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PERFORMANCE OF GRANULAR SOIL COVERS ON CANALS

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16. ABSTRACT

The characteristics and observed stability of fine and coarse soil cover layers placed on 19 selected earth-lined and unlined canal reaches to resist water erosion and to protect asphalt and plastic membrane linings are reported. The lining construction dates, canal test locations, canal design characteristics, physical properties of the covers, and observations on the performance of the covers over periods up to 25 years are given. Based on the experience of the Bureau of Reclamation with the performance of the test reaches, a range of grading for granular covers to control erosion on canals with similar conditions is proposed. Soils which have generally performed well in coarse cover layers on canals with tractive forces less than 5 N/m² (0.1 lb/ft²) have contained: (1) maximum particle sizes between 75 and 150 mm (3 and 6 in); (2) less than 50 percent passing a No. 4 (4.75-mm) sieve, and less than 10 percent passing a No. 200 (75-μm) sieve. To control sloughing of cover soils, consideration should be given to the grading of fine soil beneath coarse granular layers, and where economically justified controlling moisture and density.

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PERFORMANCE OF GRANULAR SOIL COVERS ON CANALS

by

C. W. Jones

August 1981

Geotechnical Branch
Division of Research
Engineering and Research Center
Denver, Colorado

SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

In May of 1981, the Secretary of the Interior approved changing the Water and Power Resources Service back to its former name, the Bureau of Reclamation. All references in this publication to the Water and Power Resources Service should be considered synonymous with the Bureau of Reclamation.

A free pamphlet is available from the Service entitled, "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request of the Water and Power Resources Service, Engineering and Research Center, P.O. Box 25007, Denver Federal Center, Denver, Colo. 80225, Attn: 922.

ACKNOWLEDGMENTS

The data for this report were collected between 1960 and 1980 by numerous people throughout the Water and Power Resources Service. Most of the funding was provided under Lower Cost Canal Lining and Open and Closed Conduit Systems committee research, and representatives of these committees coordinated the work in the various regions where the field test sites were located. Lyman Cox (retired), a former technician in the Soil Testing Section of the Geotechnical Branch, did much of the laboratory soil testing. Fred Clarke, now in the Analysis Branch, Division of Safety Evaluation of Existing Dams, Water and Power Resources Service, and Edward Metka, formerly with Water and Power, compiled some of the early data while they were rotation engineers. John G. Starbuck and Curtis J. Orvis of the Water and Conveyance Branch, Division of Design, and William R. Morrison of the Applied Sciences Branch, Division of Research, reviewed the report and their comments are appreciated.

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INTRODUCTION

It is necessary for canals to have surfaces that resist water erosion and displacement by other causes. For canals that do not have concrete or other hard-surfaced, exposed-type lining, selected granular soils are often used as erosion resistant covers at the canal-water interface. Such covers are also needed on most membrane type linings provided for seepage control to (1) hold them in place, (2) protect them from exposure to the elements and, (3) prevent damage to the membrane from water action, plant growth, animal traffic, and canal maintenance equipment [1][1]. Also, selected granular covers are occasionally used on earth-lined or unlined canals where the soil has insufficient cohesion to resist erosion.

The purpose of this investigation was to establish guidelines, particularly for grain-size distribution, for the selection of future covers based on past experience on canals in the Water and Power Resources Service (hereafter referred to as the Service). This report describes the performance with respect to stability against displacement of typical soil covers on a total of 19 selected reaches of canals and laterals. The work was started about 1960, under the Lower Cost Canal Lining Research Program when 10 covers on buried asphalt membrane linings, one on an earth-lined canal, and three on unlined canals were selected for long term studies. At that time, laboratory tests were made on samples of the covers and field observations of cover performance were recorded. In the late 1970's, under the Open and Closed Conduit Systems research program, the selected cover test reaches were revisited and observations of the cover conditions again recorded. Because PVC (polyvinyl chloride) linings are of comparatively recent vintage, the experience with covers on them is limited, but the performance of the three oldest are included. Also, experimental test sections of covers on one reach each of PVC and PE (polyethylene) lining placed in 1978 are included.

Although this report does not develop specific methods for selection and design of covers, the record of materials used and their past performance should be helpful in the selection of cover materials for future canals where conditions are expected to be relatively similar.

[1] The numbers in brackets refer to items in the Bibliography.

CONCLUSIONS

1. A suggested grading for a stable coarse granular cover layer on a canal with a tractive force less than 5 N/m^2 (0.1 lb/ft^2) should contain: (1) a maximum particle size between 75 and 150 mm (3 and 6 in), (2) between 5 and 50 percent passing a No. 4 (4.75-mm) sieve, and (3) less than 10 percent passing a No. 200 (75-μm) sieve (fig. 48).

2. Although the grading of the fine cover layer placed on membrane lining to prevent damage during placement of an overlying coarse layer can vary widely, predominantly medium to coarse sand in the fine layer may cause the coarser layer to be unstable during canal filling and drawdown. Also, to be stable during drawdown, the permeability of the coarse layer should be higher than that of the fine layer.

3. Some cover soils placed loosely without moisture or density control will settle when water is introduced into a canal and cause cracks to form near the top of the canal side slopes. Usually these are not serious and can be closed by dragging. However, this should be a consideration during the design and construction of a cover and the cost of moisture and density control weighed against the cost of maintenance.

4. In cold climates, freezing of soil moisture drawn to the underside of a membrane lining may cause sliding of the membrane on the subgrade during periods of thawing. However, there is only one recorded instance of this having happened. In a few cases without freezing, sliding of the membrane on the subgrade soil with folding near the toe of the slope has occurred. This is a possible area where research is needed.

5. Further investigation would be required to develop comprehensive criteria for the grading of a coarse cover layer relative to the grading of underlying soil and determine the minimum thicknesses required for fine and coarse covers.

6. Further investigations are needed to study the effects of tractive force on canal slopes and minimum canal radius requirements for erosion control.

CANAL COVERS

A canal cover may consist of one or two layers. Although a single layer has been placed on a few membrane linings, usually a fine soil layer is first placed to protect the membrane from puncture when the second layer of more granular soil is added. The first layer, sometimes called earth cover, is usually specified to be suitable soil from canal excavation ''excluding rocks, boulders, brush, large roots, and other objectionable foreign matter.'' For the coarser top layer, sometimes called the sand and gravel layer, specified ranges of particle sizes have varied, but a common one has been from 90 to 100 percent by dry mass passing the 75-mm (3-inch) screen, and from 0 to 5 percent passing the No. 200 screen along with the exclusion of the objectionable matter mentioned for the fine layer. An ideal cover material is one that can be obtained within reasonable haul distance from an approved source and meets gradation requirements without the need for processing. This usually provides a cover at the lowest cost.

The specified thickness of each layer is usually between 150 and 300 mm (6 and 12 inches), with the thicknesses depending somewhat upon the nature and availability of fine and coarse soils. The covers are usually placed by dragline or other approved equipment (fig. 1) without moisture or density control. After the soil is dumped, it is formed into more even layers by various means such as a dragline; sometimes with a special blade welded on the dragline bucket.

The test reaches for cover materials described in this report are listed in table 1. The specifications numbers, construction dates, stationing, and canal properties are shown in table A1 of the appendix. Table A2 lists sample locations, soil test data, measured cover thicknesses, and observations of cover performance.

Figure 1.—Placement of cover soils on asphalt membrane lining, East Bench Canal. Photo P801-D-79550

COVERS ON ASPHALT MEMBRANE LININGS

For asphalt membrane linings, the canal is overexcavated to allow for the thickness of cover, and, depending on the type of membrane used, the soil subgrade is sometimes compacted or smoothed to provide a firm surface without projecting rock particles. The recommended canal side slope for membrane linings is usually 2:1 or flatter.

The asphalt membrane linings in this report are the sprayed-in-place type. Catalytically blown asphalt was applied at 200 °C (400 °F) and the lining built up to a 6-mm (0.25-in) thickness; this required about 5.7 L/m^2 (1.25 gal/yd^2) of asphalt. Because of the increased cost of asphalt, this type of lining is now seldom used. Instead, plastic film linings of polyethylene or polyvinyl chloride are placed, with the later being the most popular. The most common thicknesses for plastics for Service canal lining has been 250 μm (10 mils) but 500-μm (20-mil) material is now recommended for large canals. These linings are received at the jobsite in rolls or accordian-folded panels from the fabricator and are placed manually.

Table 1.—*Test reaches for cover materials*

Canal or Lateral	Project	State
	Asphalt Membrane Lining	
West Canal, 5th Section	Columbia Basin	Washington
Lateral PE38.9	Columbia Basin	Washington
Lateral W20	Columbia Basin	Washington
Lateral W22E	Columbia Basin	Washington
Angostura Main Canal, Angosutra Unit	Pick-Sloan Missouri Basin Program	South Dakota
Wyoming Canal	Riverton	Wyoming
Pilot Canal	Riverton	Wyoming
Pavillion Main Lateral	Riverton	Wyoming
Fort Laramie Canal	North Platte	Wyoming
Helena Valley Canal, Helena Valley Unit, Helena-Great Falls Division	Pick-Sloan Missouri Basin Program	Montana
	Earth Lining	
Hudson Canal	Tucumcari	New Mexico
	Polyvinyl Chloride Lining (PVC)	
Wyoming Canal	Riverton	Wyoming
Helena Valley Canal, Helena Valley Unit, Helena-Great Falls Division	Pick-Sloan Missouri Basin Program	Montana
East Bench Canal	Pick-Sloan Missouri Basin Program	Montana
Amarillo Canal	Navajo Indian Irrigation	New Mexico
	Polyethylene Lining (PE)	
Amarillo Canal	Navajo Indian Irrigation	New Mexico
	Unlined	
Kennewick Main Canal	Yakima	Washington
Atrisco Feeder Canal	Middle Rio Grande	New Mexico
Upper Meeker Canal Meeker-Driftwood Unit	Pick-Sloan Missouri Basin Program	Nebraska

West Canal, 5th Section

The test reaches on the West Canal, 5th Section, were located between stations 1034+23 and 1034+84 m (3393+13 and 3395+13 ft), between stations 1079+96 and 1080+57 m (3543+19 and 3545+19 ft), and between stations 1097+64 and 1098+86 m (3601+18 and 3605+18 ft). These asphalt membrane lined reaches, which were constructed in 1960, had fine and coarse cover layers 200 and 125 mm (8 and 5 in) thick, respectively. The canal had a designed base width of 6.1 m (20.0 ft), a water depth of 1.885 m (6.19 ft), a capacity of 12.7 m^3/s (450 ft^3/s), side slopes of 2:1, and a longitudinal slope of 0.0002. Based on design data, the tractive force on the canal bottom is 3.8 N/m^2

(0.08 lb/ft). The tractive force is equal to the relative mass loading of water times the canal water depth times the canal longitudinal slope (see section on tractive force in the Discussion). After the first irrigation season, the cover materials were all in fair condition. There had been some slippage of the covers soon after the water was placed in the canal. This slippage ranged from 0.2 to 2 m (0.7 to 6 ft). There were some folds in the asphalt membrane and some scouring of the membrane surface; the folds were 25 to 150 mm (1 to 6 in) wide. There were a number of tears in the membrane above the folds. In nearly all of the inspection trenches, a fold occurred at the toe of the slope, and this appeared to be from movement of the cover and membrane over the entire slope during priming of the canal with water.

The 1960 samples for laboratory testing were taken from trenches dug into the side slopes at three different canal locations. The observer at the time of sampling stated that there was fine soil mixed with the granular cover for depths of 50 to 75 mm (2 to 3 in) and this seems evident from some of the grading curves (fig. 2). The silt appears to be mixed with the coarse gravel up to about equal proportions. The average thickness of the fine and coarse layers was about 150 mm (6 in) each.

The following test data were obtained on the fine soil layer:

Station meters (ft)	Density kg/m³ (lb/ft³) Field	Max lab.	Moisture (percent) Field	Lab. opt.	Ratio of field to max. lab. density
1034+53 (3394+13)	1410 (88.2)	1750 (109.2)	26.3	15.6	0.81
1080+27 (3544+19)	1380 (86.0)	1650 (102.9)	31.7	18.9	0.84

During the inspection of these selected reaches in November 1977, the cover had stabilized and was observed to be in good condition (fig. 3).

Lateral PE38.9

The test reach on this lateral was between stations 9+60 and 10+21 m (31+50 and 33+50 ft). This reach was lined with asphalt membrane lining in 1953-54. As designed, the canal had a base width of 4.9 m (16 ft), a water depth of 3.20 m (10.5 ft), side slopes of 1.75:1, a longitudinal slope of 0.000 04, a water velocity of 0.24 m/s (0.79 ft/s), and a canal capacity of 8.2 m³/s (288 ft³/s). As operated in 1960, the water depth was 2.04 m (6.7 ft), the water velocity was 0.31 m/s (1.01 ft/s), and the capacity was 5.1 m³/s (180 ft³/s). As designed, the canal would have a tractive force of 1.3 N/m² (0.03 lb/ft²) and, as operated in 1960, 0.8 N/m² (0.02 lb/ft²).

The fine cover layer had a design thickness of 300 mm (12 in) and the coarse layer, 225 mm (9 in); the thicknesses, as measured in 1960, were 300 to 350 mm (12 to 14 in) and 150 to 400 mm (6 to 16 in), respectively. At that time, it appeared that the gravel had mixed with the cover to depths from 25 to 125 mm (1 to 5 in). Excavation through the cover in 1977 showed there was about 150 mm (6 in) of silt on the membrane and about 300 mm (12 in) of granular cover on top. The fine layer was a cohesionless silt and the coarse layer, a silty gravel (fig. 4).

On this lateral there was some slippage of the cover soon after water was first turned in, but there has been none since. Maintenance costs have been very low. An inspection in November 1977 showed that the cover was still in good condition (fig. 5).

Lateral W20

The test sections on this lateral were located at stations 189+13, 192+67, 212+91 to 213+09 m (620+50, 632+12, and 698+54 to 699+12 ft). This section of the lateral was lined with asphalt membrane in 1956. The designed thicknesses of fine and coarse layers were 350 and 150 mm (14 and 6 in), respectively. As designed, the lateral had a base width of 6.1 m (20 ft), water depth 1.675 to 1.765 m (5.50 to 5.79 ft), side slopes of 2:1, a longitudinal slope of 0.000 15, and a capacity of 9.6 to 10.6 m³/s (339 to 375 ft³/s). In 1960, the canal was operated at less than one-half capacity. Based on the designed characteristics, the tractive force would be 2.4 to 2.6 N/m² (0.051 to 0.054 lb/ft²), but as operated in 1960 it would be 1.5 to 1.7 N/m² (0.032 to 0.036 lb/ft²).

The gradations of the cover materials are shown in figure 6. The gravel particles were subrounded to subangular. When this lateral was inspected in 1960, the cover at stations 189+12

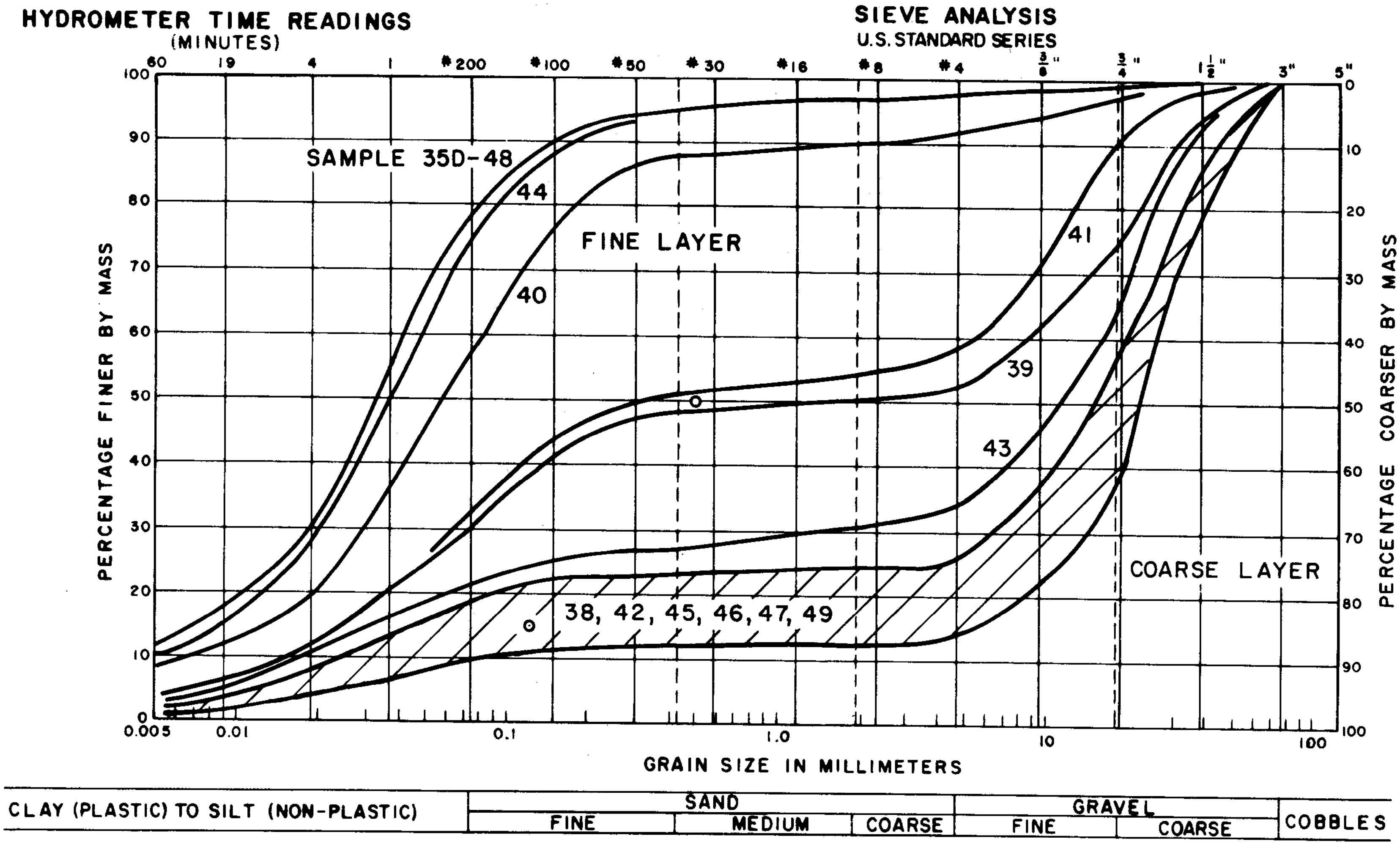


Figure 2.—Gradations of fine and coarse soil cover layers on the West Canal, 5th Section.

Figure 3.—West Canal, 5th Section, looking upstream from station 1080+06 m (3543+50 ft) (left) with a close view at the same station. November 1977 Photos P801-D-79537 and P801-D-79538

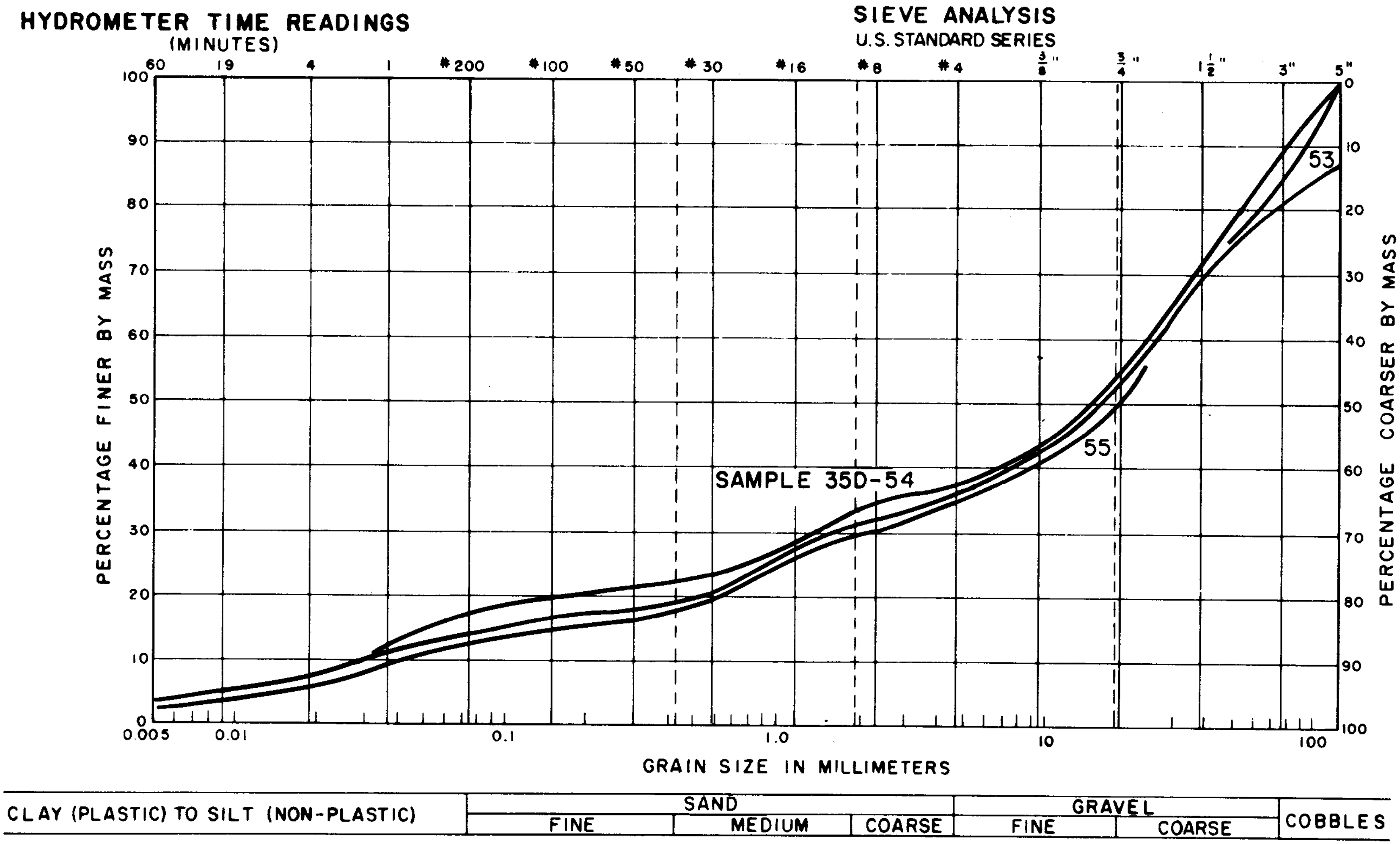


Figure 4.—Gradation of the coarse cover layer on lateral PE38.9.

