John Merriman 1541

GENERAL REPORT No. 22

EM-521 HYD-443

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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Commissioner's Office, Denver

Division of Engineering Laboratories
Hydraulic Laboratory Branch
Earth Laboratory Branch
Denver, Colorado
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General Report No. 22 EM- 521
HYD- 443

Compiled by: J. Merriman and P. "F." Enger
Checked by: E. J. Carlson
Reviewed by: C. W. Thomas and H. J. Gibbs
Submitted by: H. M. Martin and W. G. Holtz

Subject: Progress Report No. 2 of Canal Erosion and Tractive Force Study--Lower-cost Canal Lining Program

SUMMARY

To establish better design criteria for earth-lined and unlined canals, field and laboratory studies of erosion and tractive forces on fine, cohesive soil materials have been conducted under the Lower-cost Canal Lining programs of Fiscal Years 1956, 1957, and 1958. Forty-six test reaches have been selected and data and soil materials from them have been partially analyzed. The test reaches were selected from canals and laterals that had been in operation for a number of years. The maximum operating discharges vary from approximately 2 cfs to 3,000 cfs, Table 1. Three channel conditions were studied; these included: (1) canals where deposition was occuring, (2) stable canals, and (3) moderately scoured canals.

Two trips were made to each site. A field inspection party selected the sites and obtained soil samples when the canals were dry. The second trip was made to obtain hydraulic data and to make vane shear tests on the soils when the canals were operating near maximum discharge.

The soil samples were classified and tested to determine dry densities, unconfined compressive strengths, gradations, Atterberg limits, and compaction characteristics.

Hydraulic data were analyzed to determine velocity profiles, average velocities, discharge, hydraulic radius, average tractive forces, tractive force distributions, Manning's "n" values, suspended sediment concentrations, and water temperature.

A tractive force apparatus, Appendix I, was developed in the laboratories and tests were conducted on 8-inch undistrubed soil samples obtained from the field sites. Field data are analyzed by the same procedure described in General Report No. 21, Progress Report No. 1, March 1957.

Data which have been fully analyzed have been plotted. Preliminary plots have resulted in development of tentative allowable

tractive force curves which, with additional data and development, will be of value for design of channels through fine soils. Data representing mostly lean clays, which have been analyzed, is shown with tentative design curves in Figures 18, 19, 20 and 21. A comparison of field, laboratory and design data, which have been analyzed, is shown in Figures 22 and 23. Data from ~~other Regions~~ All Reaches have not been completely analyzed. Work is progressing and a final report presenting recommended design curves will be compiled.

The data used in this report is limited, and does not include all data which will eventually be available.

These statements do not engender confidence in this report since there is no way for the reader to judge for himself what the data show. Apparently only some of the data have been used. On what basis were the data reported herein chosen?

INTRODUCTION

The investigations reported here have been conducted under the Lower-cost Canal Lining program of FY56, FY57, and FY58. The program is intended to extend over a period of several years, and include several earth-lined and unlined canals with a variety of soils types which have been subjected to different climatic and hydraulic conditions. The purpose of this report is to present the analyses of data which are complete at this time and is not intended to present final conclusions. All methods of analysis are tentative and subject to modification as more data becomes available.

The purpose of the program is to establish better design criteria for earth-lined and unlined canals. To establish the behavior of soils under hydraulic forces, the physical properties of the soils are compared to the hydraulic forces and the degree of erosion. Soils and hydraulic data obtained in the field are correlated with soils and hydraulic data obtained in the laboratory.

Canal and lateral reaches for the study were selected by a field inspection party consisting of an engineer from the Earth Laboratory, an engineer from the Hydraulic Laboratory, and a regional representative. Reports of the selection of the test reaches were reviewed and approved in the Canals Branch. In 1955, nine sites were selected in each of Regions 7 and 2. During the summer of 1956, hydraulic data were obtained from the sites. The selection of these sites and the analysis of data obtained from them was reported in General Report No. 21, March 1957, (Progress Report of Canal Erosion and Tractive Force Study, Lower-cost Canal Lining Program).

Additional sites were selected and soil samples obtained from channels in Regions 1, 4, and 5 during the winter of 1956-57, Figures 1 through 7. Hydraulic data were obtained from the sites during the summer of 1957.

