for improved equipment for compacting soil on canal side slopes has been recognized since the 1940's. Since then, mostly under the auspices of Reclamation LCCL (Lower-Cost Canal Lining) research program, a few field trials of side slope compaction were made. The first record was of test reaches of thin soil lining by transverse (fig. B-1) and longitudinal (fig. B-2) roller compaction on the W. C. Austin project in Oklahoma. After these tests, the 1952 LCCL report stated:

> ". . . the Bureau of Reclamation has not employed the thin compacted-earth lining on a very large scale. A seeming disfavor of the thin lining is due primarily to the relatively high cost of side slope compaction. Greater use of this type of lining depends, therefore, on the development of special equipment or methods for more economic compaction" (Bureau of Reclamation, 1952).

The same 1952 report suggested that two rollers be yoked together in tandem and operated by a dragline to more rapidly compact canal soil (fig. B-3); however, to our knowledge this arrangement was never tried.

IN-PLACE SOIL COMPACTION ON A CANAL SLIDE SLOPE

In March 1953, one side of a 1,000-foot (305-m) test reach of Courtland Canal (fig. B-4), Pick-Sloan Missouri Basin Program, in Nebraska, was compacted in place by rolling the soil surface (Jones, 1953). During the previous fall, field forces had demonstrated that good compaction in the canal bottom to a depth of about 15 inches (380 mm) could be accomplished by grader excavation and layered roller operations at a cost of about $0.08 per square yard [see List of Pertinent Correspondence (Jones, 1953)]. Attempts at that time to compact soil on the side slopes were not successful.

The canal soil was a loessial lean clay with 20 to 32 percent of particles smaller than 0.005 mm, 93 to 99 percent passing a No. 200 sieve, and all particles smaller than No. 16 sieve size. The average maximum laboratory unit weight was 107 lbf/ft^3 (16.8 kN/m^3) at an optimum moisture content of 18.7 percent. The average liquid limit was 33 and the plasticity index 13. At the time of the test, no attempt was made to change the moisture present in the soil, which ranged from 14 to 31 percent of the dry weight with an average of 20. The undisturbed canal soil had the typical loose structure of loessial soils with characteristic root holes; the resulting natural unit weight was about 81 lbf/ft^3 (12.7 kN/m^3) or about 76 percent of maximum laboratory unit weight.

Compaction was accomplished using a tractor-drawn, single-drum, standard Reclamation-type tamping roller (fig. B-5) with 3,000-lbm (1360 kg) per linear foot [15,000 lbm (6800 kg) total] without ballast, followed by a rubber-tired roller of estimated 8,000 lbm (fig. B-6). With full ballast, the mass of the sheepsfoot roller was 4,000 lbm (1814 kg) per linear foot; but in places, the soil moisture was above optimum and the ballast was removed to reduce shear planes caused by the heavier mass. There was no improvement in soil unit weight when using 12 roller passes rather than 6 to 8 passes. The tamping roller would not "walk out," and the rubber-tired roller was needed to compact the 6 to 8 inches of loose soil remaining. In this test section, the compacted soil was finally covered with 12 to 18 inches (305 to 460 mm) of loose canal soil.

Although soil compaction by pulling the tamping and rubber-tired rollers up and down the slope by a dragline (figs. B-5 and B-6) was first tried, most of the test section was compacted by longitudinal rolling (fig. B-7), which was faster. However, by the latter method, much of the mass of the roller was concentrated on the lower end of the roller. A twin-drum roller would have been preferable because (1) twice the area would be covered for the same distance traveled, (2) the roller would be more stable on the side slope, and (3) soil compaction would be more even.

Tests showed that for 0- to 5-inch (0- to 130-mm) depth below the surface compacted by the rubber-tired roller, the unit weight was about 90 percent of maximum laboratory unit weight or higher. For 5- to 10-inch (130- to 250-mm) depths, the percent compaction was from 85 to 90. For depths of 10 to 15 inches (250 to 380 mm), where the soil was drier than optimum moisture content, the unit weight ranged between 80 to 85 percent of laboratory maximum; where the soil was wetter than optimum, only one out of four tests showed any improvement over the natural soil density.