Figure 5.—Lateral PE38.9. November 1977 Photo P801-D-79529

and 192+67 m (620+50 and 632+12 ft) was rated fair. The thickness of the fine layer ranged from 325 to 575 mm (13 to 23 in) and the coarse layer from 150 to 350 mm (6 to 14 in). There had been some sloughing of the cover, but the lining had not ruptured. The section between stations 212+91 and 213+09 m (698+54 and 699+12 ft) was rated as poor. The side slopes had sloughed badly on both sides. The underlying material over the membrane was described as coarse, poorly graded sand with occasional pockets of sandy silt. During excavation of inspection trenches, the poorly graded sandy material continually sloughed, and the trenches could not be kept open. The membrane lining and fine material had the appearance of having slipped together in one solid mass on the left side and bottom of the lateral, and the flowing water had smoothed out the mass.

During an inspection in November 1977, the cover appeared to have stabilized and was in fair condition (fig. 7). At the time, there was a considerable amount of water in the lateral.

Lateral W22E

The test section on lateral W22E between stations 41+45 and 41+70 m (136+00 and 136+80 ft) was lined with asphalt membrane in 1949 and 1950, and covered with a single layer of silty sand which had a designed thickness of 400 mm (16 in). As designed, the lateral had a base width of 2 m (6 ft), a water depth of 0.88 m (2.9 ft), side slopes of 1.75:1, a longitudinal slope of 0.0003, and a capacity of 1.3 m^3/s (47 ft^3/s). As designed, the lateral would have a tractive force of 2.6 N/m^2 (0.05 lb/ft^2).

The silty sand cover had a wide variation in sand sizes (fig. 8). When inspected in 1960, this cover had a thickness from 0 to 350 mm (0 to 14 in) and was rated in poor condition. There had been a considerable amount of erosion and an unusual amount of maintenance was required with the addition of coarse material to reduce erosion. Figures 9 and 10 show the condition of the lateral in 1978. With maintenance, the cover had apparently become stabilized. However, this soil is too fine for a stable, maintenance-free cover to protect a membrane lining. Also, the side slope were steeper than the 2:1 usually recommended.

Angostura Main Canal

In March 1961, five different reaches of covers on asphalt membrane lining were selected for observations and tests; these were located between stations 6+47 to 462+31 m (21+24 and 1516+75 ft). The reach between stations 6+47 and 10+14 m (21+24 and 33+26 ft) was lined in 1951-52 and the remainder in 1959 and 1960. As designed, the reaches between stations 6+47 to 186+45 m (21+24 to 611+70 ft) had canal capacities between 7.3 to 8.7 m^3/s (260 to 309 ft^3/s) with tractive force values from 3.2 to 4.4 N/m^2 (0.067 to 0.091 lb/ft^2); the other sections have canal capacities from 1.1 to 2.5 m^3/s (38 to 89 ft^3/s) and tractive force values between 2.4 to 3.8 N/m^2 (0.051 to 0.079 lb/ft^2). The covers consisted of a 150-mm (6-in) fine layer with the exception of a 200-mm (8-in) thickness for the reach between stations 6+47 to 10+14 m (21+24 and 33+26 ft), and a 150-mm (6-in) coarse layer. Coarse gravel was specified for beach belt areas. The gradation ranges of the cover layers are shown on figure 11.

Observations made in March 1961 on these covers showed that they were in excellent condition. The thicknesses of fine and coarse layers ranged from 100 to 325 mm (4 to 13 in) and 150 to 250 mm (6 to 10 in), respectively. For reaches between stations 182+74 to 186+45 m (599+55 to 611+70 ft), stations 313+65 to 359+62 m (1029+05 to

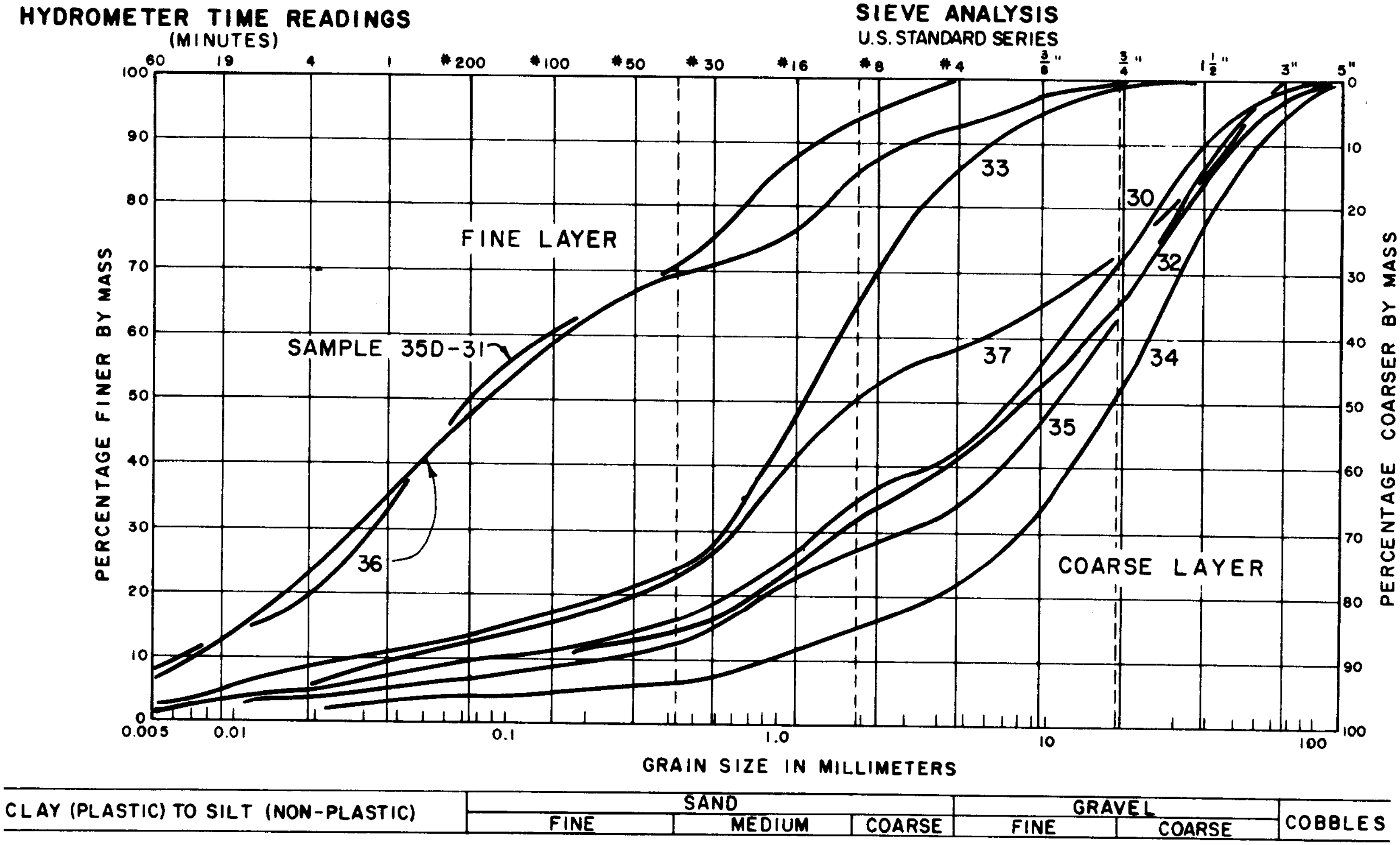
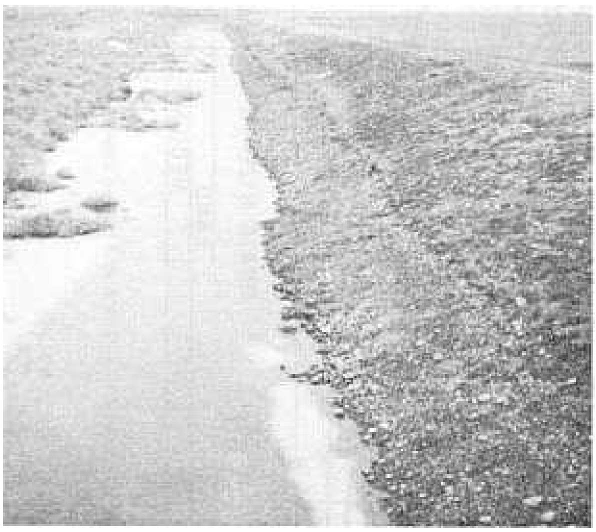


Figure 6.—Gradations of fine and coarse cover layers on lateral W20.



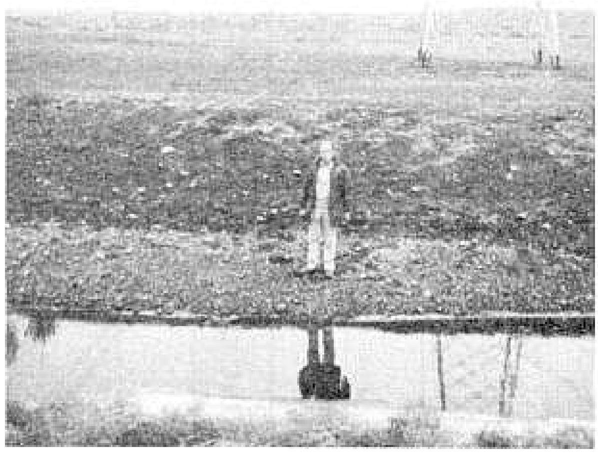


Figure 7.—Lateral W20, looking downstream from bridge at approximately station 212+84 m (698+30 ft) (left) and upstream (right) from the same station. November 1977 Photos P801-D-79551 and P801-D-79525

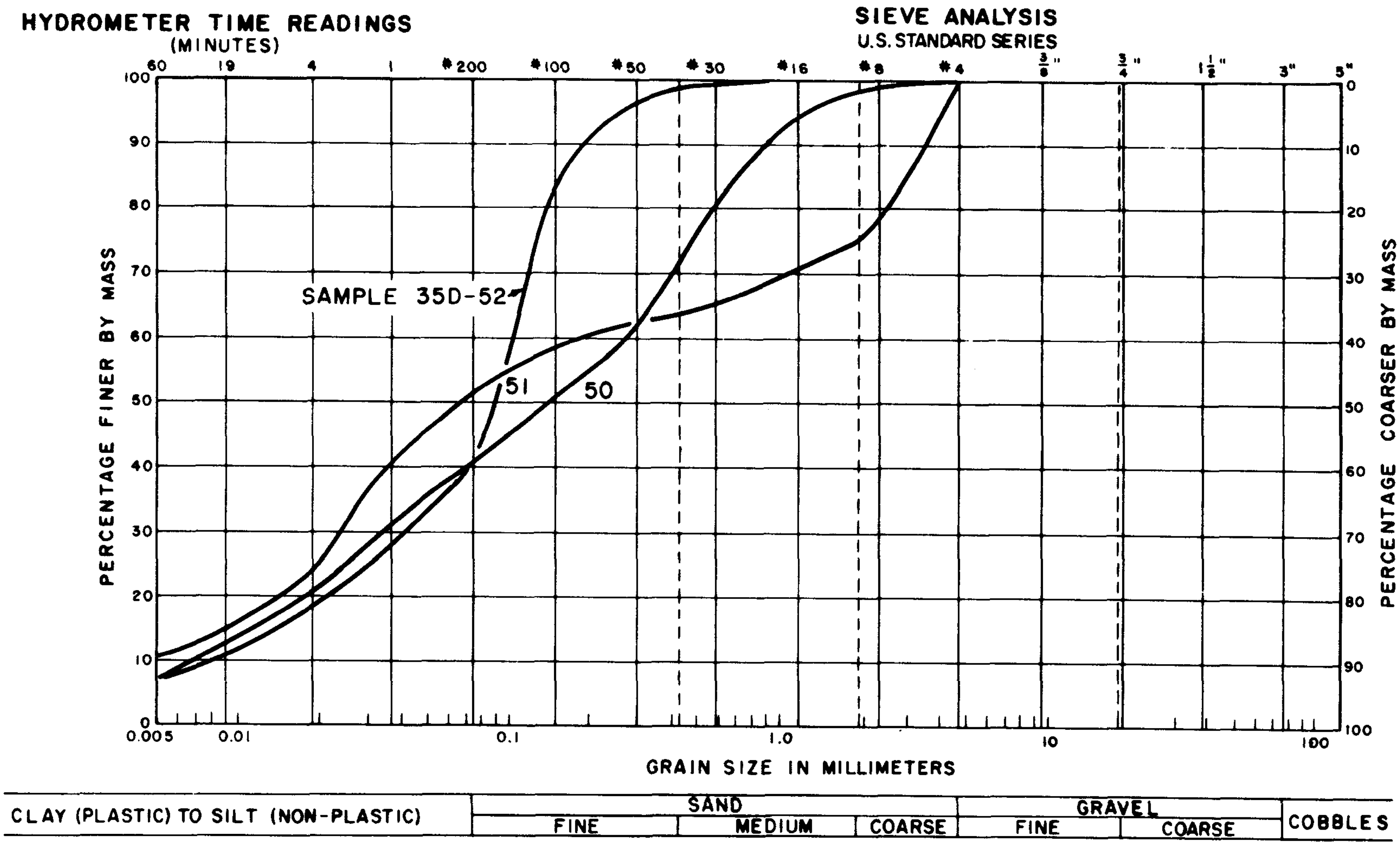


Figure 8.—Gradation of single cover layer on lateral W22E.

Figure 9.—Lateral W22E between farm units 89 and 90. November 1977 Photo P801-D-79524

Figure 10.—Left bank of lateral W22E between farm units 74 and 75. November 1977 Photo P801-D-79554

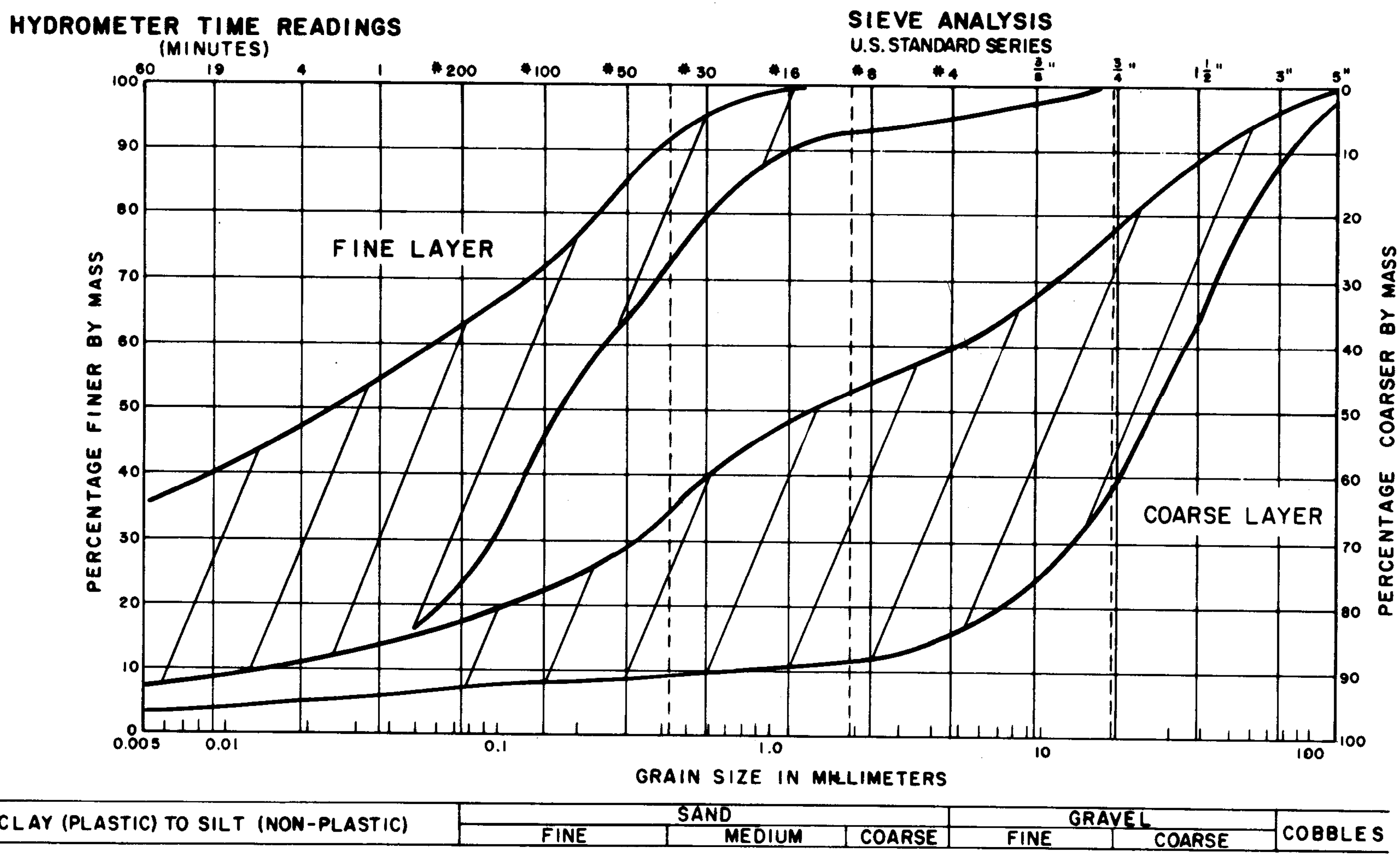


Figure 11.—Gradation ranges for fine and coarse cover layers on Angostura Main Canal.

1179+87 ft), and stations 440+82 to 462+31 m (1446+25 to 1516+75 ft), there had been slight slippage of cover materials and some consolidation causing cracks above the waterline at the top of the side slope (fig. 12). However, this was not considered to be serious for reaches between stations 86+36 and 97+51 m (283+32 and 319+90 ft) (fig. 13) and between stations 313+65 and 359+62 m (1029+05 and 1179+87 ft). It was noted that there was evidence of cattle traffic in some areas.

Wyoming Canal

The three test sections were located between stations 278+28 and 569+99 m (913+00 and 1870+05 ft) where the asphalt membrane lining was placed during 1950-53. The base width varied between 7.6 and 10.4 m (25.0 and 34.0 ft), the water depth between 1.89 and 2.65 m (6.2 and 8.7 ft), and the canal capacity between 16 and 26 m^3/s (566 and 920 ft^3/s). The design longitudinal slopes were between 0.0001 and 0.0002 and the calculated tractive force from 2.5 to 3.7 N/m^2 (0.5 to 0.08 lb/ft^2). The original side slopes on which the membrane was placed were 1.5:1, but the cover was sloped to 1.75:1. The grading of the cover materials is shown in figure 14.

The section between stations 278+28 and 483+11 m (913+00 and 1585+00 ft) originally had a single cover which, during a 1960 inspection, was considered satisfactory except at the beach belt where it was too fine to resist erosion. Also, the cover settled and moved downslope as much as 1 m (3 ft). Coarser material was later added to the beach belt. During an inspection in April 1978, there was very little gravel except for a small amount on the right side slope between stations 374+90 to 376+43 m (1230+00 and 1235+00 ft) (fig 15).

During the inspection of the section between station 568+54 to 569+99 m (1865+28 to 1870+05 ft) in 1960, it was noted that fines had eroded from the cover, and the addition of beach belt material was anticipated. During the April 1978 inspection, this reach was in poor condition (fig. 16).

Pilot Canal

The cover test sections on asphalt membrane lining on the Pilot Canal were between stations 85+34 and 101+19 m (280+00 and 332+00 ft), constructed in 1959, between stations 249+02 and 259+99 m (817+00 and 853+00 ft), constructed in 1956, and between 287+43 and 298+09 m (943+00 and 978+00 ft) constructed in 1951. These sections had designed base widths from 7.9 to 9.1 m (26 to 30 ft), water depths from 2.29 to 3.11 m (7.5 to 10.2 ft), and canal capacities between 17.8 to 23.9 m^3/s (630 to 844 ft^3/s). The longitudinal slope was 0.000 15 and the calculated tractive force 3.4 to 4.6 N/m^2 (0.070 to 0.095 lb/ft^2). The canal side slopes were 2:1. The grading of the cover soils is shown in figure 17.

When the cover materials in these canal sections were sampled in November 1960, the covers were reported to be in excellent condition. The fine layer was 200 to 300 mm (8 to 12 in) thick and the coarse layer 175 to 250 mm (7 to 10 in). Also, in April 1978, the covers were reported to be in good condition (figs. 18 and 19), with only some slight bulging at the toe of the slopes.

Pavillion Main Lateral

The three cover test reaches on asphalt membrane lining on the Pavillion Main Lateral were from stations 116+74 to 144+72 m (383+00 to 474+79 ft), constructed in 1956; and 144+72 to 150+75 m (474+79 to 494+60 ft) and 150+75 to 168+41 m (494+60 to 552+51 ft), both constructed in 1954. The canal, as designed, has base widths of 1.8 to 12.1 m (6 to 7 ft), water depths from 0.73 to 0.79 m (2.4 to 2.6 ft), and canal capacities from 1.6 to 1.8 m^3/s (57 to 65 ft^3/s). The longitudinal slope was 0.000 75 and the calculated tractive force 5.3 to 5.7 N/m^2 (0.11 to 0.12 lb/ft^2). The side slopes were 2:1. The grading of the cover materials is shown in figure 20.