During 1957, a tractive force and erosion test apparatus ~~were~~ was developed in the laboratories, Appendix I. Soil samples obtained from the field sites are being tested in this apparatus.

DATA OBTAINED

First Trip to Sites

The limits of each test reach selected were set by placing hubs, guard stakes and flags at the upper end, center, and lower end of the reach.

Soil samples for laboratory testing were taken from each test reach. These samples included: sack samples, 3-inch drive samples, 8-inch undisturbed hand-cut samples, and sediment samples (in reaches where present).

The sack samples were tested to determine the gradation, plastic properties, and the compaction characteristics of the materials. The 3-inch drive samples were tested to obtain unconfined compression values. The 8-inch hand-cut samples were obtained for use as erosion test specimens.

Second Trip to Sites

The second trip was made during the time the canals and laterals were operating near peak discharge. Data recorded in all test sections included: canal water surface slopes; the canal cross section at the middle of the reach; velocity contours at the middle of the reach, including velocities near the canal boundary, where possible; the amount of sediment being carried in suspension; the temperature of the water; the shear resistance of the banks and bottom of the canal, in place and in the saturated condition; and photographs showing the condition of the test reaches.

To record the canal water surface slopes, an engineer's level and a water surface gage were used. A Type A current meter was used to measure the velocities at 0.2 and 0.8 of the depth for discharge measurements, and a pygmy current meter was used to measure velocities near the boundary. A DH-48 hand sampler was used to obtain the water sample for suspended sediment analysis, and a vane shear tester* was used to determine the in-place shear values of the soils.

Data obtained from the field

Records of the highest sustained flow each year for at least a 1-week period over the past few years were obtained from the project offices, and cross sections of the canal, in previous years, were obtained when available.

Summary of Test Sites

Short descriptions of each test reach as observed when data were obtained follow:

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*Design, assembly and use of a portable vane shear tester, Hydraulic Laboratory Report Hyd 434, U.S.B.R., June, 1957

Region 1

Minidoka Project, Lateral PL 10A-824S Stations 28+00 to 38+00. Slight erosion on the banks. Thin deposits on the bottom. The section appears stable, Figure 8.

Minidoka Project, Milner-Gooding Canal Stations 369+00 to 379+00. Moderate erosion, Figure 8.

Minidoka Project, PA-lateral (North Side Pumping Company). Moderate erosion during past years. Considerable erosion on banks. Considerable amounts of moss and weeds in the canal, Figure 8.

Yakima Project, P. L. No. 14 (lateral) Stations 16+55 to 22+30. Reach is stable, Heavy weed growth on banks. Moss growing in lateral, Figure 9.

Yakima Project, P. L. No. 13 (lateral) Stations 149+50 to 155+50. Reach is stable. Heavy weed growth on banks. Moss growing in lateral, Figure 9.

Yakima Project, Roza Main Canal, Mile 59.1. Slight erosion. Heavy weed growth on upper banks. Moss, and aquatic weeds growing in local areas, Figure 9.

Columbia Basin Project, WC lateral W 27 B Stations 21+90 to 27+90. Heavily eroded. Grass and weed growth on banks of lateral, Figure 10.

Columbia Basin Project, WC lateral W 26 A Stations 374+90 to 382+90. Stable. Weed growth on banks, Figure 10.

Columbia Basin Project, EL lateral 68T5 Stations 180+00 to 190+00. Stable. Lateral on verge of scouring, Figure 10.

Region 4

Eden Project, Means Canal, Stations 19+17 to 29+17. Deposition in bottom of canal and slight erosion on side slopes, Figure 11.

Eden Project, Means Canal, Stations 98+00 to 106+00. Deposition occurring, Figure 11. Deposition from material eroded from side slopes.

Eden Project, Means Canal, Stations 260+00 to 270+00. Stable. Slight erosion on side slopes, Figure 11.

Eden Project, Eden Canal, Stations 345+00 to 352+00. Unlined. Stable, Figure 12.

Eden Project, Eden Canal, Stations 352+00 to 359+65. Lined. Stable, Figure 12.

Eden Project, Eden Canal, Stations 459+95 to 469+95. Deposition on canal bottom. Slight erosion on side slopes, Figure 12. Bad erosion on sides - may be due to wind waves.