Subsequent to the field test, laboratory permeability tests were performed on typical soil samples from the test section. These showed that, for soil compacted to 97 percent of maximum laboratory unit weight, the average coefficient of permeability was about 9 feet per year (8.7×10^{-6} cm/s); for 87 percent compaction, the permeability was about 20 feet per year (1.9×10^{-5} cm/s); and for 80 percent compaction the permeability was about 80 feet per year (7.7×10^{-5} cm/s). Laboratory and field permeability tests showed permeabilities from 300 to 500 feet per year (2.9 to 4.8×10^{-4} cm/s) for a typical undisturbed soil of the type at the field test section. This indicates that a significant reduction in seepage could be accomplished, even though the 95 percent minimum compaction usually specified for a soil lining is not attained. During the field test a cost estimate was made for (1) eight passes of a tamping roller winched up and down the slope, (2) a dragging operation to smooth the surface, and (3) eight passes of a rubber-tired roller. The estimate for an 11-mile (7.7-km) test reach of canal was about $0.25 per square yard ($0.30 per m^2). That cost could probably be reduced by rolling the slope longitudinally.

SOIL-CEMENT LINING ON LATERAL SIDE SLOPES

In 1956, about 1 mile (1.6 km) of 5-inch (130-mm) thick soil-cement lining was placed by a contractor on lateral W2OF of the Columbia Basin Project by longitudinal rolling on the side slopes (Jones, 1956). The soil-cement consisted of 50 percent silty sand topsoil with 50-percent underlying medium to coarse sand and 9 percent portland cement by volume of soil. After some preliminary experimentation, the mixing and placement procedures on the lateral slopes were as follows: (1) a bulldozer mixed the soils beside the lateral; (2) a dragline transferred the mixed soil to the lateral bottom where soil-cement had been placed previously; (3) a bulldozer spread the soil mixture; (4) cement was spread from bags, and with water added, mixed in place with soil by a traveling mixer (Pulvi-mixer); and (5) the mixture was spread on the slope by a grader attached to a bulldozer (fig. B-8). Compaction to unit weights above 95 percent of maximum laboratory unit weight was accomplished by successive passes of a self-propelled, rubber-tired roller attached to a bulldozer on the lateral bank (fig. B-9). By the method described above, over 2,000 feet (610 m) of lining on the slope could be placed per day; and it was estimated that about a mile of lining could be placed on slopes and bottom in a 6-day period.

VIBRATORY COMPACTION OF CANAL SOIL IN PLACE IN CANAL BOTTOM

During October and November 1966, the bottoms of three short canal test reaches were compacted by å vibratory roller (Merriman and Tiedemann, 1967). The available equipment was not suitable for use on the canal side slopes, but the general method of evaluating results of compaction are applicable to compaction on side slopes. The test reaches were near McCook, Nebraska, on the Pick-Sloan Missouri Basin Program with two being on Culbertson Extension Canal and one on Bartley Canal. The following abstract describes two of the tests supervised by Denver Office geotechnical laboratory personnel on Culbertson Canal:

> "As part of the fiscal year 1966, Lower Cost Canal Lining Program, field tests were conducted to investigate effectiveness of a vibratory roller for compaction of in situ low-density loessial soil in the bottom of 2 unlined canals. Density testing of undisturbed samples and the installation and observation of settlement plates in the canal subgrade were used to determine the magnitude and depth of compaction. Apparent contradictions among different test results prevented accurate determination of the roller's effect; however, the following observations were made: (1) Density of approximately the upper 2.0 feet of soil was increased to greater than 98 percent of Proctor after 10 roller passes. (2) The vibratory roller did not appear to affect density below 2.0 feet, but may have caused a decrease in shear strength down to 15 feet. (3) A slight reduction in coefficient of permeability was measured. Further tests to investigate degree and depth of compaction, reduction in permeability, and effects of vibration on the shear strength are recommended."

The third test was conducted on Bartley Canal by field personnel, and the results appeared to correlate with the tests on Culbertson Extension Canal.

The vibratory roller used for these field tests was a single-drum, towed, sheepsfoot with a total mass of 12,500 lbm (5670 kg), a dynamic impact of 22,000 lbm (9980 kg), and a fixed frequency of 1,500 (plus or minus 100) vibrations per minute (fig. B-10). Since vibration frequency is an important factor in soil compaction, the use of a later-generation roller with provision for variable frequency could make a significant difference in the degree of compaction attained. However, it should be noted that a static roller (or a vibratory roller with the vibrator turned off) may provide better compaction for some cohesive soils than a roller with vibration.

Figure B-1. - Transverse compaction of thin earth lining.