When these sections were sampled in November 1960, the condition of the cover materials was rated from excellent to poor. At station

Figure 12.—Angostura Main Canal near station 440 + 84 m (1446 + 32 ft). Typical crack at top of cover from settlement soon after construction. March 1961 Photo P801-D-79528

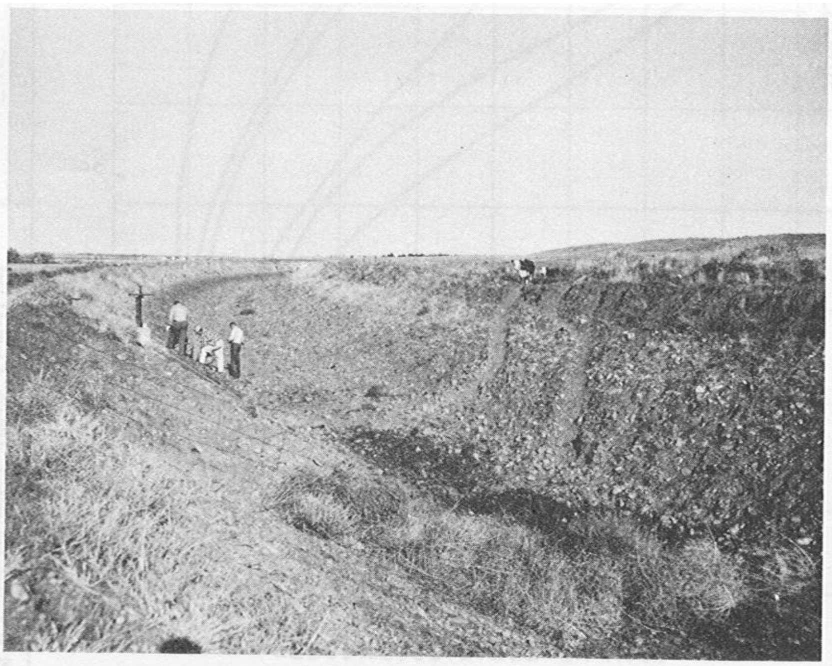


Figure 13.—Angostura Main Canal at station 93 + 12 m (305 + 50 ft) showing effect of cattle traffic on cover for asphalt membrane lining. March 1961 Photo P801-D-79531

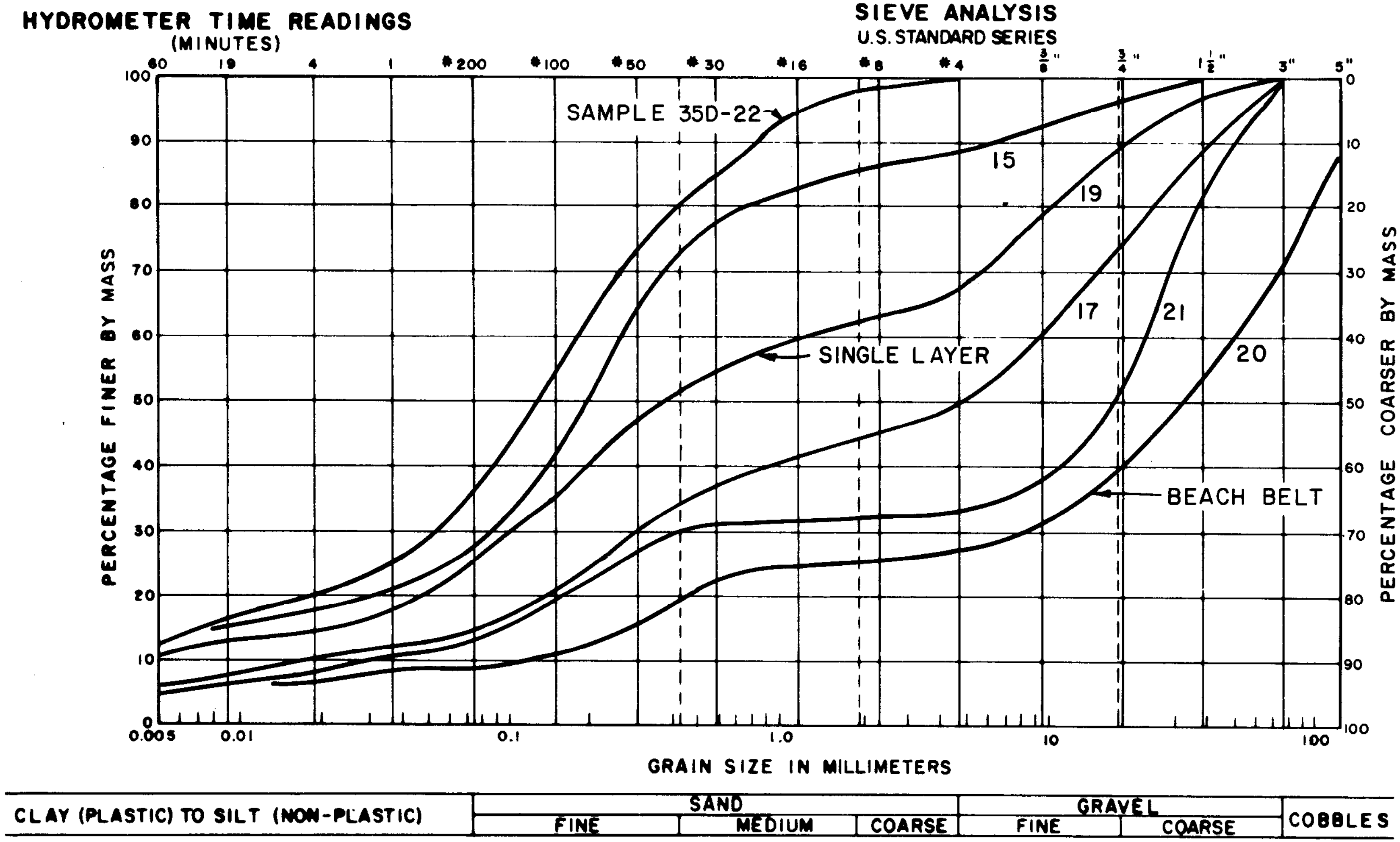


Figure 14.—Gradations of soil cover layers on the Wyoming Canal.

Figure 15.—Wyoming Canal looking upstream from station 376+43 m (1235+00 ft). April 1978 Photo P801-D-79530

Figure 16.—Wyoming Canal looking upstream from station 477+01 m (1565+00 ft). April 1978 Photo P801-D-79533

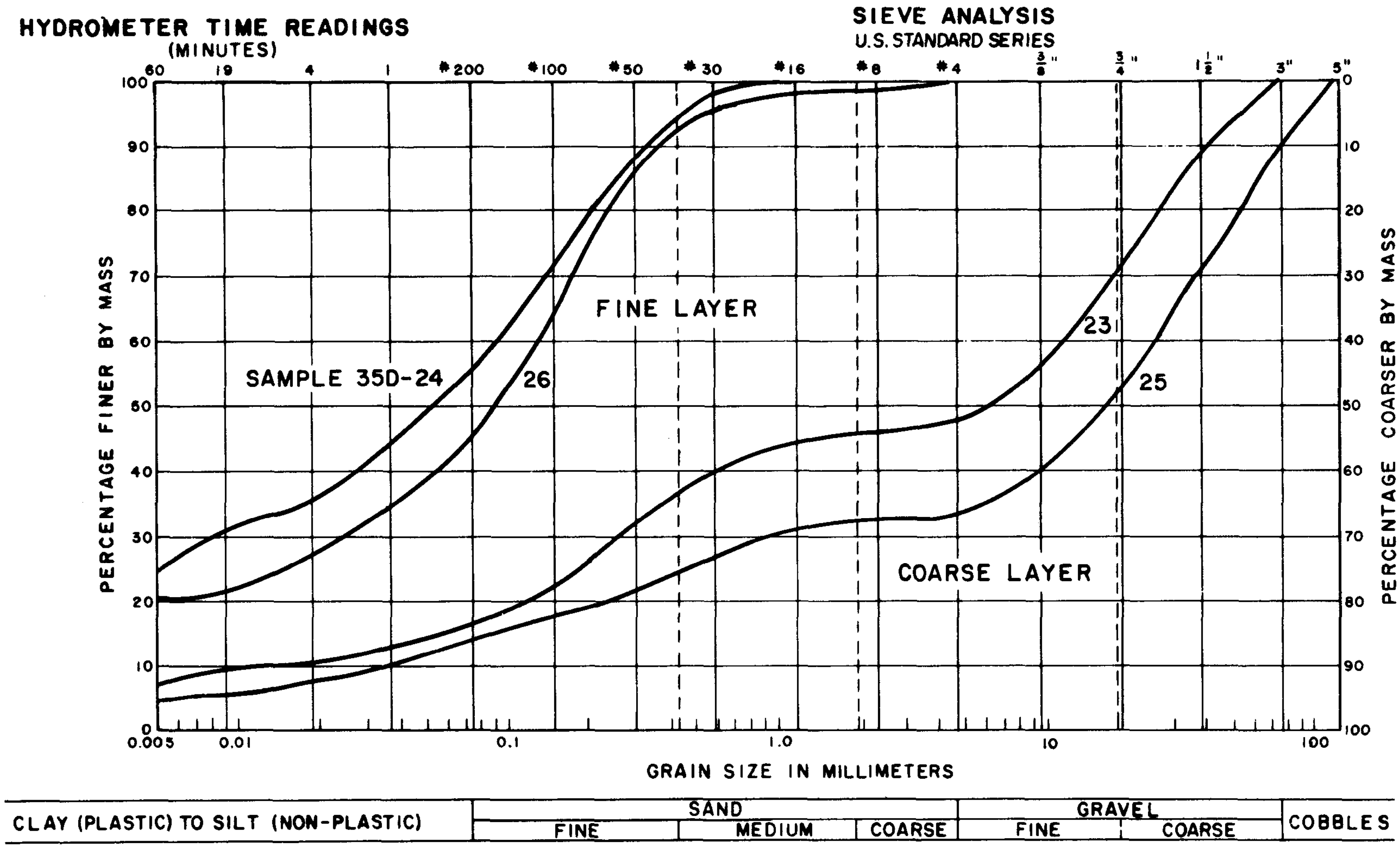


Figure 17.—Gradations of fine and coarse cover layers on Pilot Canal.

Figure 18.—Pilot Canal looking downstream from station 95+40 m (313+00 ft). April 1978 Photo P801-D-79532

Figure 19.—Pilot Canal looking downstream from station 252+68 m (829+00 ft). April 1978 Photo P801-D-79553

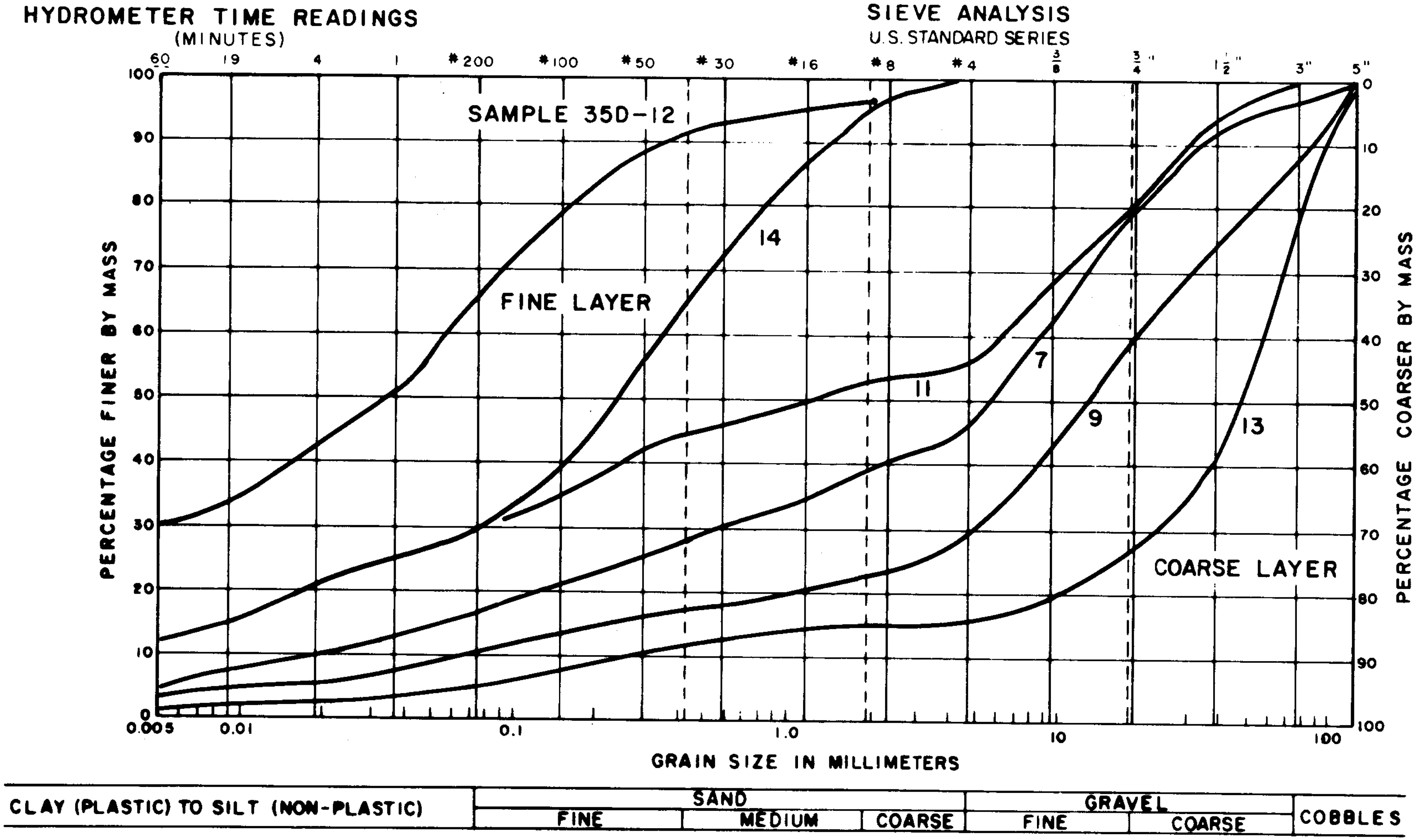


Figure 20.—Gradations of fine and coarse cover layers on Pavillion Main Lateral.

143+56 m (471+00 ft) on the outside of a curve, the cover provided excellent resistance to waterflow and wind-wave action. The top layer for this stationing had the coarsest grading of those sampled on this lateral. The sample from station 160+72 m (527+30 ft) was taken on the outside of a curve where erosion was occurring, and this material was considered to be too fine to resist erosion. At station 167+98 m (551+10 ft), the cover was rated as poor. This was on a tangent and there was grass sod at the top of the lining cover, which appeared to be more stable than the cover. At station 149 +96 m (492+00 ft), the cover was considered to have failed; this was the finest of the gravel covers sampled on this reach. In a general inspection from stations 144+72 to 168+41 m (474+79 to 552+51 ft), it was found that the cover material on the outside of curves ranged from very thin to completely eroded.

When inspected in April 1978 (figs. 21 and 22), the cover was largely removed from the top half of the canal and deposited in the canal bottom. The lining was exposed and deteriorating in many places. Grass was growing in the top half of the section.

The calculated tractive force of 5.3 to 5.7 N/m² (0.11 to 0.12 lb/ft²) was higher than for the other test reaches on this project and may have been a factor in causing the deterioration of the covers.

Fort Laramie Canal

The test sections of asphalt membrane covers on this canal were between stations 609+11 and 622+85 m (1998+38 and 2043+46 ft) which was constructed in 1950 and selected to represent a stable cover, and between 1374+71 to 1390+50 m (4510+20 and 4562+00 ft), constructed in 1954, representing a failing cover. The respective base widths were 13.4 and 8.5 m (44 and 28 ft), the water depths 2.63 and 2.13 m (8.63 and 6.98 ft), the canal capacities 37 and 19 m³/s (1305 and 675 ft³/s), the longitudinal slopes 0.000 09 and 0.000 14, and the calculated values of tractive force 2.3 and 2.9 N/m² (0.05 and 0.06 lb/ft²), respectively. The side slopes for both sections were 2:1. The gradings of the cover materials are shown in figure 23; note the absence of coarse grain sizes.

In April 1961, the cover at MP (milepost) 38.1 was in excellent condition; that at MP 86.1 was fair. The cover had failed in spots with the asphalt membrane being exposed in 2- to 3-m (6- to 10-ft) patches; in these areas, the gravel had sloughed to the toe of the slope. The sloughing had occurred intermittently at 15- to 60-m (50-to 200-ft) intervals.

A review of reports of inspections on this canal, with the latest one in October 1976, reveals that there was some longitudinal cracking of the cover near the top of canal sides soon after the lining was placed and erosion of the cover later occurred in different areas. Repairs were made by adding larger-sized gravel.

An inspection of this canal at MP 38.1 and MP 86.1 in November 1977 showed that the original cover had eroded badly on some of the side slopes and what was left was in poor to fair condition. O&M personnel had replaced much of the cover with Brule Formation material as riprap; in one place the depth of this was 225 mm (9 in). The Brule Formation is a claystone that breaks down upon weathering and may not provide a permanent cover material. It is apparent that the original cover was too fine grained to be stable for the canal conditions imposed.

Helena Valley Canal

The reach of the canal between stations 84+76 and 107+71 m (278+08 and 353+39 ft) was lined with asphalt membrane in 1962. This section had a designed bottom width of 3.7 m (12 ft), a water depth of 1.67 m (5.44 ft), a capacity of 8.5 m³/s (300 ft³/s), and 2:1 side slopes. The longitudinal slope as 0.000 25 and the calculated tractive force 4.1 N/m² (0.085 lb/ft²). The designed thickness of the fine layer was 200 mm (8 in). This soil, which had a liquid limit of 38 and a plasticity index of 13, was classified as a sandy clay. This cover layer was rolled by two passes of a smooth-drum roller with a specified mass of more than 892 kg/m (50 lb/in). The top layer had 125 mm (5 in) of screened gravel (fig. 24) with angular to subrounded particles.

When inspected in October 1977 [2], this cover was in very good condition (fig. 25).

Figure 21.—Pavillion Main Lateral, looking upstream from station 124+05 m (407+00 ft). April 1978 Photo P801-D-79534

Figure 22.—Pavillion Main Lateral, looking downstream from station 161+54 m (530+00 ft). April 1978 Photo P801-D-79535

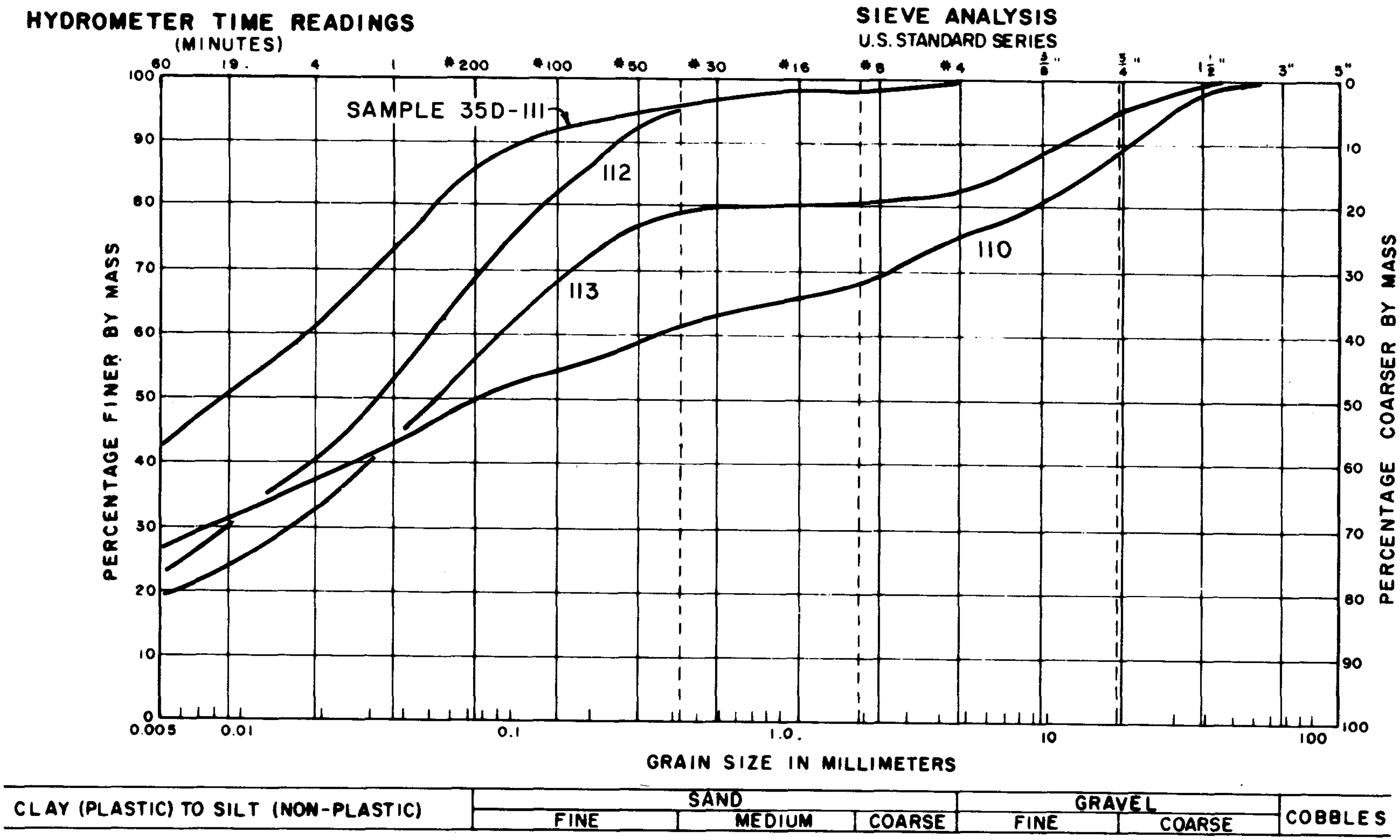


Figure 23.—Gradation of single cover layer on Fort Laramie Canal.