Eden Project, Eden Canal, Stations 640+00 to 650+00. Light deposition on bottom. Slight erosion on side slopes, Figure 13. Erosion near water surface due to wind waves.

Eden Project, Eden Canal, Stations 829+00 to 839+00. Deposition occurring on bottom. Slight erosion on side slopes, Figure 13.

Paonia Project, Fire Mountain Canal, Stations 414+00 to 424+00. Stable. Weeds and brush growing on canal banks. A few rocks to 6-inch diameter were in canal bottom near toe of slopes, Figure 14.

Paonia Project, Fire Mountain Canal, Stations 643+00 to 653+50. Slight erosion. Weeds and brush growing on canal bank, Figure 14. 6 inch ± dumped clay lining.

Paonia Project, Fire Mountain Canal, Stations 1338+00 to 1345+00. Stable, Figure 14.

Region 5

Tucumcari Project, Conchas Canal, Stations 3210+00 to 3220+00. Deposition occurring on bottom. Slight erosion on side slopes due to wind waves, Figure 15.

Tucumcari Project, Conchas Canal, Stations 3957+86 to 3967+86. Stable. Weeds, and grass growing on banks, Figure 15.

Tucumcari Project, Conchas Canal, Stations 4051+00 to 4061+00. Stable, Figure 15. Scoured about 0.8' before gravel blanket was put on canal.

Tucumcari Project, Hudson Canal, Stations ~~mile 5~~ 269+57 to 279+57. Bottom stable. Heavy erosion on the side slopes, probably due to wind waves, Figure 16.

Tucumcari Project, Hudson Lateral, Stations 1086+00 to 1096+00. Stable. Heavy weed growth on side slopes above water line, Figure 16.

W. C. Austin Project, West Canal, Stations 183+00 to 193+00. Slight deposition occurring, Figure 17.

W. C. Austin Project, Altus Canal, Stations 794+50 to 804+50. Stable. Heavy weed growth on banks, Figure 17.

W. C. Austin Project, Ozark Canal, Stations 311+00 to 321+00. Slight erosion occurring, Figure 17.

Laboratory Test Data (Tractive force apparatus)

To obtain more closely controlled data to correlate with field tests, a laboratory tractive force testing apparatus was developed, Appendix I. The apparatus is being used to test the undisturbed 8-inch soil samples. Results from the machine and field tests have been used to establish tentative allowable tractive force curves for fine cohesive soils.

As shown in Appendix I, the tractive force apparatus includes a 35-inch-diameter tank, a variable-speed air motor, a plastic lid, impeller blades, pressure gage, and pressure regulator. An 8-inch saturated sample is placed in the apparatus and covered with 12 inches of water. The impellers are started to rotate slowly, which forces water to flow across the soil sample, thereby creating tractive forces of low value. After subjecting the soil to these tractive forces for 10 minutes, the speed of rotation is increased and this increased tractive force is allowed to act on the soil for another 10 minutes. This procedure is followed until the soil begins to erode and the rpm at this time is recorded. The tractive force is related to the rpm by calibration curves. The total time of test is recorded, as is the time the machine operated at the speed which caused the erosion. Notes on the behavior of soil tested and sketches of the eroded area are included in the data. Photographs taken of the soil sample before and after the test permit comparison of all samples tested. Upon the completion of the erosion test, the soil density and vane-shear strength are determined. Samples of the soil are taken for mechanical analysis and Atterberg Limits tests.

ANALYSIS OF DATA

Field data are analyzed by the same procedure described in General Report No. 21.

Laboratory data have been analyzed by plotting the fundamental soil properties against the critical tractive force obtained in the laboratory. The fundamental soils properties used are: the plasticity index, the liquid limit, the soil density, and the gradation of the soil. The data are analyzed by the method of deviations as described by M. Ezekiel in "Methods of Correlation Analysis" second edition, Wiley, New York, 1941.

Analysis of a larger number of saturated soil samples previously tested in the Laboratory has indicated that cohesion generally increases as the plasticity index and liquid limit increases, and in a direction parallel to the A-line on the standard plot used in the Unified Soil Classification procedure. To make the plasticity index a near function of the liquid limit, the graph was divided into areas, (one area is shown on Figure 18) which cover the range of soils tested. As the plasticity index is the most important measure of cohesion, the plasticity indices from a given area on the plasticity index versus liquid limit graph, were plotted against the critical tractive forces obtained from laboratory tests, Figure 18. Only a small percent of the soil

samples obtained from the test reaches have been completely analyzed to date. Further testing will permit the inclusions of considerably more data which will make the final conclusions and analyses more definite.