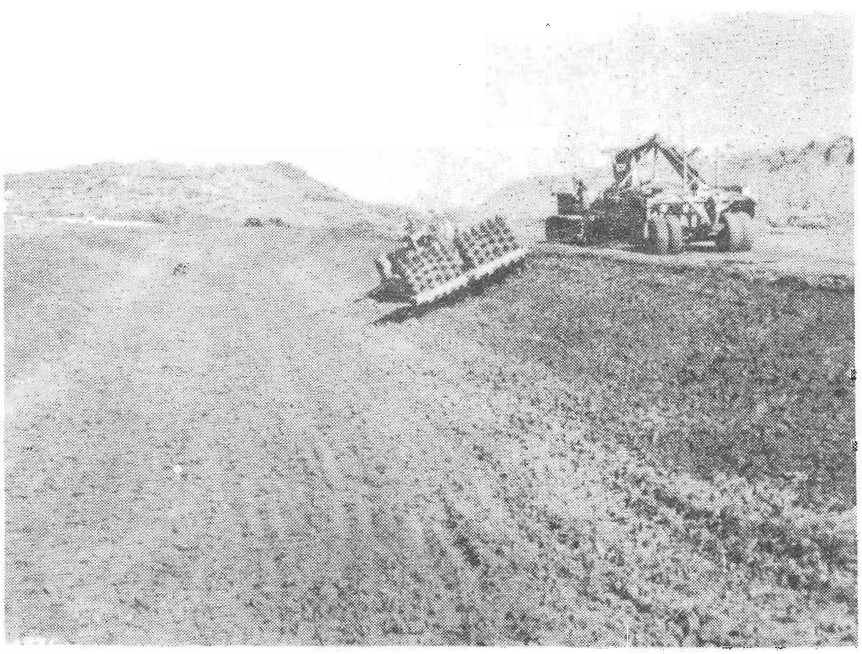


Figure B-2. - Compacting thin lining longitudinally on side slopes.