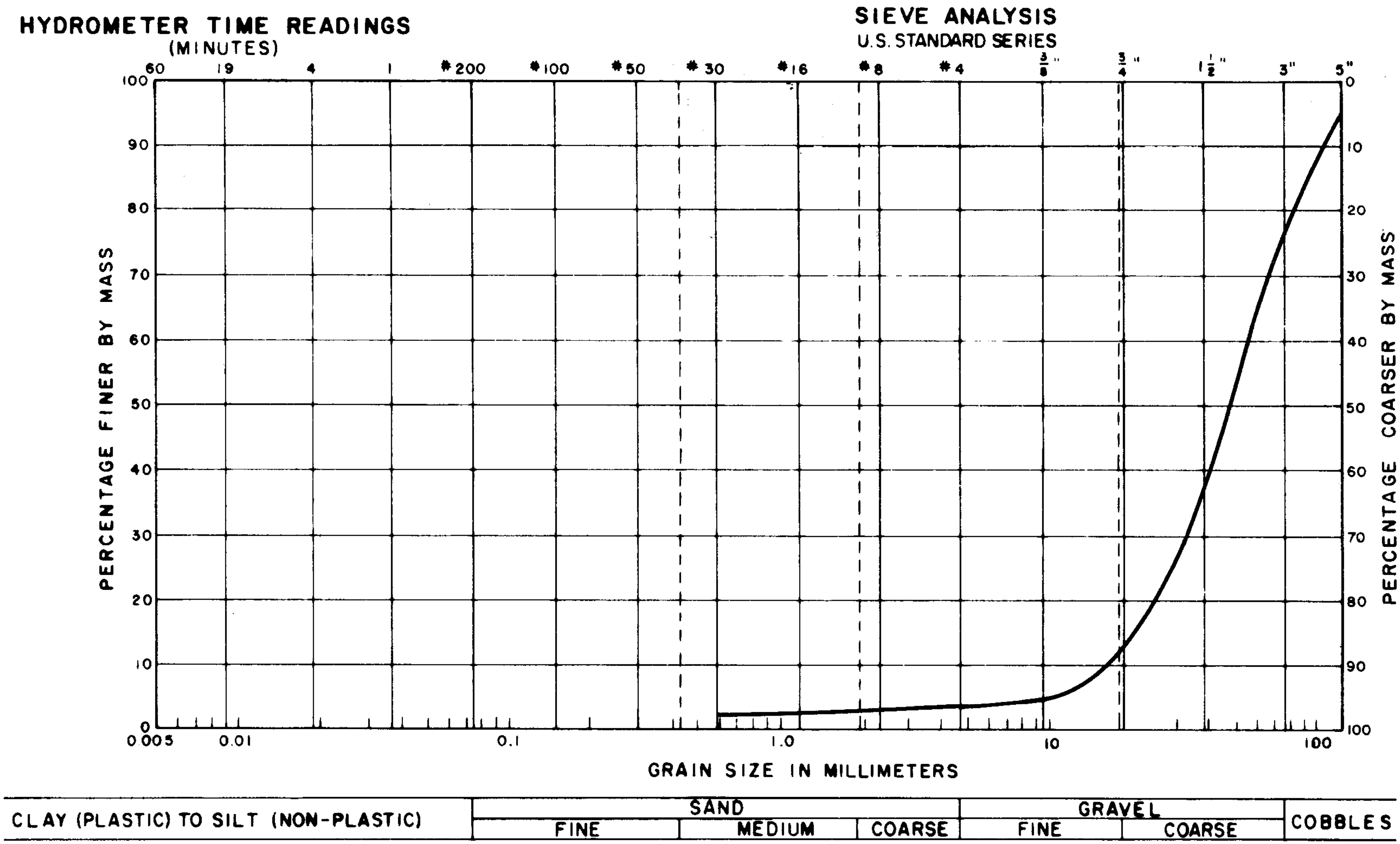


Figure 24.—Gradation of single cover layer on Helena Valley Canal at station 92+66 m (304+00ft).

Figure 25.—Helena Valley Canal, looking downstream from station 92 + 45 m (303 + 30 ft) (top) and cover surface at station 92 + 66 m (304 + 00 ft). March 1978 Photos P801-D-79555 and P801-D-79527

COVER ON EARTH LINING FOR HUDSON CANAL

In 1954, a coarse cover layer was placed on compacted soil lining between stations 143+26 and 147+83 m (470+00 and 485+00 ft) of the Hudson Canal. The lining was a sandy lean clay. The canal as designed had a base width of 4.3 m (14 ft), a water depth of 1.71 m (5.6 ft), and a capacity of 7 m^3/s (260 ft^3/s). The longitudinal slope was 0.000 17 and the calculated tractive force 2.8 N/m^2 (0.059 lb/ft^2). The side slopes were 1.75:1. The grading curves for the lining and cover layer are shown in figure 26.

When samples of the coarse cover layer were obtained in June 1961, the cover was reported to be in excellent condition. A 1962 photograph of the cover is shown in figure 27. When inspected in March 1978, it was rated as good. There was some sloughing on the upper levels of the south slope. The manager of the Arch Hurley Conservancy District believed that the removal of woody vegetation had caused the sloughing in isolated spots. At station 146+00 m (479+00 ft), there was a sloughed area about 9 m (30 ft) long that could have been caused by wind-wave action.

COVERS ON POLYVINYL CHLORIDE LINING

Wyoming Canal

The test reach on this canal was between stations 146+00 and 148+13 m (479+00 and 486+00 ft), and the lining was placed in 1975. As designed, this section of canal had a base width of 18.3 m (60 ft), a water depth of 2.870 m (9.41 ft), a canal capacity of 62 m^3/s (2200 ft^3/s), and 2:1 side slopes. The longitudinal slope was 0.0002 and the calculated value of tractive force 5.7 N/m^2 (0.12 lb/ft^2). The fine and coarse layers were each 250 mm (10 in) thick. The gradings of these soils are shown in figure 28. The fine layer was classified as a sandy to lean clay and the coarse layer a sandy gravel.

During an inspection in October 1977, the cover in this canal reach was considered to be in very good condition on both side slopes and bottom. Chief Inspector John Rossi who made the inspection had the following comments:

"Sometime after water was turned into the Wyoming Canal, two slides occurred on the right side slope, stations 479+00 to 479+70 ft and 481+25 to 482+00 ft. The PVC membrane lining split at the top of the side slope above water level and slipped down the side slope approximately two feet. The cover material sloughed down the side slope towards the bottom. The break in the PVC lining is above water level and no repairs have been made to date.

"The exact cause of these slides is unknown. However, the subgrade for the lining placed in this reach of the Wyoming Canal was dragged and rolled, providing a hard smooth subsurface. On recent buried PVC membrane lining contracts, the rolling of subgrade has been eliminated."

Pilot Canal

On February 15, 1977, a slide occurred on the PVC-lined right bank of Pilot Canal of the Riverton Project, Wyoming, between stations 185+93 and 186+54 m (610+00 and 612+00 ft) (fig. 29). This section of canal has a water depth of 3.1 m (10 ft), bottom width of 9.1 m (30 ft), and 2:1 side slopes. The 250-μm (10-mil) thick lining was placed in November 1976 to replace deteriorated asphalt membrane lining. The cover over the membrane consisted of 225 mm (9 in) of soil from canal excavation superimposed with 225 mm of pit run gravel.

For a major portion of the slide, slippage occurred between the membrane and the soil underneath, and the membrane was torn in places. Observations of an adjacent section of lining, soon after the slide, revealed ice under the lining. Also, for about a 50-mm (2-in) depth under the lining, there was a series of ice lenses about 1 to 3 mm (1/16 to 1/8 in) thick, alternating with layers of soil; this is typical of frost action in soil. The soil beneath the membrane was a sandy clay with a liquid limit of 37 and a plasticity index of 19. Ninety-six percent of the soil particles passed the No. 4 sieve, 90 percent passed No. 40, 60 percent passed No. 200, and 25 percent was finer than 0.005 mm.

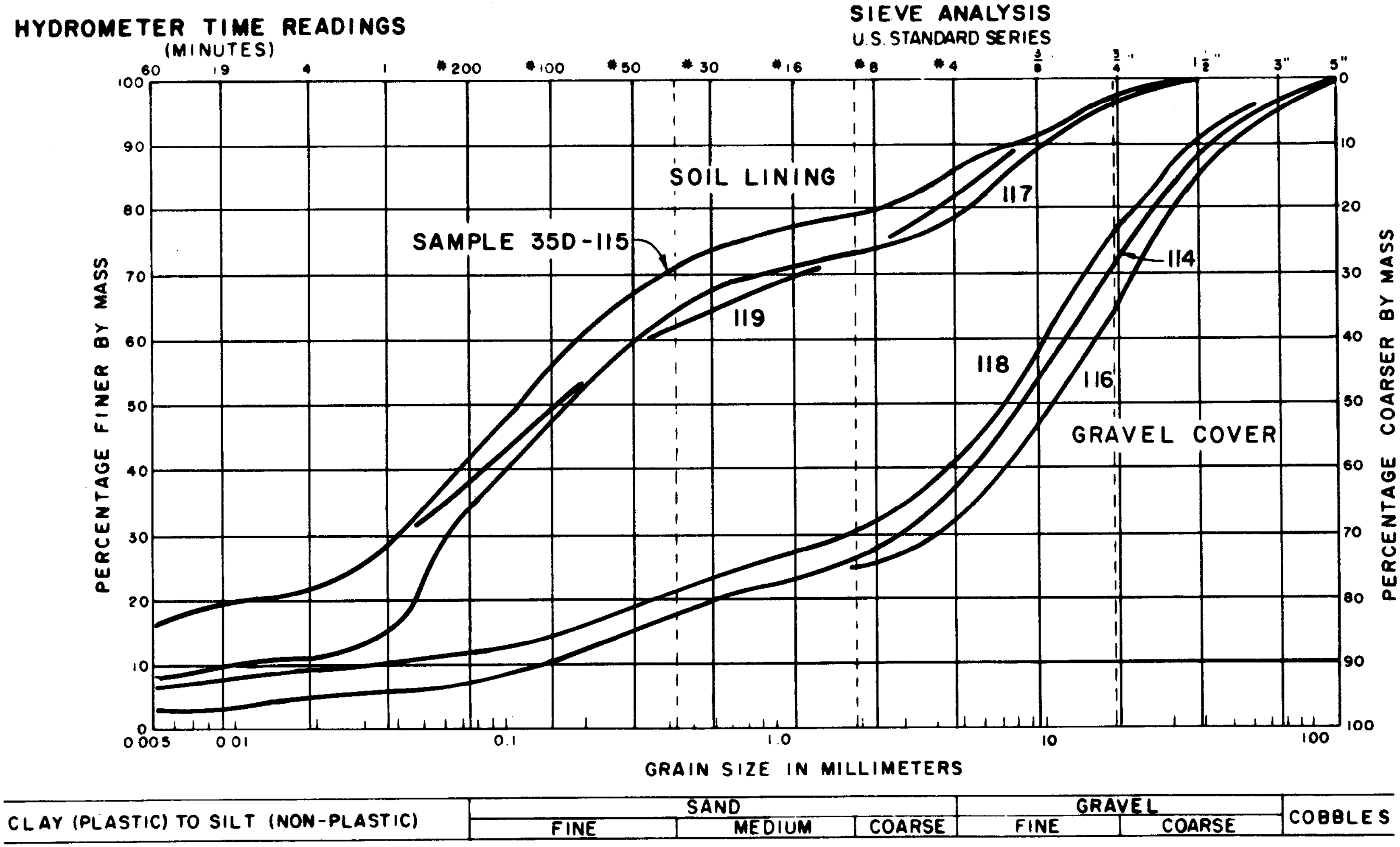


Figure 26.—Gradations of compacted soil lining and gravel cover layer on Hudson Canal.

Figure 27. — View of gravel blanket material on the right slope of Hudson Canal at station 145+05 m (475+89 ft). February 1962 Photo P801-D-79526

There was no water table under the lining sufficiently near the canal surface to have caused open-system frost action. Apparently, as frost penetrated into the subgrade, moisture migrated upward and froze at and in thin lenses immediately below the plastic lining barrier. The record of daily temperatures in the general area showed an unseasonable warming trend for a few days prior to the slide, with a maximum temperature of 13 °C (55 °F) which probably caused thawing to depths immediately below the plastic membrane. Melting water would be trapped between the membrane and frozen material below, and the resulting lubrication seems to be a plausible explanation for the cause of the slide.

Previous to the slide, the subgrade was lightly rolled to form a smooth surface to avoid puncturing the plastic by rock particles. Current specifications provide for dragging the subgrade surface with the removal of projecting particles likely to cause puncturing. Also, a 50-mm (2-in) thick sand layer of unspecified gradation may be applied at the option of the contracting officer. These measures are intended to provide more frictional resistance to sliding.

Helena Valley Canal

Covers on two reaches on this canal lined with PVC membrane were examined in October 1977 [2]. These were located from stations 282+26 to 304+24 m (926+05 to 998+17 ft), placed in 1971, and 402+95 to 422+45 m (1322+02 to 1386+00 ft), placed in 1969. These reaches had the following canal characteristics, respectively: base width 3.7 and 2.7 m (12 and 9 ft), water depth 1.490 and 1.277 m (4.89 and 4.19 ft), capacity 6.4 and 4.2 m^3/s (225 and 150 ft^3/s), and longitudinal slopes of 0.0003 and 0.000 35. Each reach had a calculated tractive force value of 4.4 N/m^2 (0.092 lb/ft^2). The side slopes of both reaches were 2:1. Both sections had covers with single layers, the first one had a designed thickness of 400 mm (16 in) and the second one 350 mm (14 in). The grading curves for these covers are shown in figure 30.

During an October 1977 examination [2], the conditions of cover materials and the underlying PVC membrane were observed, with samples of each at stations 295+14 and 405+57 m (968+30 and 1330+60 ft) being obtained for laboratory testing. The covers were considered to be in good condition. However, near station 295+14 m (968+30 ft), there had been heavy animal traffic in a zone 7 to 10 m (25 to 30 ft) wide which had caused some uncovering and damage to the cover. At the time, the following methods were discussed to minimize problems due to animal traffic: (1) installation of fences, (2) use of a thicker, and possibly compacted, cover, and (3) use of a 375-μm (15-mil) rather than a 250-μm (10-mil) thick membrane to provide greater resistance to puncture.

East Bench Canal

In 1970, a reach of this canal between stations 276+19 and 412+58 m (906+15 and 1353+60 ft) was lined with PVC lining. In this section, the designed base width was 6.1 m (2.0 ft), and the side slopes 2:1. The designed water depth was 1.963 m (6.44 ft) and the canal capacity was 11.5 m^3/s (405 ft^3/s). The longitudinal slope was 0.000 13 for a calculated tractive force of 2.5 N/m^2 (0.053 lb/ft^2). A single-cover layer 400 mm (16 in) thick was used.

When examined in October 1977 [2], the cover was stable and in good condition. During the preceding irrigation season, the canal had been operated at 12 m^3/s (425 ft^3/s), and the water depth was 1.98 m (6.5 ft). The corresponding tractive force would be 2.5 N/m^2 (0.053 lb/ft^2). The gradings of samples obtained at stations 276+19 and 412+58 m are shown in figure 31 and a photograph taken at the latter station in figure 32. The cover was about 375 mm (15 in) thick at station 276+19 m and 300 mm (12 in) at station 412+58 m.

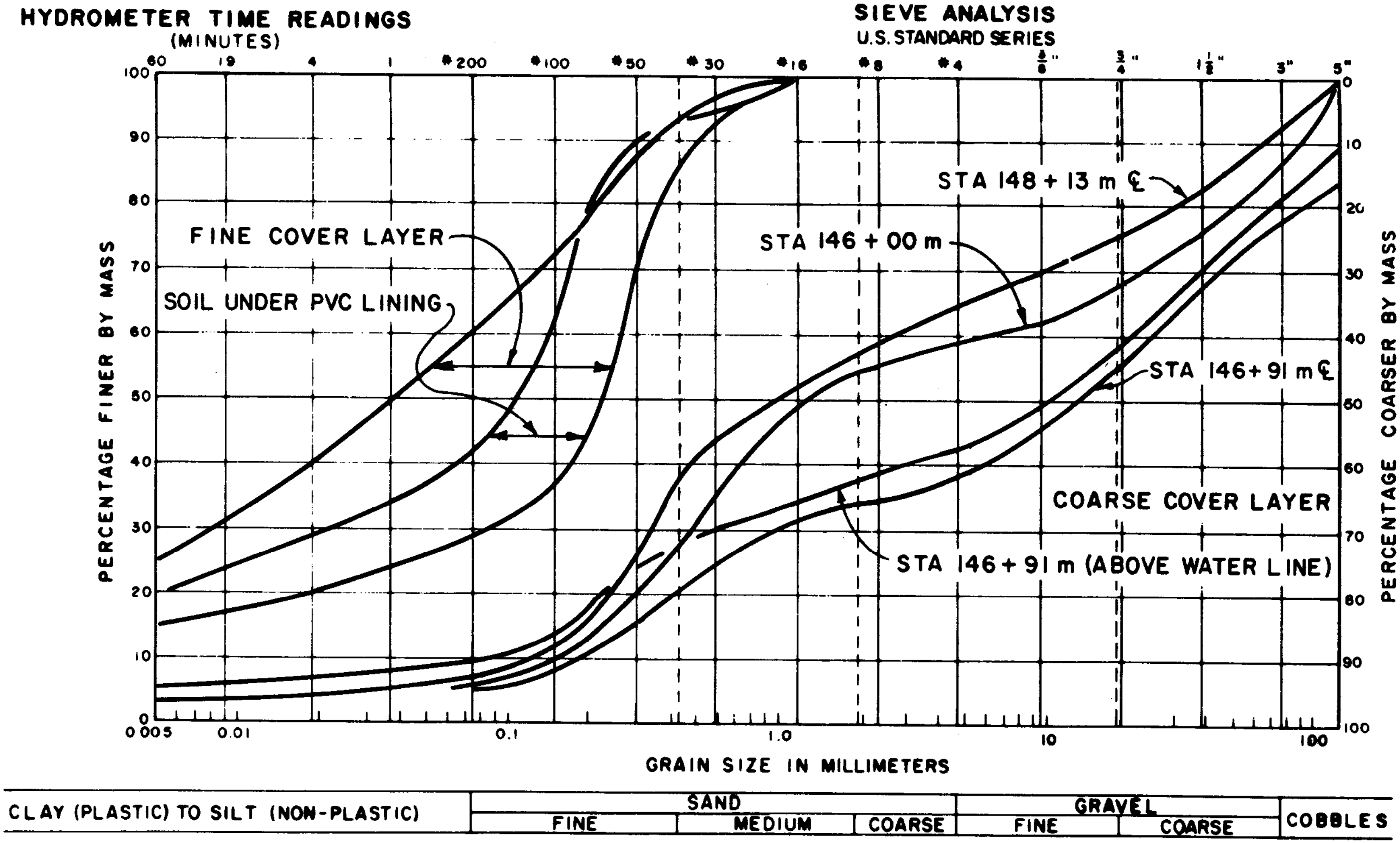


Figure 28. – Gradations of cover layer and underlying soil for polyvinyl chloride membrane lining on the Wyoming Canal - stations 146 + 00 to 148 + 13 m (479 + 00 to 486 + 00 ft).

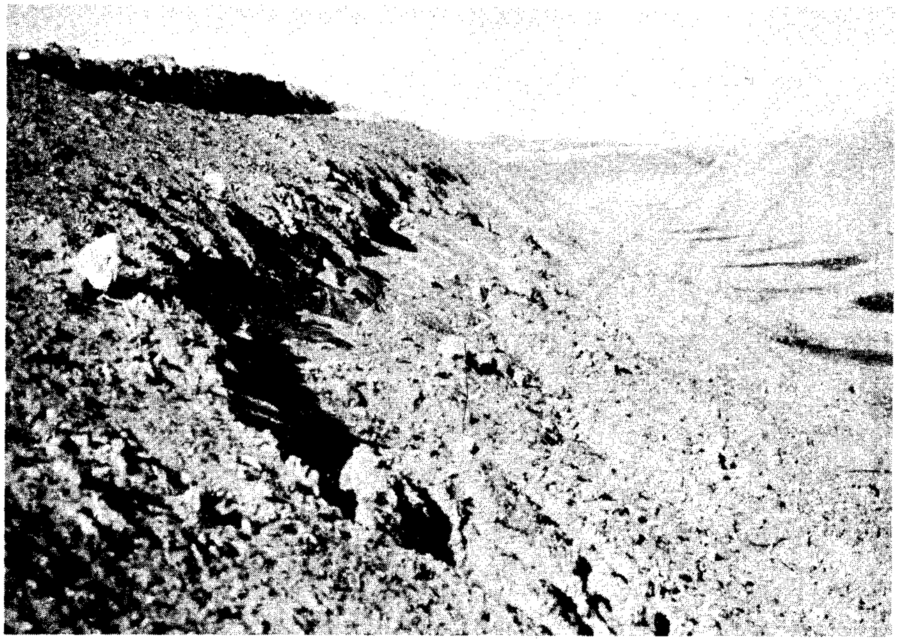


Figure 29.—Slippage of PVC membrane lining on Pilot Canal, stations 185+93 to 186+54 m (610+00 to 612+00 ft). February 1977 Photo P801-D-79547

COVER ON POLYETHYLENE LINING FOR AMARILLO CANAL

In 1978, as part of a joint U.S.A.-U.S.S.R. experiment a 250-μm (10-mil) thick PVC membrane lining was placed in reach 5A between stations 173+72 and 184+25 m (569+96 and 604+50 ft). A 250-μm (10-mil) thick PE (polyethylene) membrane lining was placed in reach 4A between stations 123+10 and 132+89 m (403+87 and 436+00 ft) on the Amarillo Canal of the Navajo Indian Irrigation Project near Farmington, N.M. [3].

Reach 4A has a capacity of 5.4 m^3/s (190 ft^3/s), a base width of 3.20 m (10.5 ft), a water depth of 1.743 m (5.72 ft), a longitudinal slope of 0.0001, and a calculated tractive force of 1.9 N/m^2 (0.04 lb/ft^2). Reach 5A has a capacity of 4.8 m^3/s (170 ft^3/s), a base width of 3.28 m (10.75 ft), a water depth of 1.340 m (4.40 ft), a longitudinal slope of 0.000 25, and a calculated tractive force of 3.3 N/m^2 (0.069 lb/ft^2). The side slopes for both reaches were 2:1.

Each reach, about 1 km (0.6 mi) long, had the first third covered with an uncompacted 200-mm (8-in) layer of silty sand superimposed with 200 mm of sandy gravel (fig. 33), the second third was the same as the first third, except after placement the cover was compacted by a smooth-wheel roller operated longitudinally with the canal, and the final third had a single layer of uncompacted sandy gravel about 400 mm (16 in) thick.