Following the method of deviations, the deviation from the curve, which best fitted the points of the preceeding graph, was plotted against the density, Figure 20. The final curve was obtained by plotting the deviations from the density curve versus a function of the soil gradation, Figure 21. The final curve is thought to be a function of the energy needed to move the soil particles, and as the soil particles are small, it has a minor effect in the allowable tractive force. The procedure for obtaining the curves shown in Figures 19, 20, and 21 involves a series of trial plots to arrive at the best curves for the data used. The first step was to plot tractive forces against plasticity indices and a trial curve was drawn. Next the deviations from this trial curve are plotted against the second soil property (density) and a trial curve plotted for this property. The deviations from this curve ~~was~~ were plotted against the third soil property (gradation). The method was repeated by adjusting the first curve by considering the deviations shown in the last curve, and additional adjustments were made for the second and third curves. Figures 19, 20, and 21 were the result of sufficient number of trials so that the deviations for the points of each soil property were comparable to each other so that when using the curves the three soil properties were given comparable consideration.

A rather tricky method but I can't think of a better one offhand. Joe

In using the curves, the plasticity index and liquid limit of the soil, for which the allowable tractive force is desired, are first established. These data provide a guide to the correct series of curves which cover the proper area. From the first curve in the series, Figure 19, the plot of the allowable tractive force versus the plasticity index, a resulting allowable tractive force due primarily to the cohesive forces of the soil, is determined. Proceeding to the second curve, Figure 20, a correction in the allowable tractive force is obtained. This correction is due to the density at which the soil is placed and may be either plus or minus. The final curve, Figure 21, shows the tractive force to add due to the energy needed to move the particles. As the soil particles are small, the final curve results in relatively small corrections. For instance, if critical tractive force is desired for a soil having a plasticity index of 14, a liquid limit of 33, a dry density of 110 pcf, and a 70 percent size of 0.04 mm, the procedure would be:

(1) From Figure 18, determine the proper set of curves (included).

(2) In Figure 19, the tractive force corresponding to a P. I. of 14 is 0.053 pounds per square foot.

(3) In Figure 20, the correction shown for a dry density of 110 pcf is +0.007 pounds per square foot.

(4) In Figure 21, the correction for the 70 percent size is +0.002.

(5) Totaling the values of 2, 3, and 4 gives a critical tractive force of 0.062 pounds per square foot. For values higher than this critical value erosion of the soil would occur.

The curves may be used in different order when desired. As an example, it may be desired to know the allowable tractive force on a given soil at different densities, or the density at which a given soil must be placed to withstand a given tractive force.

Final curves will cover the tractive force range from approximately 0.001 to 0.1 pounds per square foot, and will be presented in equation and curve form. While small tractive force differences, as that between 0.05 and 0.1 pounds per square foot, appear to be relatively small, a few simple calculations will show they make a considerable difference in design conditions. For example, assume a canal is to be designed for the following conditions: Q = 200 cfs; Manning's n value = 0.02; side slopes = 2:1; and bottom width divided by depth = 5. If the canal were designed for a tractive force of 0.05 pounds per square foot, when a tractive force of 0.10 pounds per square foot could have been used, it would result in the use of lower velocities than permissable and in more than 20 percent over excavation. This is arrived at by the following method:

Using the equation $T = WRS$

where T = the tractive force in $^{\#}/ft^2$

R = Area / divided by the wetted perimeter = 0.738d

S = the slope from Manning's equation:

$$S = \frac{V^2(N^2)}{1.49^2 R^{4/3}}$$

$$\text{where } V = \frac{Q}{A} = \frac{Q}{7d^2}$$

substituting in the above equation and solving for d for each case, we arrive at the two cross sections needed. If freeboard is used the difference in quantities of materials you must over excavate per lineal foot becomes greater.