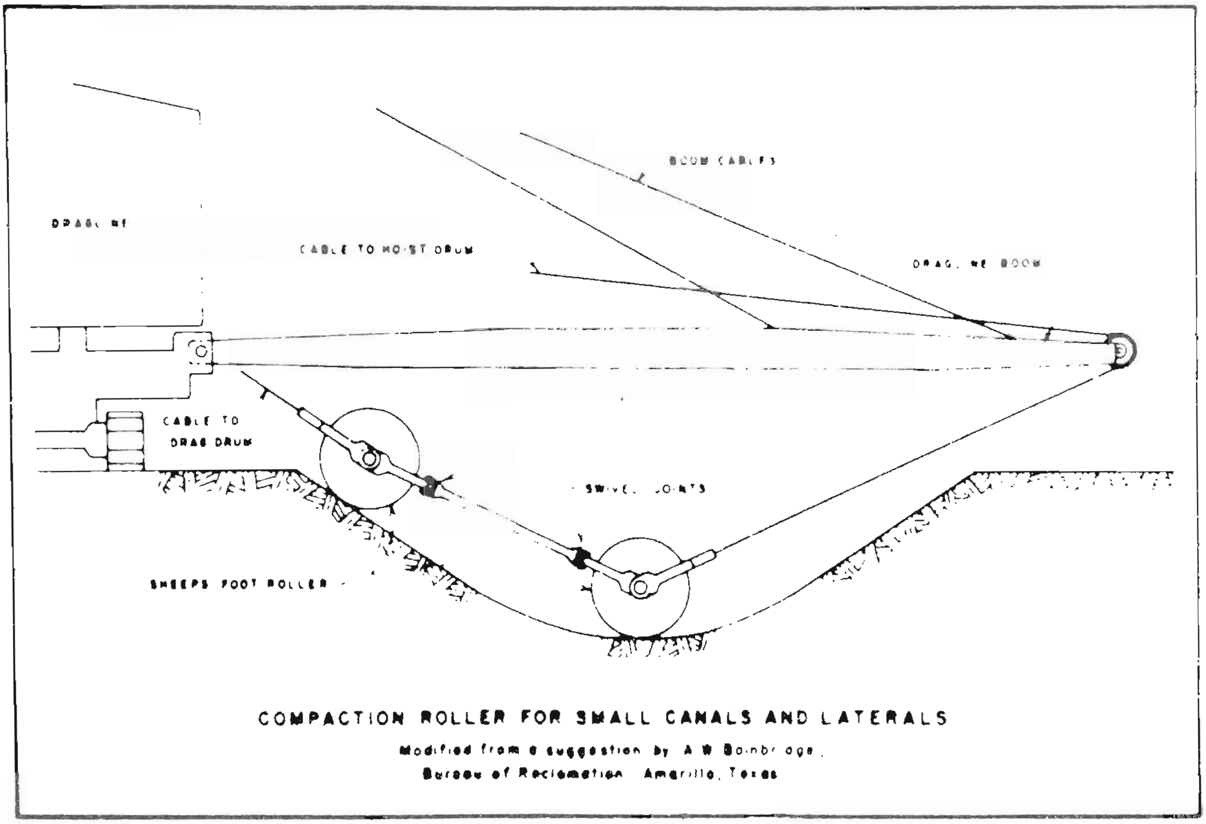


Figure B-3. - Suggested arrangement of tandem rollers.

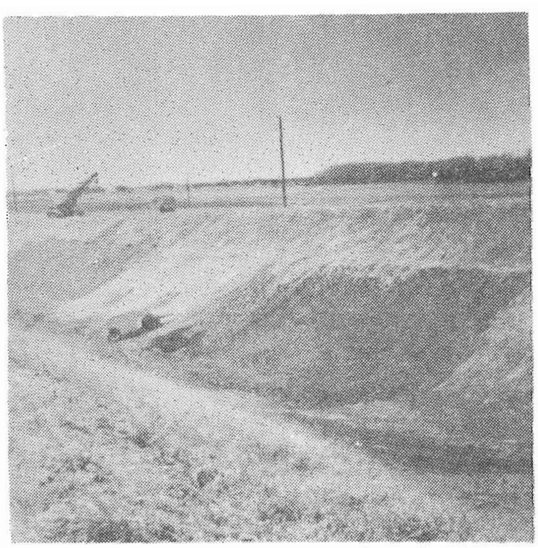


Figure B-4. - General view of test section near station 455+80 on Courtland Canal.

Figure B-5. - Canal side slope compacted by a sheepsfoot roller winched by a dragline.

Figure B-6. - A rubber-tired roller compacting loose soil left after compaction by a sheepsfoot roller.

Figure B-7. - A sheepsfoot roller operating longitudinally with canal to compact soil on side slope.

Figure B-8. - Use of a grader to spread soil-cement on the lateral side slope.

Figure B-9. - Compaction of soil-cement on lateral side slopes with a self-propelled, pneumatic-tired roller attached by cables to a tractor.

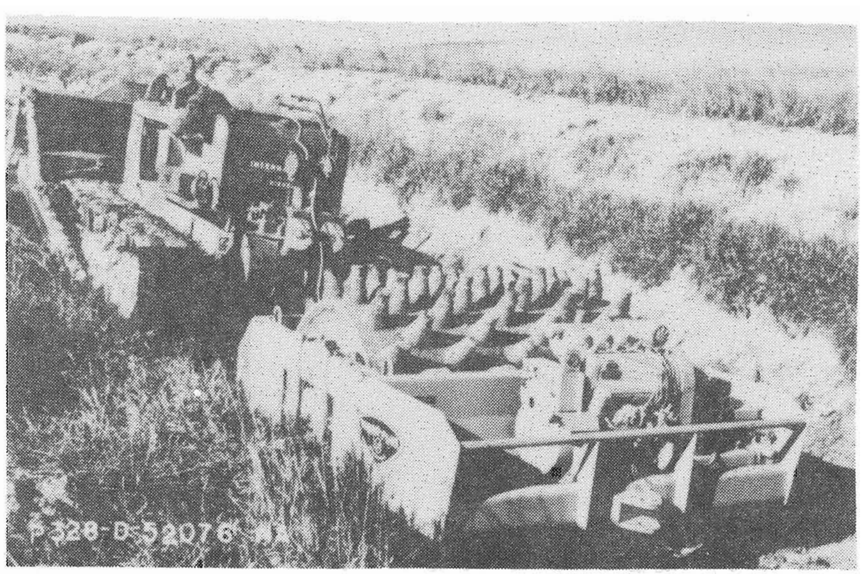


Figure B-10. - Vibratory roller used to compact soil in place.

*U.S. Government Printing Office: 1990 774-470

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.