During placement of the cover material on the polyethylene lining, some slippage occurred between the membrane and the subgrade; the berm at the top of the bank, for anchoring the membrane, was modified to provide a better grip to hold the lining from slipping. Scarifying the subgrade before placement of the lining did not seem to prevent slippage.

The PE lining did not conform to irregularities in the soil subgrade surface as well as the PVC lining, and was more subject to puncturing. The labor cost to install the PE lining was significantly higher than for the PVC.

When the canal was filled with water, some sloughing of the cover on the PE lining occurred which caused cracking of the cover at the top of the slope. For the PVC lining, only a few small cracks in the cover of the PVC lining were noticed after the canal was filled with water.

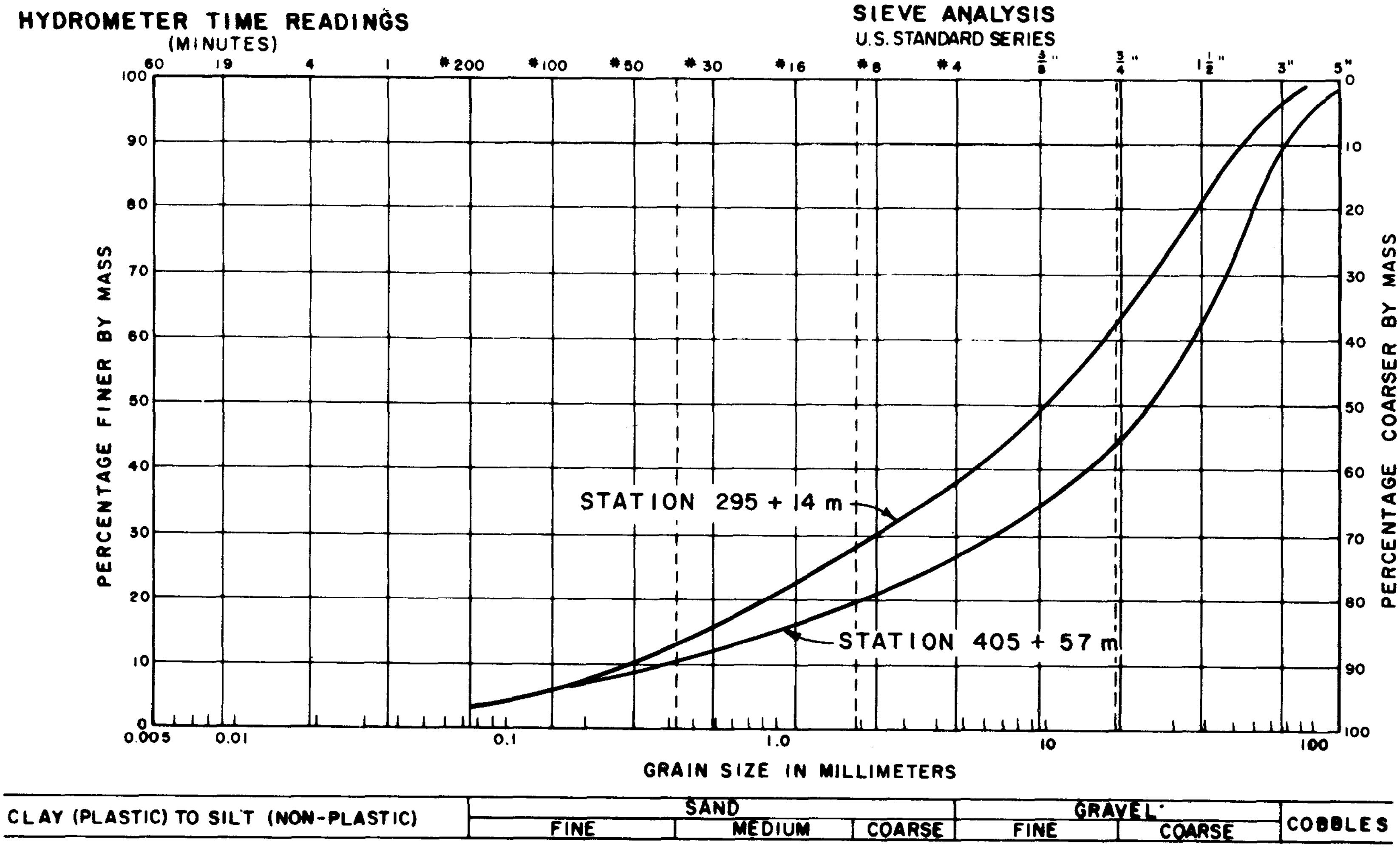


Figure 30.—Gradation of cover layer on Helena Valley Canal.

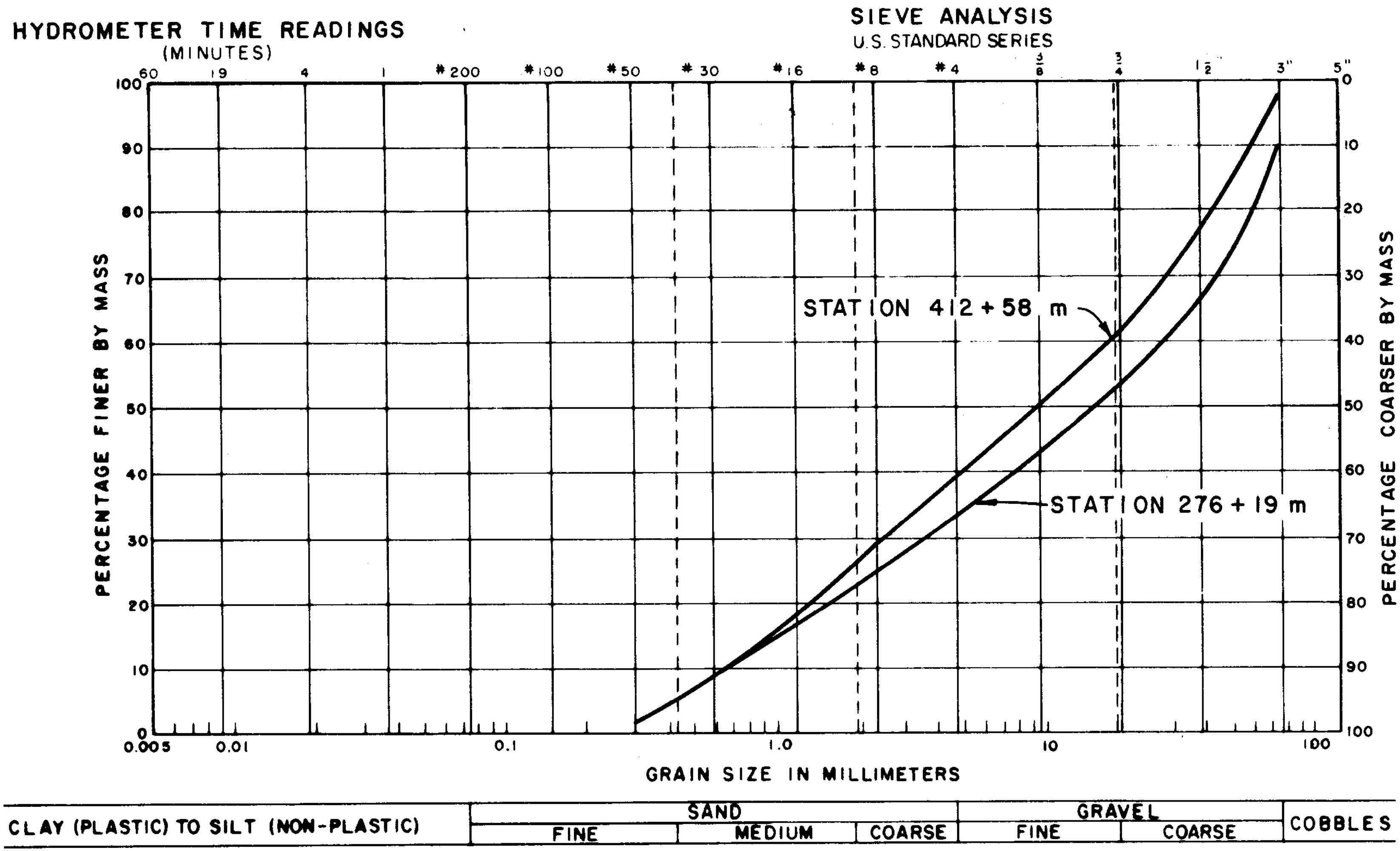


Figure 31.—Gradations of cover layer on East Bench Canal.

Figure 32.—East Bench Canal. Excavation through single layer of gravel cover to PVC membrane at station 412+58 m (1353+60 ft). October 1977 Photo P801-D-79546

When these experimental reaches were last inspected in April 1980, they were reported to be in good condition. There were no significant differences in the appearance of the covers on the various test sections. The photographs in figures 34, 35, and 36 show the appearance of the granular cover after nearly 2 years of canal operation. The fence seen in figure 34 was installed to protect the lining from grazing cattle.

COVERS ON UNLINED CANALS

Kennewick Main Canal

During 1954-55, an unlined section of Kennewick Main Canal near Yakima, Wash. was excavated in cohesionless silt which required a granular cover to prevent erosion of the canal section. The canal had a capacity of 14.2 m^3/s (500 ft^3/s), a longitudinal slope of 0.000 15, and a calculated tractive force of 3.4 N/m^2 (0.071 lb/ft^2). Both subrounded silty gravel and angular talus were available for use as cover. Prior to canal construction, extensive laboratory wave erosion tests at the Denver Engineering and Research Center and a special ponding field test were conducted to determine the best selection of cover materials.

The laboratory wave tests [4] were conducted in an existing hydraulic model flume approximately 0.6 m (2 ft) wide, 1.8 m (6 ft) deep, and 7.3 m (24 ft) long. In one end of the flume, a 2:1 slope of plywood was constructed on which the soils were placed. The other end of the flume contained a machine capable of generating waves of various frequencies and heights. The gradings of the silty gravel, talus, and base soils are shown in figure 37. The cover soils with and without the base material were placed in the flume in 100-mm (4-in) layers both as received and in fine and coarse layers separated on 12.5-mm (0.5-in), 19-mm (0.75-in), and 25-mm (1-in) sieves. Fourteen different tests were conducted on various combinations of base fine and coarse layers to determine those acceptable for use on the canal. The various gradings were compared with Service criteria established for filters [5], and where the gradings were within the criteria, performance of the covers was found to be acceptable.

The best combinations found from these tests were the talus separated on the 19-mm

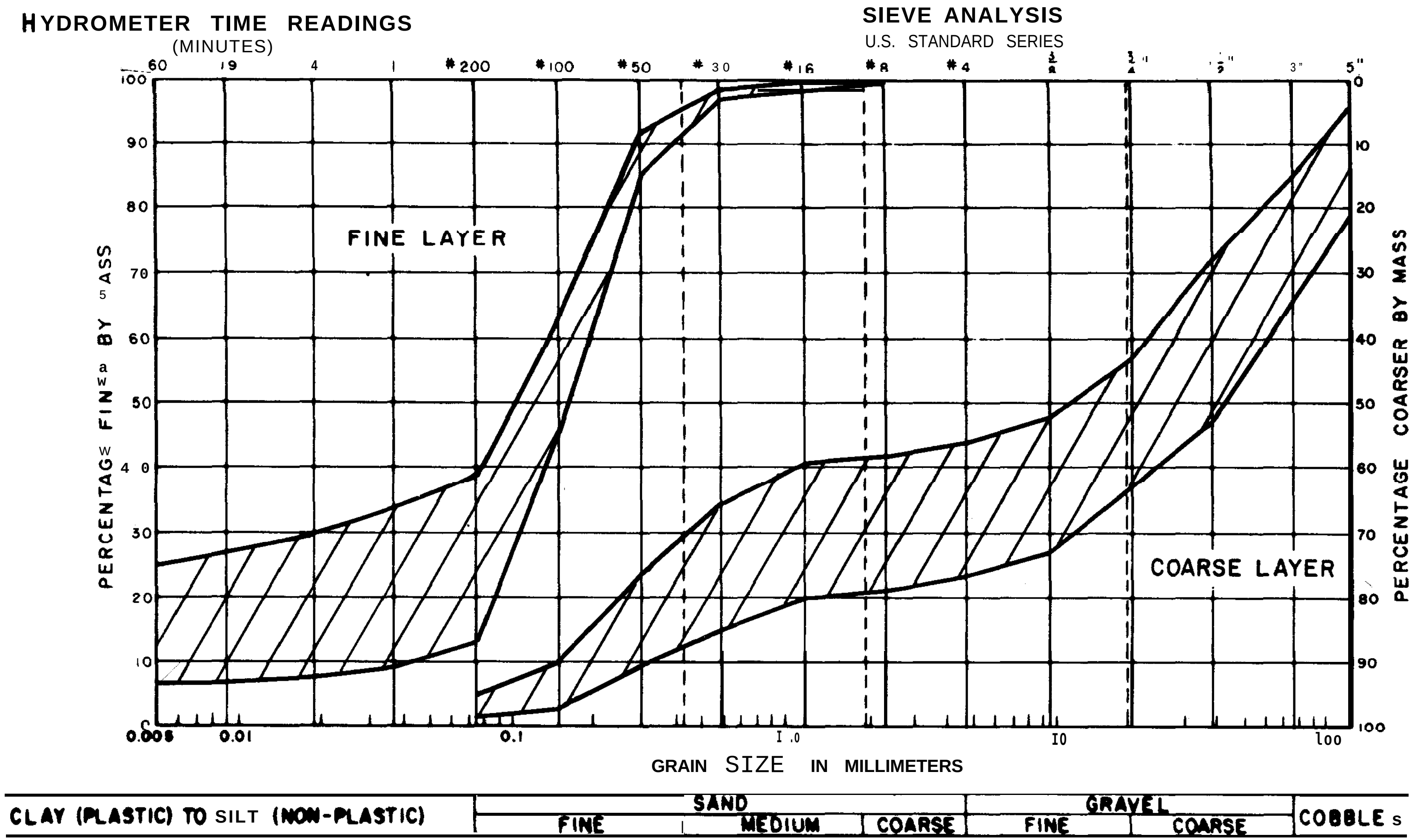


Figure 33. -Gradations of fine and coarse cover layers on Amarillo Canal.

Figure 34.—Amarillo Canal looking upstream from station 183+79 m (603+00 ft) in section 5A. August 1980 Photo P801-D-79545

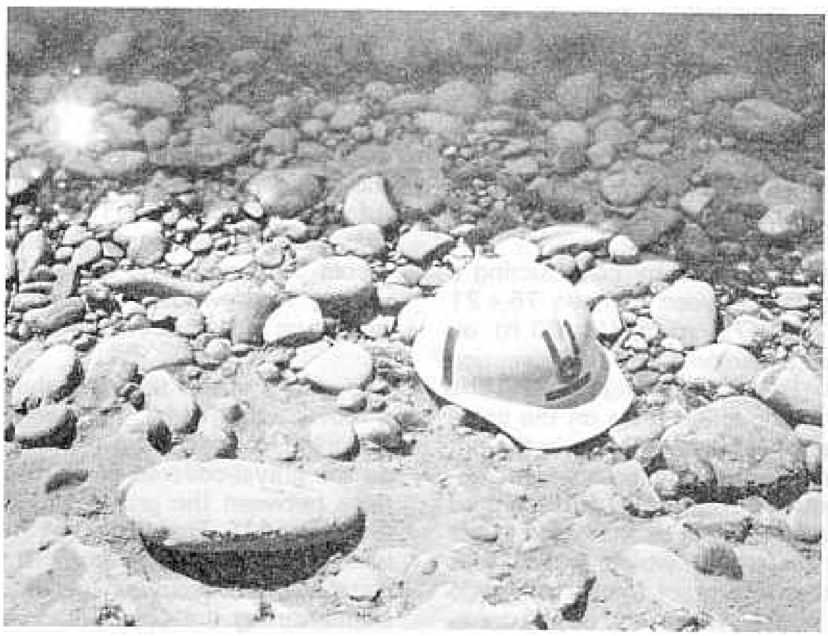


Figure 35.—Amarillo Canal. Typical slope condition at station 123+14 m (404+00 ft) in section 4A. August 1980 Photo P801-D-79544

Figure 36.—Cover and exposed membrane on Amarillo Canal. Photo P801-D-79543

(0.75-in) screen and placed in two 100-mm (4-in) layers which resisted erosion from waves up to 150 mm (0.5 ft). The gradings for these materials fell within the filter criteria.

The gravel separated on the 19-mm (0.75-in) screen performed reasonably well up to a 150-mm (0.5-ft) wave height. However, when the gravel was placed moist and sand particles adhered to the gravel, the material was less stable than when it was placed dry. The unseparated gravel when placed moist and uncompacted in a 150-mm (6-in) layer failed when subjected to a wave height of 90 mm (0.3 ft).

The field test was performed by constructing a full-scale test section between stations 75+21 and 75+90 m (246+75 and 249+00 ft) on the proposed canal alinement. The cross section of the test reach is shown in figure 38. The results of Proctor compaction tests on the canal foundation soils and field density tests in the undisturbed subgrade and in the compacted embankment are shown in figure 39. Unseparated silty gravel (the same grading as that used in the laboratory wave tests and which failed) was used in the field test to protect the silt subgrade from erosion by water waves and rapid drawdown conditions. One-third of the test section was left uncovered, one-third was covered with a 150-mm (6-in) layer of the silty gravel, and one-third was covered with a 300-mm (12-in) layer of the gravel. The field test was conducted from January 14 to April 8, 1954, when the test section was filled with water except during drawdown tests. Observations and measurements were made of any erosion on the canal side slopes, together with subsurface moisture conditions around the test section and climatic conditions for the general area. Winds up to 18 m/s (40 mi/h) and wave heights to 60 mm (0.2 ft) were measured. During an extended cold period, water in the pond froze and some of the particles on the cover adhered to the ice and a few were dislodged. This would not happen in the canal after construction because water would not normally be in the canal during winter. A drawdown test was conducted at a maximum rate of about 240 mm/h (0.8ft/h).

The results of this field test showed that without a cover, the canal soil would erode at the waterline (fig. 40). However, the only erosion on the gravel-covered sections was some of the fines between the gravel particles near the surface (fig. 41). Therefore, a 150-mm (6-in) layer was considered to be sufficient to protect the canal soil, and this was applied on the canal side slopes during the construction of the remaining portion of the canal. The difference in the performance of the cover in the hydraulic laboratory tests and the field tests was due to the much

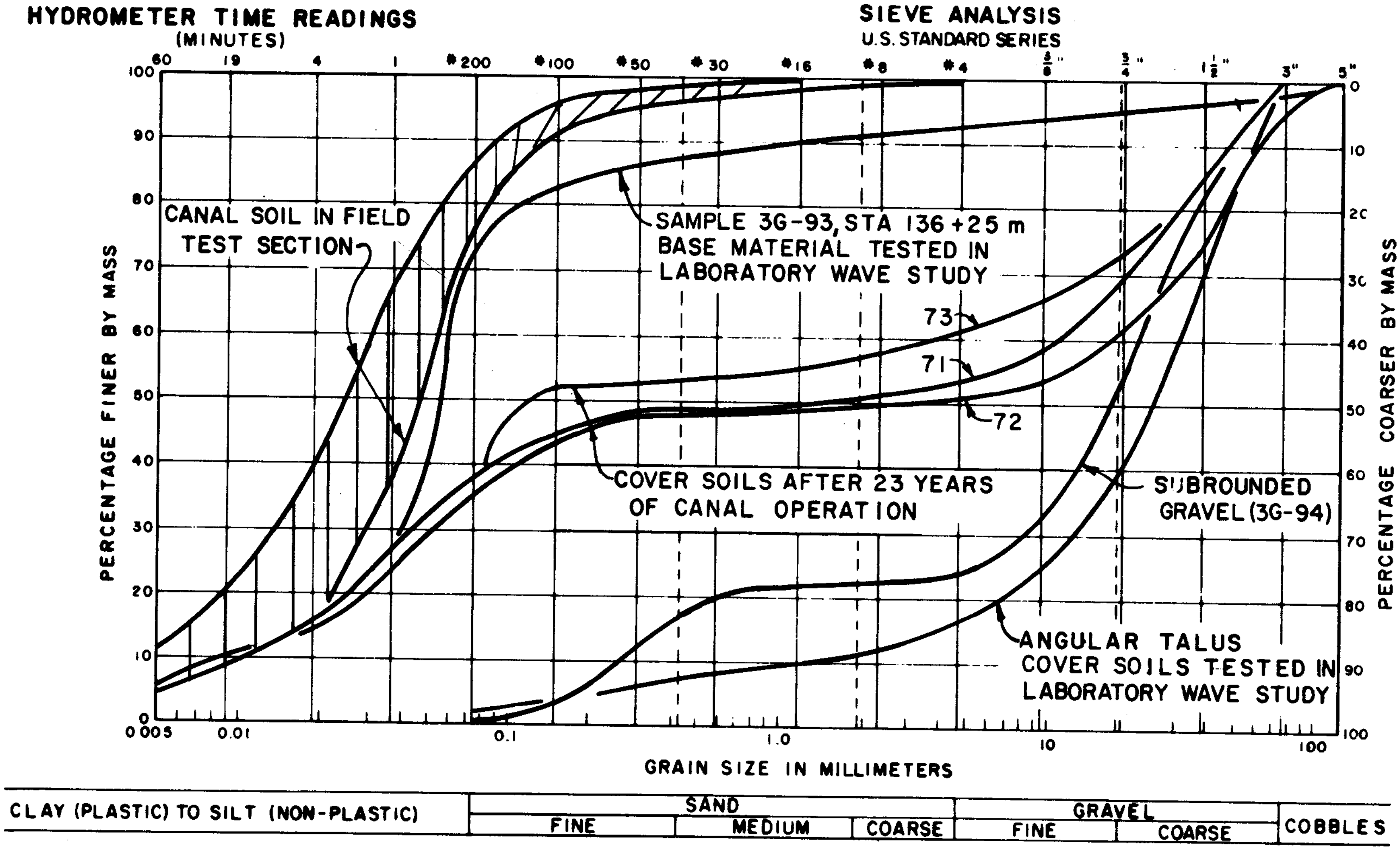


Figure 37.—Gradations of canal and cover layer soils on the Kennewick Main Canal.