Figure 22 shows a comparison of tractive forces computed from the original design of the reaches tested, and tractive forces which should have been used, based on critical tractive forces from the tentative curves. The figure shows many reaches agree closely with the tentative design curves, while other reaches vary considerably from them. Figure 23, which shows the critical tractive force as found from the tentative curves plotted with the average maximum sustained tractive force as derived from the field data, indicates few reaches shown ever reached the average critical tractive force. This would indicate that, except for localized scour and changes toward a more stable shape, these reaches were stable, or slight deposition was occurring in them.

The present curves are tentative. Insufficient data have been analyzed to present final curves, and to locate the proper base. Laboratory and field data are being compared, and investigations regarding

the effect of the percent moisture in the sample when saturated are proceeding. Test data are being plotted, as it is obtained and analyzed and a final report covering the complete range of data will be compiled.

Limitations of Procedure

The concept for determining the critical tractive force as presented here is subject to limitations. The limitations are related to soil properties which have not been studied in this program. The first limitation is that the plasticity index has never been directly related to the cohesion. Although the relationship used is generally accepted, unusual particle shape or surface activity may result in variations from the graphs. The effects of varying specific gravities were not studied and values which are considerably different than 2.65 would result in erroneous critical tractive forces. Effects of suspended sediment are not shown in the graphs. Additional corrections will result from the study of suspended sediments. The studies were on saturated soils and should not be used for soils at lower moisture contents.

These curves are tentative only, and designs should not be based on them. Further corrections for tractive force fluctuations over the boundary will be presented in a final report.

Conclusions and Recommendations

Analysis of data to date has been promising and it has indicated correlations between erosion resistance and basic soil properties. Tentative curves are presented in this report. Additional curves covering the complete range of data studied in fine cohesive soils will be included in a final report. These curves will be of value in channel design.

It is recommended that tests be concluded on present samples and that two or more sections be selected from canals constructed in fat clays. This would extend our present data over a more complete range of soil types. Further studies of the effect of suspended sediments should be undertaken as should studies on the effect of percent moisture in the soil. Studies on clay-gravel mixtures would furnish a more complete range of design data.

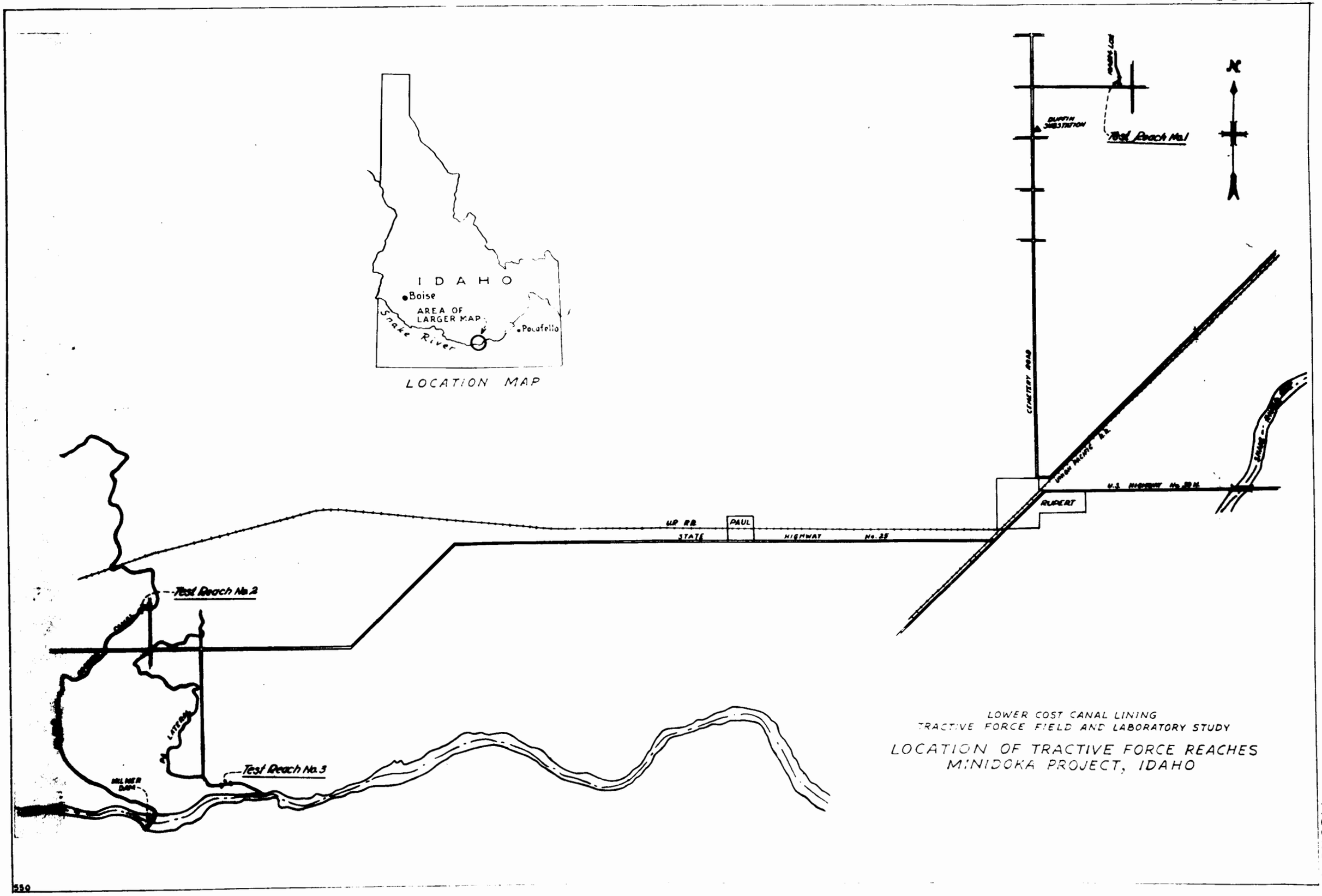
This may be productive because the P.I. alone is not the best measure of strength. All clays have the same strength at their liquid limits, but very different strengths at their plastic limits. The actual water content (or density) of a saturated clay affects the strength according to its position with respect to the liquid limit and the plastic limit. For example $B = \frac{W - P.L.}{LL - PL}$ should indicate strength similar to the relative density (P.I.) concept. J.W.H.

TABLE I

Region	Project	Canal or lateral	Stations	Test discharge cfs	Avg. tractive force when tested in field #/ft^2	Soil type
1	Minidoka	Lateral PL 10-A-824S	28+00 to 38+00	3.79	0.0162	ML
1	Minidoka	Milner-Gooding Canal	369+00 to 379+00	1540	0.0452	ML
1	Minidoka	PA Lateral (North Side Pumping Co.)		67.7	0.0252	ML
1	Yakima	PL No. 14 (Lateral)	16+55 to 22+30	18.6	0.0526	ML
1	Yakima	PL No. 13 (Lateral)	149+50 to 155+50	18.4	0.0336	SM
1	Yakima	Roza Main Canal	Mile 59.1	514	0.0225	ML
1	Columbia Basin	WC Lateral W27B	21+90 to 27+90	26.4	0.0633	ML
1	Columbia Basin	WC Lateral W26A	374+90 to 382+90	47.1	0.0196	ML
1	Columbia Basin	EL Lateral 68T5	180+00 to 190+00	5.81	0.0404	ML
4	Eden	Means	19+17 to 29+17	289	0.0370	CL
4	Eden	Means	98+00 to 106+00	253	0.0293	SP
4	Eden	Means	260+00 to 270+00	188	0.0209	SM
4	Eden	Eden	345+00 to 352+00	176	0.0209	SM
4	Eden	Eden	352+00 to 359+65	160	0.0265	SC - CL
4	Eden	Eden	459+95 to 469+95	176	0.0289	CL - SC
4	Eden	Eden	640+00 to 650+00	129	0.0215	CL - SC
4	Eden	Eden	829+00 to 839+00	125	0.0268	SM
4	Paonia	Fire Mountain	414+00 to 424+00	86.3	0.0834	CL
4	Paonia	Fire Mountain	643+00 to 653+50	79.8	0.0451	CL
4	Paonia	Fire Mountain	1338+00 to 1345+00	55.2	0.0936	CL
5	Tucumcari	Conchas	3210+00 to 3220+00	68.6	0.00754	CL
5	Tucumcari	Conchas	3957+86 to 3967+86	57.4	0.0133	CL
5	Tucumcari	Conchas	4051+00 to 4061+00	39.0	0.0213	CL - with Gravel Blanket
5	Tucumcari	Hudson	269+57 to 279+57	138	0.00695	CL
5	Tucumcari	Hudson	1086+00 to 1096+00	61.7	0.0108	SC - CL
5	W.C. Austin	West	183+00 to 193+00	78.5	0.0176	CL
5	W.C. Austin	Altus	794+50 to 804+50	160	0.0122	CL - CH
5	W.C. Austin	Ozark	311+00 to 321+00	41.2	0.0427	CL - CH

Data for Regions 2 and 7 are summarized in General Report No. 21.