Conversion Table

Inch-pound	SI metric
3.0′	0.91 m
5.0′	1.5 m
7.6	2.32 m
10.61′	3.234 m
6″	150 mm
12″	300 mm
18″	450 mm

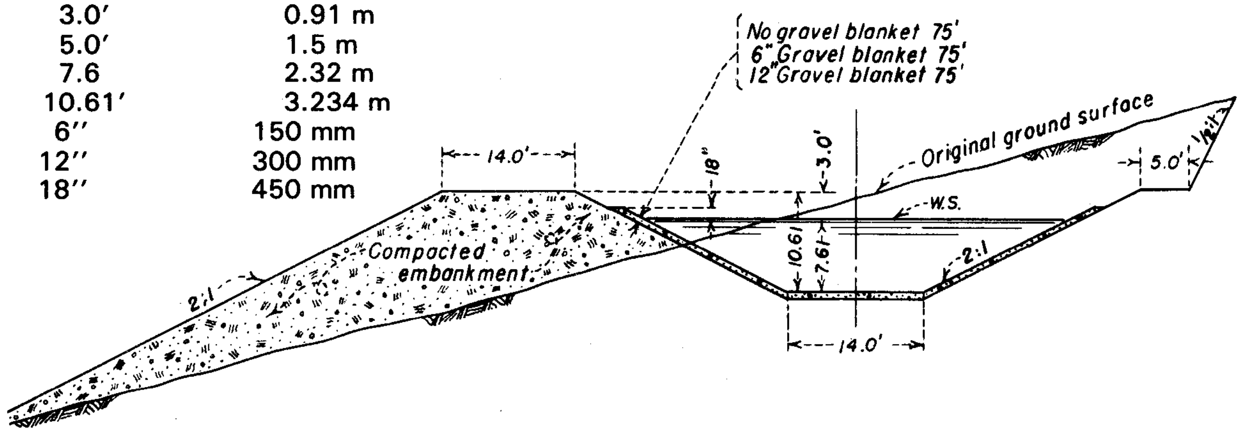


Figure 38.—Kennewick Main Canal test section.

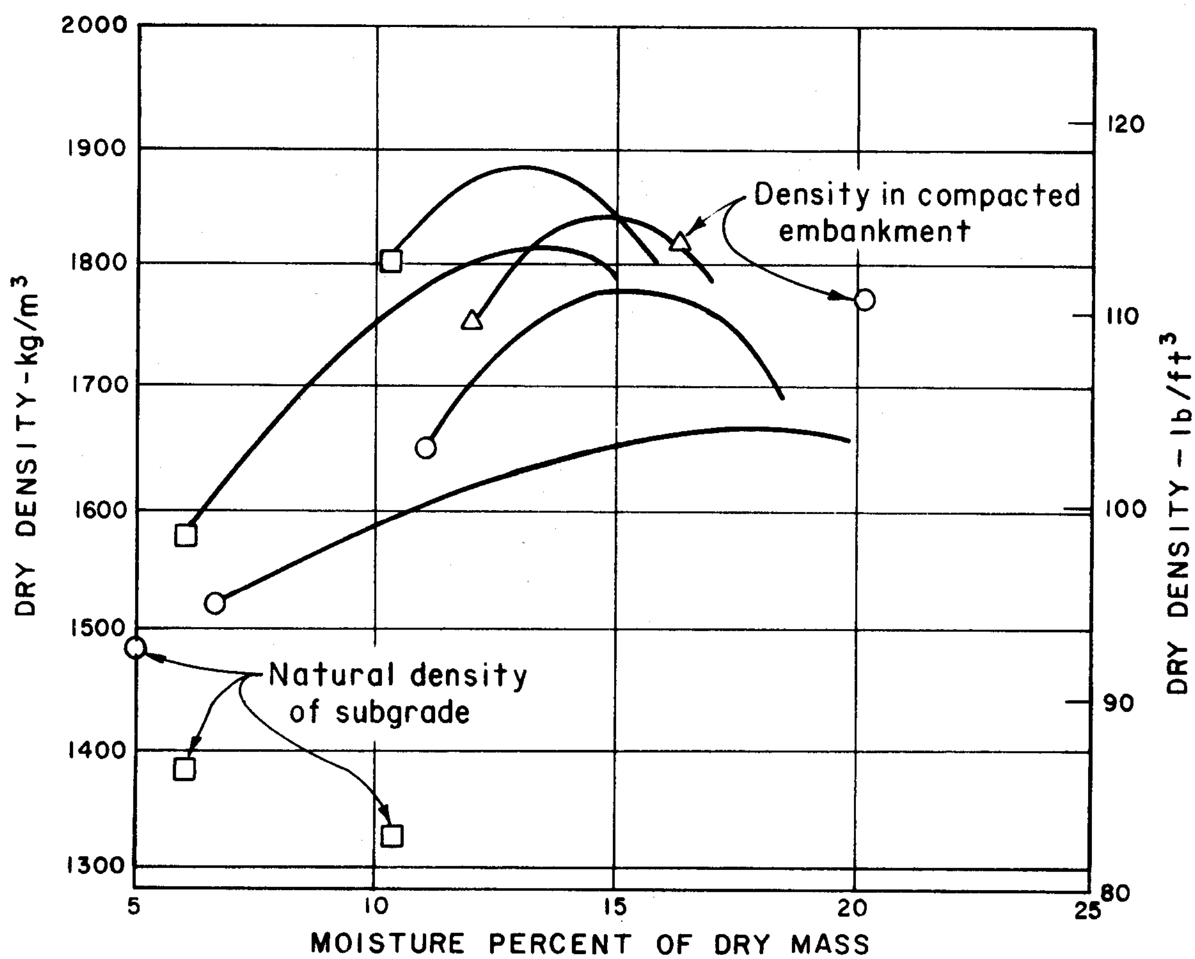


Figure 39.—Moisture-density relations of canal soils. Kennewick Main Canal, stations 75+21 to 75+90 m (246+75 to 249+00 ft).

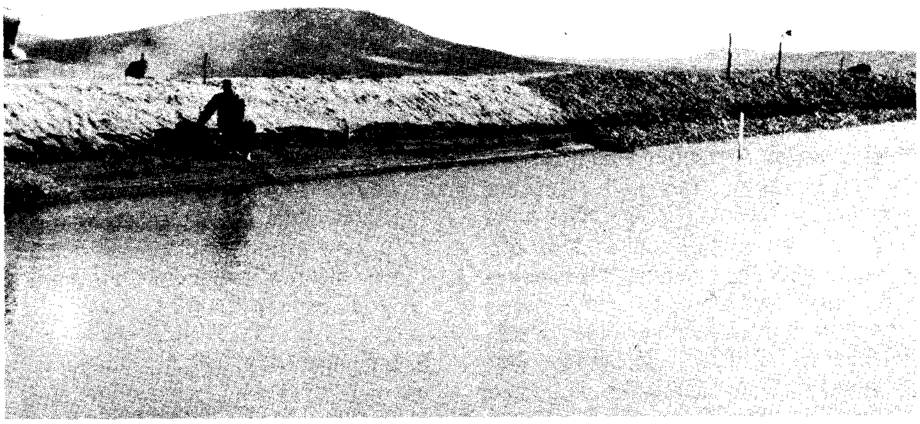


Figure 40.—The difference between erosion of compacted canal embankment with and without a single layer of gravel cover. Kennewick Main Canal test section. March 1954 Photo P801-D-79542

Figure 41.—Start of 150-mm (6-in) gravel cover on embankment for Kennewick Main Canal test section. March 1954 Photo P801-D-79539

lower wave heights occurring in the field than were applied in the laboratory. Also in 1978, the canal was operated at less than designed capacity (table A1).

Since canal construction in 1955, the cover has required little maintenance, and during an inspection in March 1978, it was considered to be in good condition (fig. 42).

Atrisco Feeder Canal

The test reaches on the Atrisco Feeder Canal, Rio Grande Project were between stations 115+82 and 178+00 m (380+00 and 584+00 ft). This is an unlined canal and the granular cover was placed to prevent the erosion of poorly graded sand. As designed, the canal had a base width of 9.1 m (30 ft), a water depth of 0.730 to 0.785 m (2.40 to 2.57 ft), and canal capacity from 7.1 to 7.9 m^3/s (250 to 280 ft^3/s). The longitudinal slope was 0.000 82 to 0.001 with a calculated tractive force of 6.2 to 9.6 N/m^2 (0.13 to 0.2 lb/ft^2). The canal side slopes were 2:1 but the cover was placed on a 3:1 slope for a 600-mm (2-ft) depth above the toe of the slope. Over this variable thickness, the designed cover thickness was 225 mm (9 in). Cover was placed on the canal sides only. The particles were subangular to subrounded and grading curves for the subgrade and cover are shown in figure 43.

When inspected in 1961, this cover was rated in poor condition. Failure was attributed to the steepness of the longitudinal canal slope and resulting high-water velocities. When this cover was inspected in November 1977 by Hydrologic Technician Robert Grano, he made the following comments:

> "On November 17, 1977, Messrs. Joe Pargas, Ralph Nau, and myself inspected the Atrisco Feeder Canal to try and define the granular cover placed in 1956. The following determinations were made from observations and field inspections:
>
> "1. East bank - granular cover difficult to define. Cover has been partially or completely destroyed by placement of jetties and O&M canal maintenance. Although some reaches of the canal did have some gravel at water's edge, it was difficult to determine if this was the granular cover or not; thus no evaluation of the east bank was made.
>
> "2. West bank - although the west bank has been sloped during canal maintenance, a more representative granular cover was present as originally placed. The cover extends approximately 1.5 to 2 feet into the canal. This cover represented the original cover placed and was evaluated as such. In general, the cover is well mixed with different sized particles distributed throughout. A more coarse layer is noticeable at the surface, attributed to the washing action of the flow in the feeder canal. Sediment is well mixed with the cover and no definition between the coarse layer and the underlying soil can be made. This could result as canal maintenance is performed and cover disturbed. Attached are photos and cover evaluation obtained on November 22, 1977."

See figure 44.

Upper Meeker Canal

In 1956, a 100-mm (4-in) granular cover of railroad ballast was placed on the side slopes of an unlined reach of Upper Meeker Canal, and a section between stations 38+40 and 51+82 m stations (126+00 and 170+00 ft) was selected for observation and sampling. This is in a typical loessial area where the fine-grained canal soils of low plasticity would be subject to erosion.

The canal in the test reach had a designed base width of 4.3 m (14 ft), a water depth of 1.535 m (5.03 ft), side slopes of 2:1, and a canal capacity of 8 m^3/s (282 ft^3/s). The longitudinal slope was 0.000 25, and the calculated tractive force is 3.8 N/m^2 (0.079 lb/ft^2). The grading of the cover which had angular particles is shown in figure 45. No grading of the subgrade soil was obtained at the location of cover placement, however, the grading of soil between stations 220+68 to 224+94 m (724+00 and 738+00 ft) which is typical for the general area is shown in figure 45. When the cover was sampled for gradation testing in November 1961, it was considered to be in excellent condition. There were very few locations where the cover had been displaced or otherwise eroded. Erosion had occurred in places below check structures and siphons and where surface water had entered the canal. However, riprap or drainage inlet structures should have been provided at these locations.

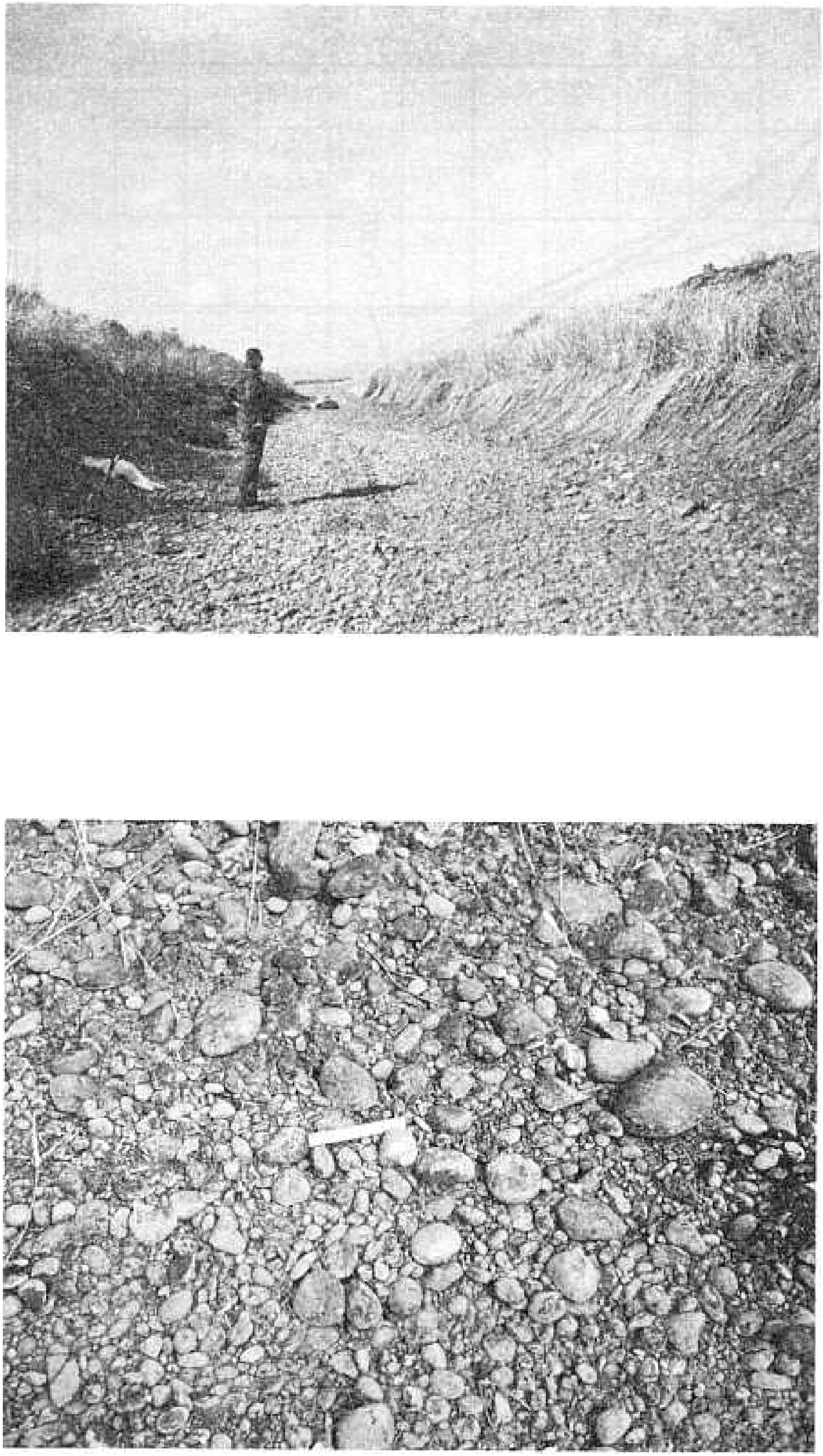


Figure 42.—Distant and close views of Kennewick Main Canal at station 74+98 m (246+00 ft). March 1978 Photos P801-D-79541 and P801-D-79549

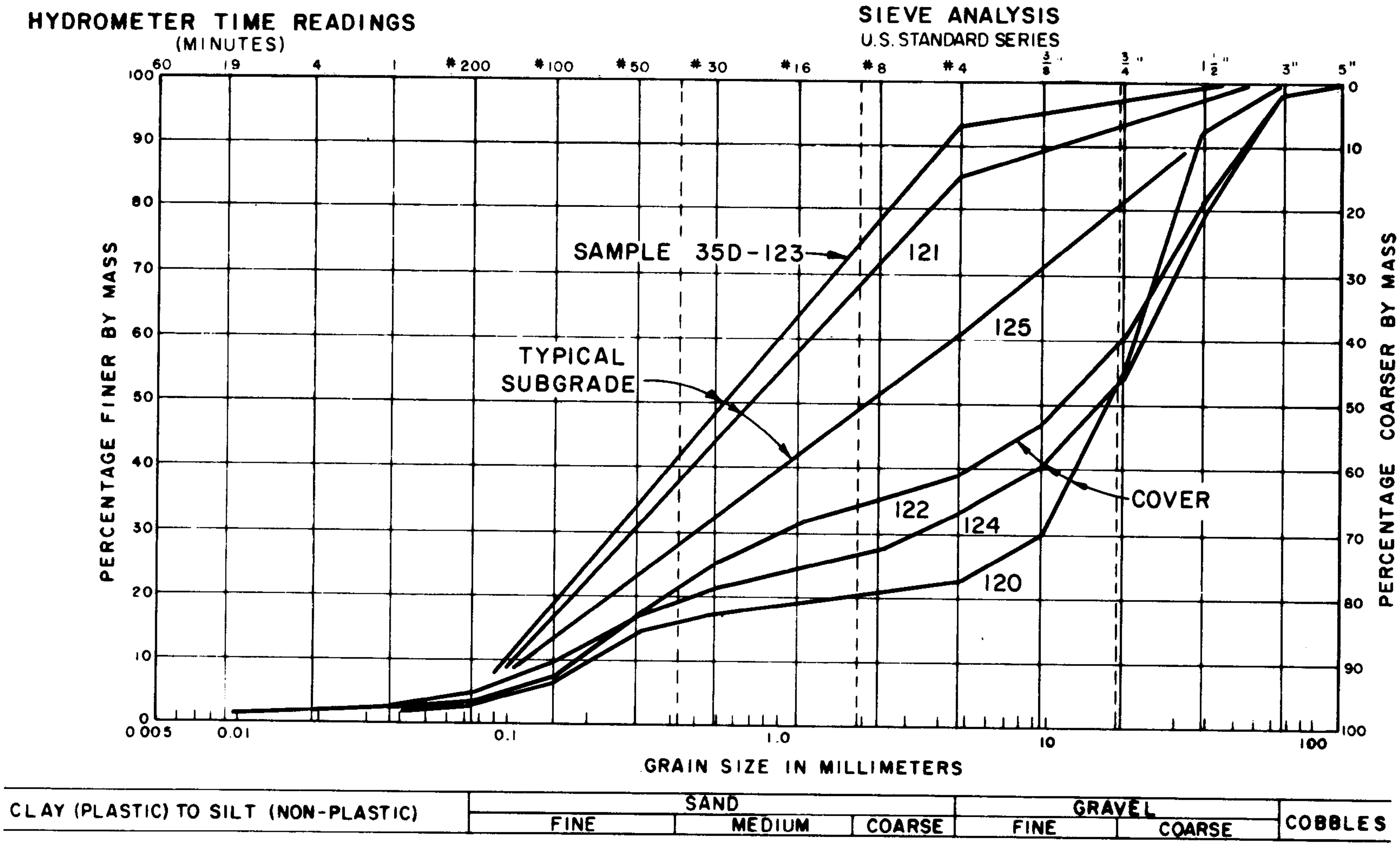


Figure 43.—Gradations of canal subgrade and cover layer on Atrisco Feeder Canal.

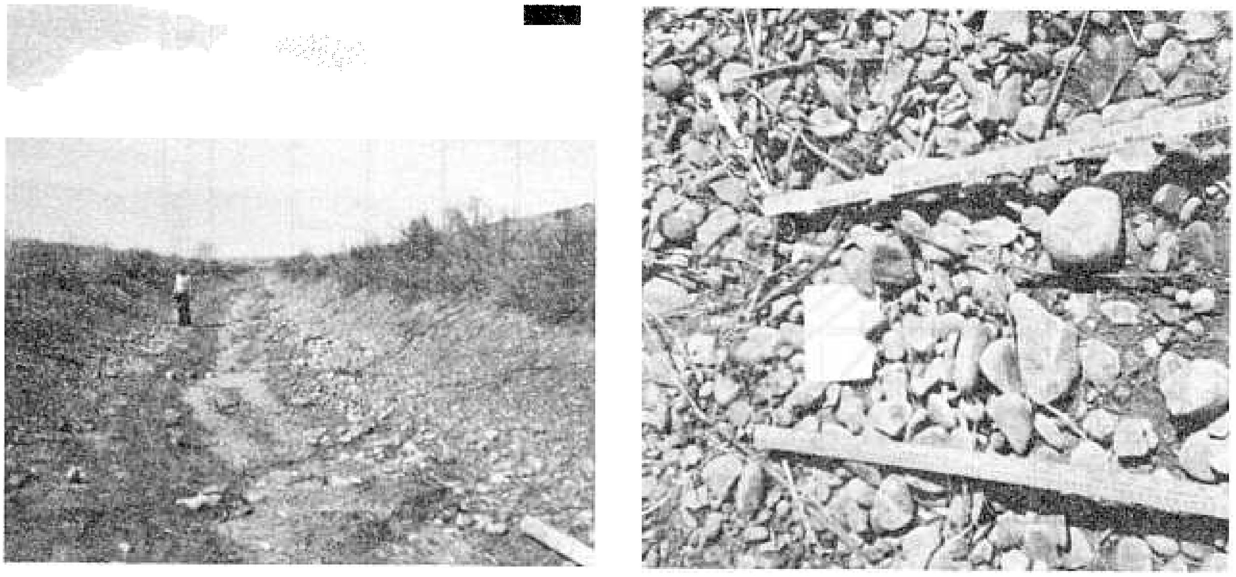


Figure 44.—Distant (left) and close views of cover on Atrisco Feeder Canal at station 147+83 m (485+00 ft). November 1977 Photos P801-D-79536 and P801-D-79540

When the cover was inspected in January 1978, it was rated in good condition. The measured depth of cover was 75 to 125 mm (3 to 5 in). Photographs of the canal obtained at that time are shown in figure 46.

DISCUSSION

Cover Settlement and Membrane Slippage

Because covers for membrane linings are generally unprocessed material from local sources and are loosely dumped on the membrane without moisture and density control, settlement of some covers with resulting crack formation is probably inevitable. Such settlement has usually been corrected with a minor amount of maintenance. In locations where settlement is critical, consideration should be given to moisture and density control during cover placement. The condition of the subgrade under the membrane and the instability of the cover, may both contribute to membrane folding as happened to a limited extent for the asphalt membrane of West Canal, 5th Section, and the PE membrane of Amarillo Canal.