LOWER-COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY
CANAL AND LATERAL REACHES
FOR FY - 1958



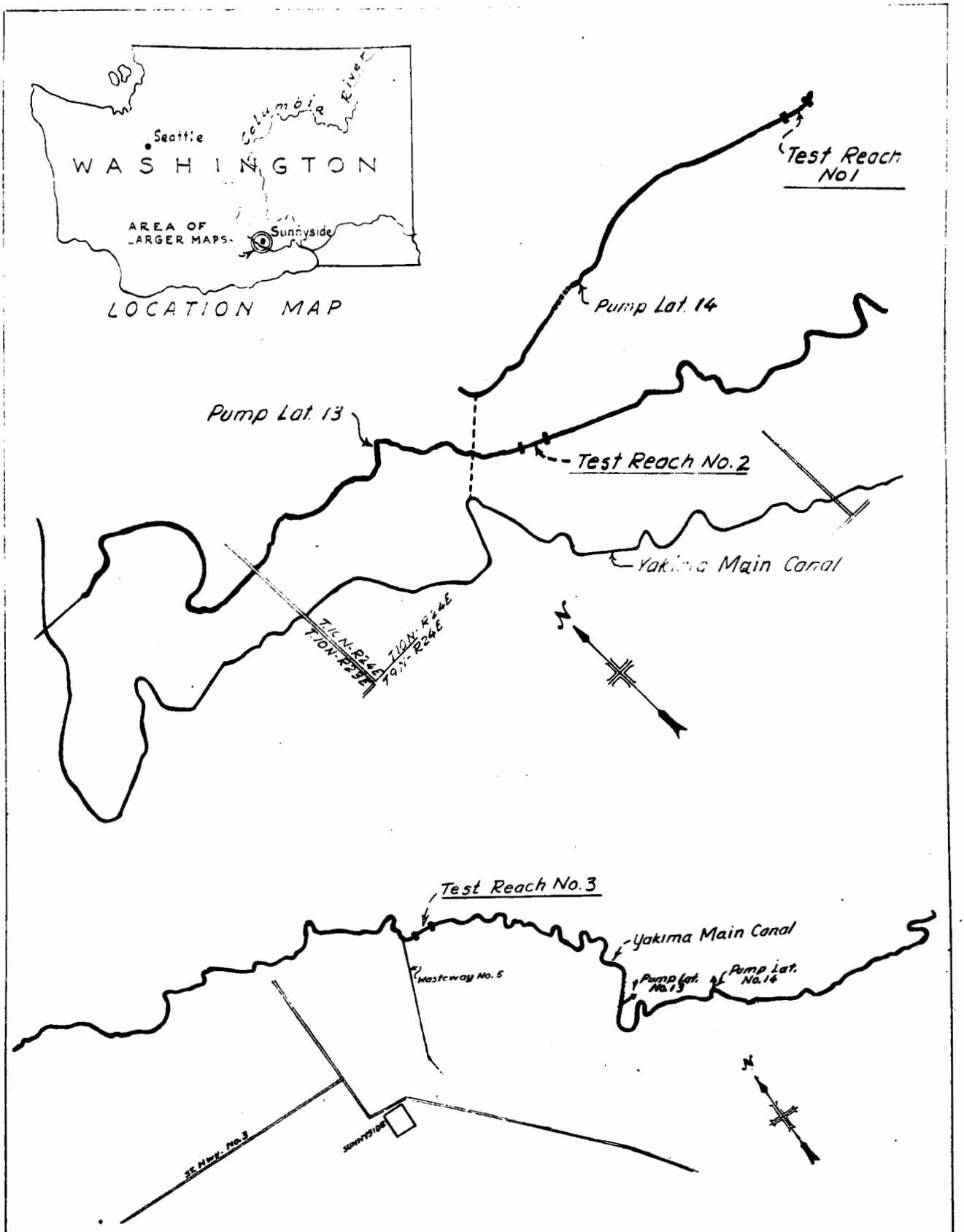
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