The formation of an ice layer under the PVC lining of Pilot Canal with resulting slippage during melting was an isolated incident. Measures to prevent slippage might consist of (1) a sand layer of sufficient coarseness to prevent water from reaching the underside of the membrane, and (2) roughening the subgrade surface under the sand layer to prevent a smooth plane of ice from building up between sand and subgrade. It would not be practicable to use these measures on a widespread basis if slippage occurs on a small scale and repairs can easily be made. On structures where slippage is more critical, as on a forebay lining where there is frequent opportunity for freezing and thawing, and interruption of services for repair is costly, extra measures to prevent slippage might be justified.

Although there are undoubtedly some differences in frictional resistance between types of membranes and soil subgrades and covers, this has not received extensive investigation in this country. Investigators in the Soviet Union have determined experimentally the friction between polyethylene film and soils of different grading [6]. Their main conclusion was that "in designing slope stability for hydraulic structures with membranes of low-density polyethylene film, the value of the friction coefficient must be taken as constant and equal to 0.30." As mentioned previously, on the Amarillo Canal, sliding was noticeably greater with the PE than the PVC lining, both during cover placement and canal filling with water.

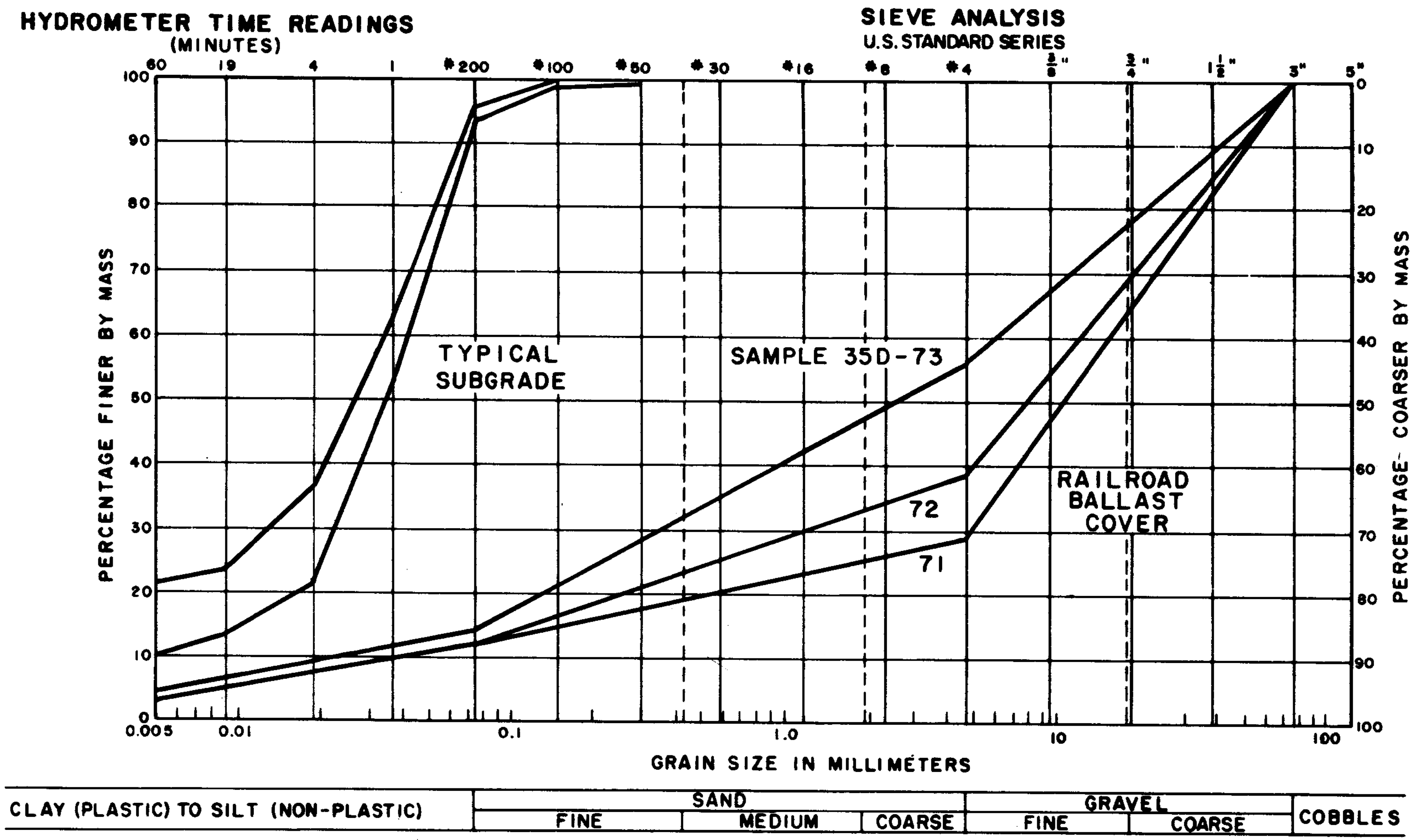


Figure 45.—Gradations of canal subgrade and railroad ballast cover layer on Upper Meeker Canal.

Figure 46.—Distant (top) and close views of the cover on Upper Meeker Canal. January 1978 Photos P801-D-79548 and P801-D-79552

In the selection of cover materials, the effects of one layer on the other should be considered. If the fine layer is too sandy, it may affect the stability of the coarse layer. The grading of the coarse cover on lateral W20 of the Columbia Basin Project appears to be within acceptable limits, but the poorly graded sand with sandy silt pockets in the underlying fine layer contributed to instability in the top cover layer. Conversely, if the grading of the top layer should be too coarse relative to the underlying layer, there would be a danger from water flow or wave action plucking out cohesionless soil fines from the bottom layer and causing instability.

Criteria for Grading and Thickness of Cover Soils

It would seem logical that there should be a range of grading for soil in a coarse cover of given thickness that would be suitable to protect a specific underlying soil from erosion and remain stable, and that criteria for this purpose could be developed. The Service filter criteria [5] provided a reasonably good guide for evaluating stable and unstable combinations of gradings in the laboratory wave test of Kennewick Main Canal where most of the covers were 100-mm (4-in) thick. However, it is apparent from some of the gradings of covers in the field installations that the Service criteria could be exceeded without causing instability. The action of water on fine soil particles is different in a conventional filter for drainage than in a cover. For the filter, the water passes through fine soil into the coarse, tending to carry soil particles with it. For the soil covers, any infiltration of fines from underyling soil is most likely to occur at the beach belt from wave action. However, depending on the thickness and grading of the coarse cover, the energy of water tending to dislodge fines at the interface between layers will be dissipated in the voids of the coarse cover. For example, the angular railroad ballast cover on the silty subgrade of Upper Meeker Canal was significantly outside the Service filter criteria as far as the median (50 percent) sizes were concerned, yet it remained stable. Also, in some cases, sediment carried by the canal water deposits in the voids of the coarse soil layer partially blocking water inflow.

It will be noted that the thickness of the coarse cover on Upper Meeker Canal was only 100 mm (4 in) thick which is less than half the thickness for many of the covers. From the data in this report, there is no clear indication of criteria for the minimum thickness for stable covers.

Tractive Force

A basic consideration in the design of a canal in erodible soil is the shearing action of flowing water tending to dislodge soil particles. The concept of tractive force has been formulated to provide a method for calculating values of the shearing action. The tractive force (T) on the bottom of the canal is expressed by the formula $T = wds$, where w is the unit force of water, d is the canal water depth, and s is the longitudinal slope of the canal bottom relative to the horizontal [7]. In this equation, T is the tractive force in units of force on a unit area of streambed by a column of flowing water. The tractive force determined by this formula applies to a channel of infinite width. Laboratory flume tests have been conducted to determine the distribution of tractive forces on the sides and bottom of channel [8]. The tractive force on the side slopes of a canal would be less than on the canal bottom because of the lesser water depth. However, the material on the side slopes tends to roll downslope due to gravity, and the combined effect of this action with the tractive force of the water may result in a greater tendency to scour on the side slopes than on the bottom. Research has been conducted to determine critical tractive forces, that is, forces necessary to begin to move various sizes of noncohesive sands and gravels. However, critical tractive forces for cohesive soils have not been conclusively established. Sometimes erosion occurs on curves as was noted for Pavillion Main Lateral. This may occur when the curve has too short a radius. Further investigations are needed to study the effects of tractive force on canal side slopes and minimum radius requirements for erosion control.

In large canals, wind-generated waves often cause erosion of earth materials at the waterline and this may damage a granular cover. Some data have been collected from field and laboratory tests on effects of wave heights and water drawdown of cover materials [4,9].

Cross sections of the canals at the granular cover test sites were obtained with the elevations of high water marks on the side slopes for some of the sections. Where possible, the sections were obtained at 150- and 300-m (500-and 1000-ft) intervals for each test site. From the cross sections, an attempt was made to determine the actual tractive force values for the test sections. For this, the water surface profile computer program PSEUDO, as used in the

Hydrology Branch of the Division of Planning Technical Services, was tried. This effort was not successful, mainly because water surface elevations with coincident values of canal discharge were not available.

Longitudinal canal slopes could be calculated from elevations in the canal bottom and tractive force calculated by assuming a water depth based on design. However, this did not seem to be sufficiently accurate. In some cases, the measured slope was negative; this may have resulted from irregularities in the section caused by canal cleaning or other maintenance. The tractive force values reported in table A1 are based on the canal design properties.

Gradations for Coarse and Fine Cover Layers

Most of the gradings of stable coarse covers investigated fell within the upper and lower limits shown in Figure 47. Gradings of covers with poor stability were generally above the upper limit but some fell below this limit into the shaded overlap area. An overlap would be expected because of variable soil, design, operating, and climatic conditions. The individual gradings, from which the plot was made, were obtained on samples after the canals had been in operation for some time and may not reflect the original grading of the cover as placed because of infiltration of fines. The stability of gravel with infiltrated fines would be higher than if the fines had been present during cover placement. For these reasons some of the gradings for gravels with a large amount of fines, such as those from the West Canal 5th Section, of the Columbia Basin Project, which have proved to be stable, did not fall entirely within the stable grading range as shown.

Judging from the grading of Atrisco Feeder Canal, which fell within the stable range except for the medium to coarse sand extending into the lower part of the overlap, and the placement of the cover on a 3:1 side slope, one would expect a greater stability than that reported. However, based on the design longitudinal slope and the approximate slope of the thalweg calculated from canal cross sections the tractive force was over 6.2 N/m^2 (0.13 lb/ft^2) which was higher than any of the other covers described in this report. Also, the reported disturbance of the cover by maintenance procedures would have contributed to the deterioration of the cover.

Although the cover on the PVC lining on the Wyoming canal between stations 146+00 and 148+13 m (479+00 and 486+00 ft) has generally shown good performance, there was some slippage after the water was turned into the canal. The grading of the coarse layer (fig. 28) at stations 146+00 and 148+13 m extended slightly above the upper stable limit as shown in figure 47 in the medium to coarse sand range. Also, the design tractive force, 5.7 Pa (0.12 lb/ft^2), was higher than for most of the other canals investigated.

Suggested grading limits for coarse granular covers for canals are shown by dashed lines on figure 47. Because some of the cover samples probably contained fines which accumulated after cover placement, the selected upper limit restricts the amount of fines passing the No. 200 screen to 10 percent. The lower limit was arbitrarily made a little finer than the most extreme of the coarse gradings.

Note that this report focuses on stability and there may be other factors in canal design which could influence the gradings of covers. For example, the suggested grading of the coarse stable limit might have too high a friction factor for some canals an this must be considered.

Figure 48 shows the suggested new limits plotted in comparison with those in standard specifications paragraphs (C-190) for "Buried Polyvinyl-Chloride Lining." These paragraphs were written in 1969; revisons are presently being considered. From this investigation of covers, it appears that both the upper and lower limits should be made coarser than those in C-190, except that 10 percent passing the No. 200 sieve could be allowed instead of 5 percent. Furthermore, the data indicates that the suggested grading limits should be used only where the tractive force is less than 5 N/m^2 (0.1 lb/ft^2).

Figure 49 shows the range of gradings for the fine cover layers on the test sites with the coarser grading of lateral W20 at station 192+67 m (632+12 ft) plotted separately. The covers with gradings falling within the range generally performed satisfactorily; however, some sloughing occurred. The coarse limit of the range has 90 percent of particles passing the No. 4 sieve and 20 percent passing the No. 200. The grading for lateral W20 at station

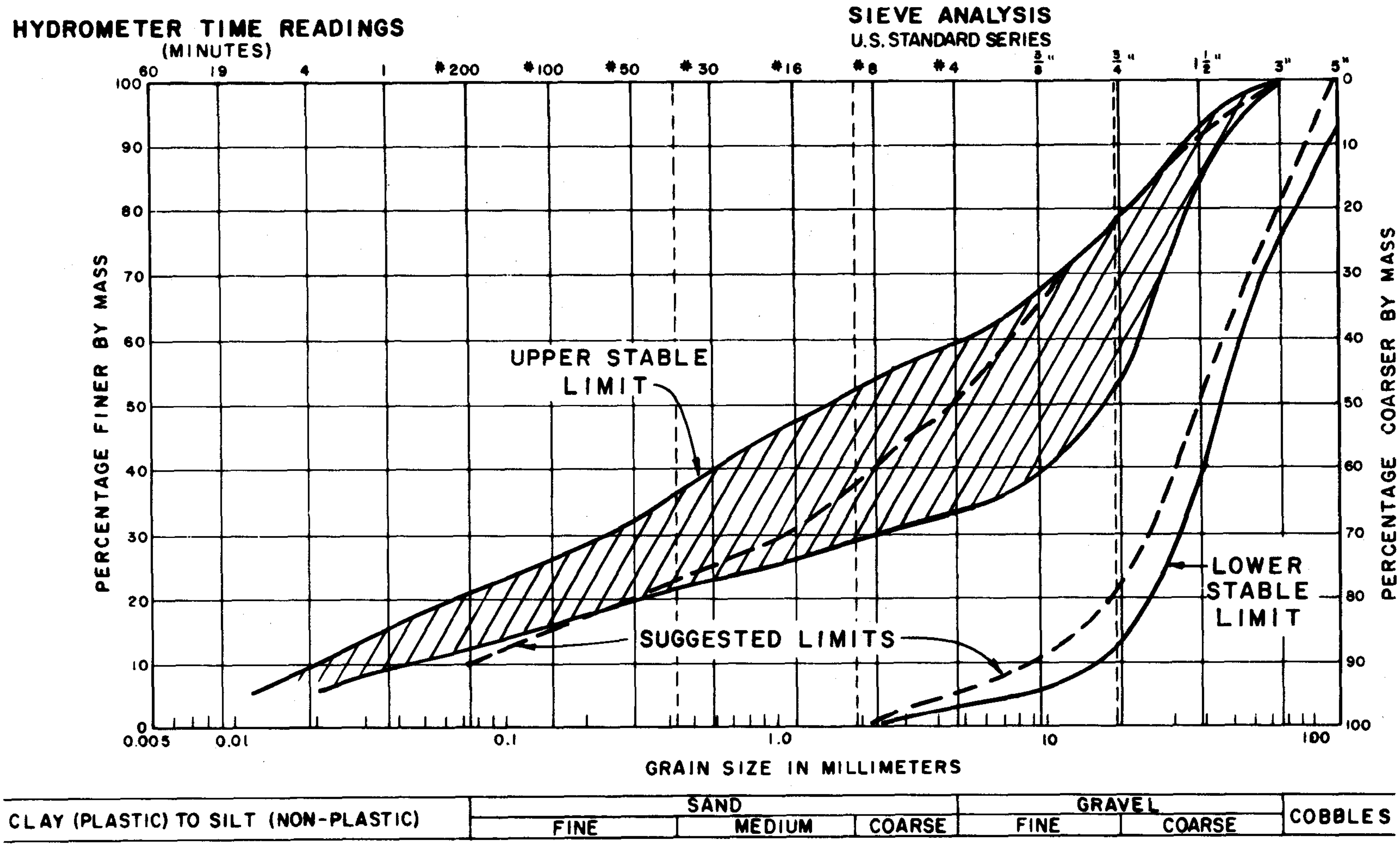


Figure 47.—Gradation ranges for good to poor performance of coarse soil cover layers with suggested new limits.

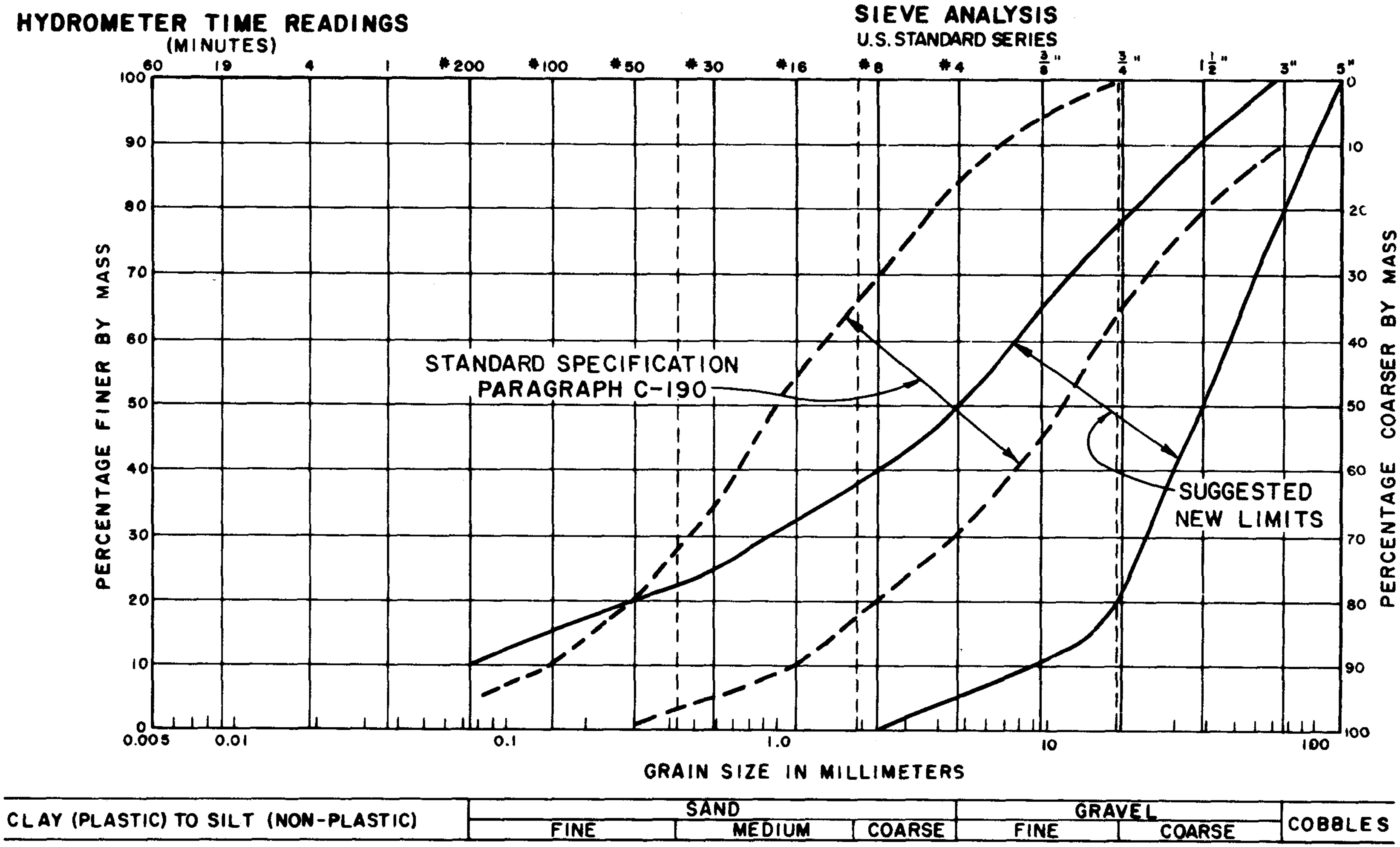


Figure 48.—Comparison of suggested new grading limits with previous limits specified for a coarse soil cover layer.

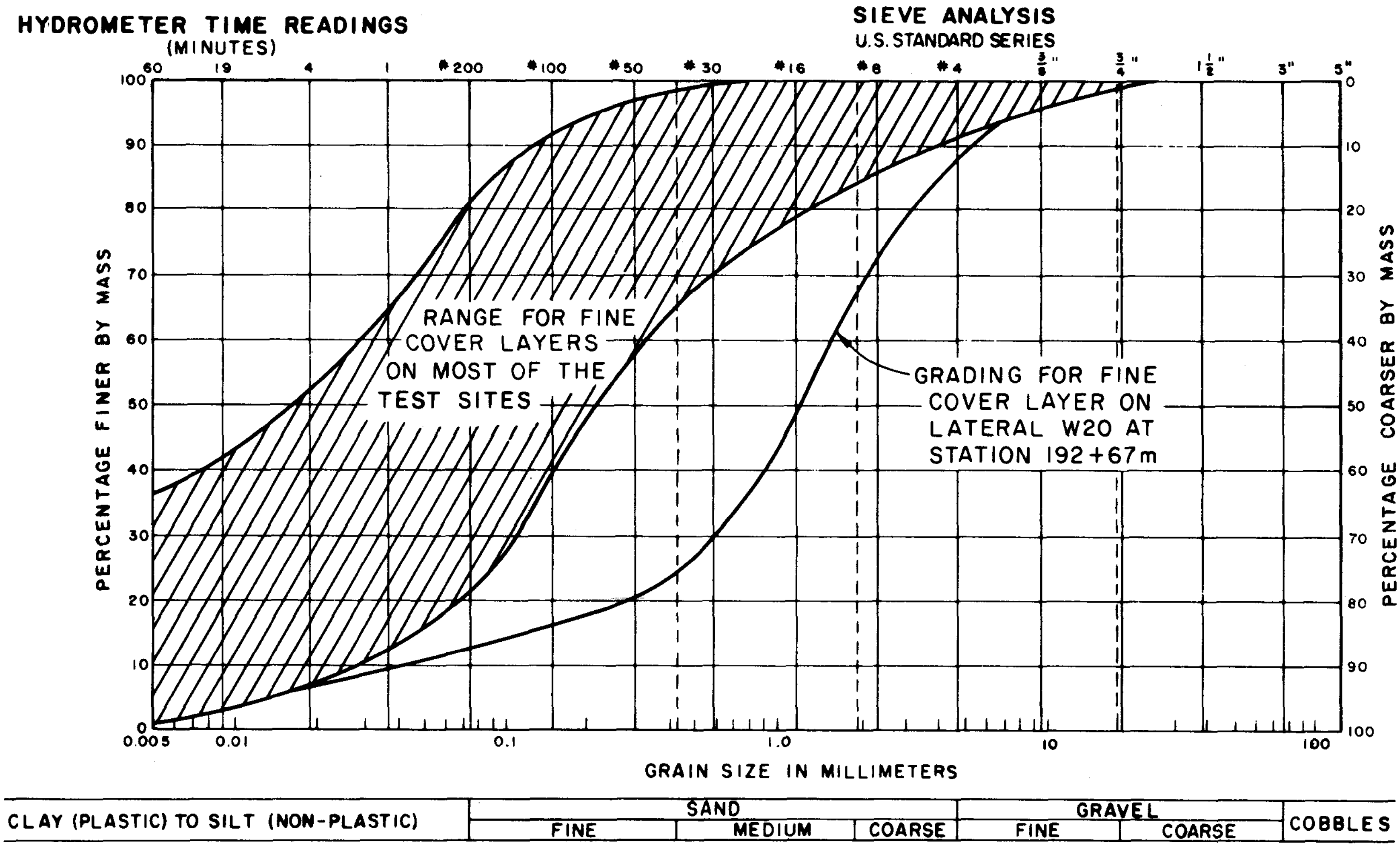


Figure 49.—Gradations of fine cover layers on canal test sites.

192 + 67 m fell far outside the coarse limit. Observations show that at this location there was an unusual amount of sloughing, and trenches excavated in the cover would not stand open. Although this is only one instance, and definite conclusions cannot be drawn, there is an indication that some sands in the medium to coarse range should be avoided for the fine cover layer.

It is possible that cover instability during canal drawdown could result if the permeability of the fine layer should be higher than that of the coarse layer. Sometimes the permeability of a well-graded coarse, granular soil with even a relatively small amount of fines will be lower than expected, relative to a medium to coarse sand. For example, for lateral W20 at station 192 + 67 m, there might be some question about whether the permeability of sample 35D-33 from the fine layer would be higher or lower than that of 35D-34 from the coarse layer (figure 6). This could also have been a factor in the poor performance of the cover on the unlined Atrisco Feeder Canal where the permeability of the cover may have been less than that of the subgrade (fig. 43).

APPLICATIONS

This report describes in general terms the performance of selected cover soils on Service canals. Detailed histories of the operation and maintenance of the canals in question are not available, and the data were collected by many different persons guided by written instructions. The data are not sufficiently detailed to warrant extensive analysis and the compilation of formulas or neat comprehensive curves to be applied indiscriminately in design. Such results generally come from tests where experiments can be conducted more precisely. However, the information in this report can be used as a general guide for future selection of soil grading for covers where similar canal conditions are expected.

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APPENDIX

Table A1.—Location and characteristics of granular cover test sections.

Table A2.—Field and laboratory test data and observations.

Table A1.—*Location and characteristics of granular cover test sections*

Canal or lateral	Specifications	Construction date	Stationing (feet) From	Stationing (feet) To	Canal Properties (as designed) Flow (Q) ft³/s	Velocity (v) ft/s	Base (b) ft	Depth (d) ft	Side slope	Gradient (s)	Cover thickness (in) Fine layer	Cover thickness (in) Coarse layer	Tractive force lb/ft²
					Asphaltic Membrane Lining								
West Canal, 5th Section	DC-4009 & 117C-567	1960	3393+13	3395+13	450	2.48	20.0	6.19	2:1	0.000 2	8	5	0.08
			3543+19	3545+19	450	2.48	20.0	6.19	2:1	0.000 2	8	5	0.08
			3601+18	3605+18	450	2.48	20.0	6.19	2:1	0.000 2	8	5	0.08
Lateral PE38.9	DC-4001	1953-54	31+50	33+50	288	0.79	16.0	10.5	1.75:1	0.000 04	12	9	0.03
					180[a]	1.01[a]		6.7					0.017
Lateral W20	DC-4312	1956	620+50		375	2.05	20.0	5.79	2:1	0.000 15	14[b]	6	0.054
					135[a]	1.41[a]	22.5[a]	3.4[a]	2.3:1	0.000 15			0.032
			632+12		375	2.05	20.0	5.79	2:1	0.000 15	14[b]	6	0.054
					135[a]	1.55[a]	24[a]	3.7[a]	2.4:1	0.000 15			0.035
			698+54	699+12	339	1.99	20.0	5.5	2:1	0.000 15	14[b]	6	0.051
					116[a]	1.43[a]	18.5[a]	3.8[a]	2.25:1	0.000 15			0.036
			699+00		116[a]	1.43[a]	18.5[a]	3.8[a]	2.25:1	0.000 15	14[b]	6	0.036
Lateral W22E	DC-2880	1949-50	136+00	136+80	47	1.48	6.0	2.9	1.75:1	0.000 3	16	–	0.05
Angostura Main Canal[c]	DC-3372	1951-52	21+24	33+26	309	2.24	14.0	5.51	2:1	0.000 21	8	6	0.072
	602C-23	1959	283+32	310+75	unknown	2.25	14.0	5.75	2:1	0.000 20	6	6	0.072
			310+75	319+90	295	2.40	12.0	5.40	2:1	0.000 20	6	6	0.084
	602C-30	1960	599+55	611+70	260	2.46	12.0	4.86	2:1	0.000 30	6	6	0.091
			1029+05	1172+25	89	2.11	8.0	3.02	2:1	0.000 42	6	6	0.079
			1172+25	1179+87	72	2.00	7.0	2.84	2:1	0.000 42	6	6	0.074
			1446+25	1474+00	42	1.58	6.0	2.33	2:1	0.000 35	6	6	0.051
			1474+00	1516+75	38	1.91	6.0	2.00	2:1	0.000 60	6	6	0.075
Wyoming Canal	617C-32 & 617C-38[d]	1952	913+00	1585+00	920	2.24	34.0	8.4	1.75:1	0.000 1	16	8	0.05
	2890	1950	1225+00	1330+00	910	2.27	31.0	8.7	1.75:1	0.000 1	12	2	0.05
	617C-32	1953	1865+28	1870+05	566	2.58	25.0	6.2	1.75:1	0.000 2	7	6	0.08
Pilot Canal	617C-53	1959	280+00	332+00	844	2.5	30.0	7.5	2:1	0.000 15	–	16	0.070
	617C-50	1956	817+00	853+00	630	2.21	26.0	7.5	2:1	0.000 15	–	18	0.070
	617C-25	1951	943+00	978+00	670	2.2	27.3	10.2	2:1	0.000 15		16	0.095
Pavillion Main Lateral	617C-50	1956	383+00	474+79	65	2.38	7.0	2.6	2:1	0.000 75	–	10	0.12
	617C-43	1954	494+60	552+51	57	2.46	6.0	2.4	2:1	0.000 75	–	10	0.11
			474+79	494+60	60	2.23	7.0	2.5	2:1	0.000 75	–	10	0.12
Fort Laramie Canal	2660	1950	1998+38	2043+46	1305	2.47	44.0	8.63	2:1	0.000 09	4	12	0.05
	DC-4017	1954	4510+20	4562+00	675	2.30	28.0	6.98	2:1	0.000 14	9	6	0.060
Helena Valley Canal	604C-49	1962	278+08	353+39	300	2.44	12.0	5.44	2:1	0.000 25	8	5	0.085

Table A1.—*Location and characteristics of granular cover test sections*—Continued

Canal or lateral	Specifications	Construction date	Stationing (feet) From	Stationing (feet) To	Canal Properties (as designed) Flow (Q) ft³/s	Velocity (v) ft/s	Base (b) ft	Depth (d) ft	Side slope	Gradient (s)	Cover thickness (in) Fine layer	Cover thickness (in) Coarse layer	Tractive force lb/ft²
[redacted]													
Hudson Canal	DC-4041	1954	470+00	485+00	260	2.07	14.0	5.6	1.5:1	0.000 17	–	–	0.059
[redacted]													
Wyoming Canal	617C-99	1975	479+00	486+00	2200	3.09	60.0	9.41	2:1	0.000 2	10	10	0.1
Helena Valley Canal	604C-86	1971	926+05	998+17	225	2.16	12.0	4.89	2:1	0.000 3	–	16	0.09
	604C-72	1969	1322+02	1386+00	150	2.10	9.0	4.19	2:1	0.000 35	–	14	0.092
East Bench Canal	604C-77	1970	906+15	1353+60	405	1.98	20.0	6.44	2:1	0.000 13	–	16	0.052
					425[e]	2.00	20.0	6.50	2:1	0.000 13	–	16	0.053
Amarillo Canal Section 5A	DC-7248	1978	569+96	604+50	170	1.98	10.75	4.40	2:1	0.000 25	(f)		0.069
[redacted]													
Amarillo Canal Section 4A	DC-7248	1978	403+87	436+00	190	1.51	10.5	5.72	2:1	0.000 1	(f)		0.04

Table A1.—*Location and characteristics of granular cover test sections*—Continued

Canal or lateral	Specifications	Construction date	Stationing (feet) From	Stationing (feet) To	Canal Properties (as designed) Flow (Q) ft³/s	Velocity (v) ft/s	Base (b) ft	Depth (d) ft	Side slope	Gradient (s)	Cover thickness (in) Fine layer	Coarse layer	Tractive force lb/ft²
[redacted]													
Kennewick Main Canal	DC-4311 & DC-4046	1954-55	243+37	249+37	500	2.25	14.0	7.61	2:1	0.000 15	–	6[g]	0.071
					334[h]	2.02	14.0	6.25	2:1	0.000 15	–	6[g]	0.059
Atrisco Feeder Canal	DC-4585	1958	174+15	495+00	280	3.00	30.0	2.57	3:1	0.000 82	–	–	0.13
	DC-4982	1958	495+00	613+12	250	2.99	30.0	2.40	3:1	0.001	–	9[i]	0.2
Upper Meeker	DC-4604	1956	126+00	170+00	282[j]	2.33	14.0	5.03	2:1	0.000 25	–	4[g]	0.079

Footnotes:

a. As operated in 1960.

b. Cover is 14 inches on the side and 6 inches on the bottom; all samples are from the slopes.

c. From 1960 notes, this canal was operated at or below designed capacity.

d. Original cover material was too fine and eroded at waterline. Coarse beach belt material was added in 1954 under Specifications 617C-38. The beach belt material had a minimum thickness of 12 inches for a vertical depth of 2 feet.

e. As operated in 1977.

f. One third of the reach had a 8-inch layer of silty sand and 8 inches of sandy gravel; one third had the same layer thicknesses but was compacted; and one third of the reach had only 8 inches of sandy gravel.

g. Cover on side slopes only.

h. Reported operation in 1978.

i. Cover on canal sides only. Original side slopes 2:1. Cover surface on 3:1 slope for a 2-foot vertical height above toe of slope and 9 inches thick 2 feet above the toe.

j. Reported in 1978 as having been operated at 340 ft³/s, 20 percent over the design flow.

Table A2.—*Field and laboratory data and observations*

Canal or lateral	Sample station (ft)	Offset (ft)	Cover thickness (in.) Fine layer	Cover thickness (in.) Coarse layer	Sample No.	Soil classification	Specific gravity (+No. 4)	Percent absorbtion (+No. 4)	Particle shape	Condition of cover
West Canal,	3393+13	16R	–	–	35D-38	GM	–	–	angular	December 1960.-Fair.
5th Section	3394+13	23R	–	6	-39	GM	2.61	0.4	angular	Some slippage of cover
		23L	7	–	-40	ML			angular	when water was first
	3395+13	18R	–	–	-41	GM			angular	turned into canal. No
	3543+19	20R	–	–	-42	GM			angular	erosion or other
	3544+19	20R	–	6	-43	GM	2.65	2.7	angular	problems.
	3544+19	20L	6	–	-44	ML			angular	
	3545+19	19R	–	–	-45	GM			angular	
	3601+18	17R	–	–	-46	GM			angular	November 1977.-Good.
	3603+18	18R	–	–	-47	GM			angular	
		18L	–	–	-48	ML			angular	
	3605+18	16R	–	–	-49	GM	–	–	angular	
Lateral PE38.9	31+50	left slope	14	16	35D-53	GM	2.64	3.6	subrounded	December 1960.-Fair. Cover
	32+50	left slope	12	10	-54	GM	–	–	to	slipped soon after water
	33+50	left slope	12	6	-55	GM	–	–	subangular	was turned into canal.
										There has been no
										subsequent cover
										slippage. Maintenance
										costs are very low.
Lateral W20	620+50	15L	–	6	35D-30	GM	2.69	0.025	–	December 1960.-Fair. Any
			18	–	-31	SM-ML			–	sloughing that occurred
										did not rupture lining.
										November 1977.-Fair.
	632+12	15R	–	8	-32	GM	2.69	2.2	subrounded	December 1960.-Fair. Right
			23	–	-33	SM			to angular	side slope has sloughed
										slightly.
										November 1977.-Fair.
	698+54	14R	–	10	-34	GM	–	–	subrounded	December 1960.-Poor. Side
	698+94	15R	–	14	-35	GM	2.75	0.1	to	slopes have sloughed
									subangular	badly on both sides.
										November 1977.-Fair.
										Cover stabilized.
	699+00	14L	13	14	-36	SM	–	–	subrounded	December 1960.-Poor.
	699+12	16R	–	12	-37	SM			to	Both side slopes sloughed
									subangular	badly.
										November 1977.-Fair.
										Cover stabilized.

Table A2.—*Field and laboratory data and observations*—Continued

Canal or lateral	Sample station (ft)	Offset (ft)	Cover thickness (in.) Fine layer	Cover thickness (in.) Coarse layer	Sample No.	Soil classification	Specific gravity (+No. 4)	Percent absorbtion (+No. 4)	Particle shape	Condition of cover
Lateral W22E	136+00	right slope	0 to 14	–	35D-50	SM			subrounded	December 1960.-Poor.
	136+40	right slope	0 to 14	–	-51	SM			to	Cover badly eroded and
	136+80	right slope	0 to 14	–	-52	SM			subangular	requires considerable
										amount of maintenance.
										November 1977.-Fair.
										Cover stabilized.
Angostura	25+24	left slope		8	35D-74	GP-GC	2.66	0.8	angular,	March 1961.-Excellent.
			8		-92	CL			some flat	
	29+24	right slope		10	-75	GP-GC	2.52	0.6	angular,	
			7		-93	ML			some flat	
	32+26	℄		10	-76	GP-GM	—		angular,	
			7		-94	SM	2.63	1.1	some flat	March 1961.-Good to
	305+50	left slope		6	-80	GW-GM	2.50	3.0		excellent. Frequent stock
			10		-98	SM				crossing.
	312+00	℄		8	-81	GP-GM	2.36	4.4		
			5		-99	SM				
	319+00	right slope		7	-82	GW-GM	2.48	3.1		
			7		-100	SW				
	570+00	left slope		6	-83	GP-GM	2.45	3.4	subrounded	March 1961.-Good to
			10		-101	SM			to subangu-	excellent. No failure, but
	590+00	right slope		10	-85	GC	2.52	2.6	lar, some	cover has slipped due
			4		-103	SC			flat	to consolidation.
	611+00	℄		6	-84	GP-GM	2.46	2.9		
			11		-102	SM				
	1084+00	2R		5	-86	GP-GM	2.55	2.3	subrounded	March 1961.-Slight slip-
			13		-104	SM			to subangu-	page; many cattle tracks
	1115+00	left slope		8	-87	GP-GM	2.56	2.0	lar, some	on bottom and slopes.
			6		-105	SM			flat	
				7	-88	GP-GM	2.59	1.9		
			5		-106	SM				
	1451+00	right slope		8	-89	GM	2.59	2.2	subrounded	March 1961.-Good.
			4		-107	CL			to subangu-	Consolidation crack at
	1477+00	right slope		7	-90	GC-SC	2.58	2.1	lar, some	top of slope. Severe
			4		-108	SC			flat	erosion below structure.
	1514+75	℄		7	35D-91	GC	2.58	2.0		
		℄	6		-109	SC				

Table A2.—*Field and laboratory data and observations*—Continued

Canal or lateral	Sample station (ft)	Offset (ft)	Cover thickness (in.) Fine layer	Coarse layer	Sample No.	Soil classification	Specific gravity (+No. 4)	Percent absorbtion (+No. 4)	Particle shape	Condition of cover
Wyoming Canal	1229+00	left beach line	—	—	-21	GM-GC	2.59	0.58	subrounded	1960.-Fair. Some movement of the rounded particles downslope.
			—	—	-22	SC-SM				April 1978.-Poor.
	1540+50	left beach line	—	1 ft (min) for 2 ft depth	-20	GC	2.65	0.87	subrounded	1960.-Beach belt material added in 1954 is in good condition.
	1541+80	left beach line	14	none	-19	SM-SC				1960.-Original cover too fine to resist wave action. Cover consolidated and moved down slopes as much as 3 ft in some sections.
	1865+75	20R	—	6	-15	—	—	—	subuangular to	1960.-Fair. Some fines eroding.
			7	—	-16	SM-SC			subrounded	April 1978.-Poor.
		18L	—	10	-17	GC-GM	2.64	1.53	subangular	
			11		-18	SM-SC				
Pilot Canal	306+80	left beach line	—	7	-23	GM-GC	2.51	2.19		1960.-Excellent, very stable.
			12	—	-24	CL				April 1978.-Good, slight bulging in slope at toe.
	100 ft upstream Hinkle Bridge	below left beach line	—	10	-25	GM-GC	2.50	2.68	subrounded to subangular	
			8	—	-26	SC				

Table A2.—*Field and laboratory data and observations*—Continued

Canal or lateral	Sample station (ft)	Offset (ft)	Cover thickness (in.)		Sample No.	Soil classification	Specific gravity (+No. 4)	Percent absorbtion (+No. 4)	Particle shape	Condition of cover
			Fine layer	Coarse layer						
Pavillion Main Lateral	471+00	2L	—	12	-13	GP	—	—		1960.-Excellent; resistant to erosion. March 1978.-Cover non-uniform and located mostly near toe of slope (Sta. 402 +00 to 412+00)
			4	—	-14	SM				
	492+00	1L	—	4	-11	GC	—	—	subangular	1960.-Poor. Granular cover eroding. April 1978.-Cover absent from top half of slopes. Remaining cover has small particles (Sta. 525+00 to 535+00).
			6	—	-12	CL				
	527+30	5R	—	1	-9	GP	2.70	2.76	subangular	1960.-Poor; granular cover badly eroded.
			1	—	-10	SM-SC				
	551+10	4L	—	11	-7	GM-GC	—	—	subangular	1960.-Fair; stabilized by sod
			5	—	-8	SM-SC				
Fort Laramie Canal	MP38.1	37L	—	4	-110	GC-CL	2.65	0.66	subrounded	1961.-Excellent. Sediment mixed with cover. Coarse particles on top and graded into soil cover. 1977.-Fair. Gravel eroded in places and replaced with Brule Clay riprap.
			12	—	-111	CL				
	MP86.1	21L	—	2	-112	CL	2.59	0.94	subrounded	1961.-Fair. Cover failed in spots, exposing 8 to 10 ft of the asphalt membrane. Most of the gravel cover was washed down to the toe of the slope. 1977.-Poor. Eroded cover had been replaced with Brule Clay riprap.
			14	—	-113	CL				
Helena Valley Canal	304+00		—	—		SC			angular to subrounded	October 1977.-Very good

Table A2.—*Field and laboratory data and observations*—Continued

Canal or lateral	Sample station (ft)	Offset (ft)	Cover thickness (in.)		Sample No.	Soil classification	Specific gravity (+No. 4)	Percent absorbtion (+No. 4)	Particle shape	Condition of cover
			Fine layer	Coarse layer						
[illegible]										
Hudson Canal	471+00	15R	—	13	-114	GP-GM	2.57	1.5	subangular to subrounded	1961.-Excellent. Distinct division between gravel cover and underlying earth lining
			40[a]	—	-115	SC-CL				
	475+89	15R	—	13	-116	GP-GM	2.55	1.8		
			40[a]	—	-117	SC-CL				
	484+00	15R	—	13	-118	GM	2.58	1.4		
			40[a]	—	-119	SC-CL				
PVC lining										
Wyoming Canal	479+00		9[b]	12[b]		SC-CL	—	—	subangular to subrounded	October 1977.-Very good
	482+50		9[b]	12[b]		GM	—	—		
	486+00		8[b]	12[b]			—	—		
Helena Valley Canal	968+30	—	—	15		GW	—	—		November 1977.-Good. Some damage from animal traffic.
	1330+60	—	—	14		GP	—	—		
East Bench Canal	906+15	13L	—	15		GP	—	—	subrounded to subangular	October 1977.-Excellent
	1353+60	15L	—	12		GP	—	—		
[illegible]										
Kennewick Main Canal	243+37	8L	—	2	3G-71	GM	2.74	—	subrounded	March 1978.-Good
	246+37	8R	—	2 to 4	-72	GM	2.73	—		
	249+37	℄	—	5 to 6	-73	GM	2.76	—		
Atrisco Feeder Canal	466+50	right of ℄	—	—	35D-122	GP	2.57	1.0		November 1977.-Cover in poor condition because of erosion. Some damage from maintenance operations. Also high tractive force.
		right of ℄	—	—	-123	SP				
	380+00	left of ℄	—	—	-124	GW	2.64	0.6		
		left of ℄	—	—	-125	SP				
	584+00	left of ℄	—	—	-120	GP	2.56	1.1		
		left of ℄	—	—	-121	SP				
Upper Meeker Canal	135+50	12L	—	6	-71	GM-GC	2.97	0.5	angular	1961.-Excellent. January 1978.-Good.
	155+60	10L	—	5	-72	GM-GC	3.12	0.7		
	167+93	12L	—	5	-73	GM	3.32	0.3		

[a] The earth lining was 40 in thick.

[b] These values are the average of measurements for the bottom and the slopes.

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