LOCATION OF TRACTIVE FORCE REACHES
MINIDOKA PROJECT, IDAHO

FIGURE 1

550

FIGURE 2

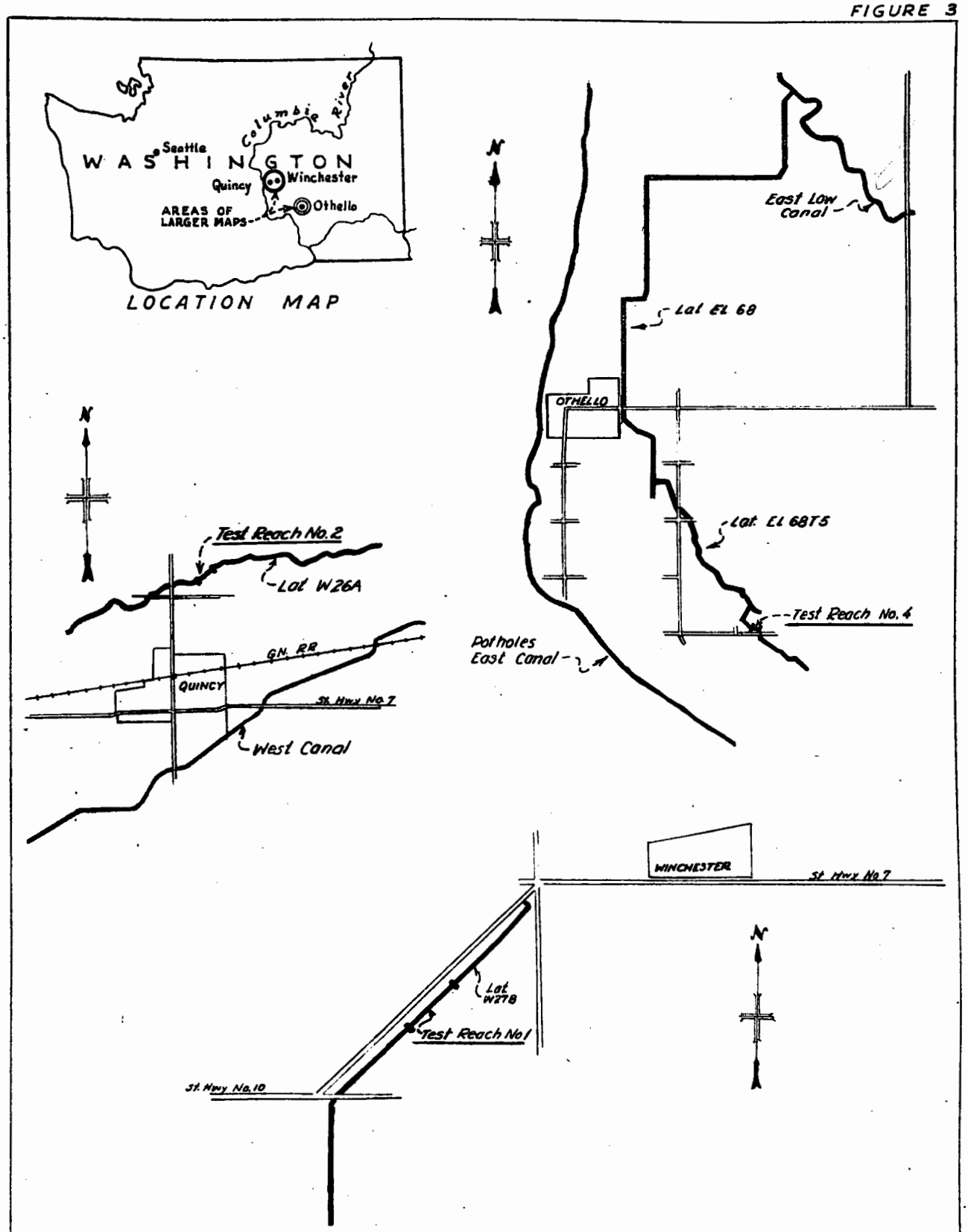


LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

LOCATION OF TRACTIVE FORCE REACHES
YAKIMA PROJECT, WASHINGTON

550

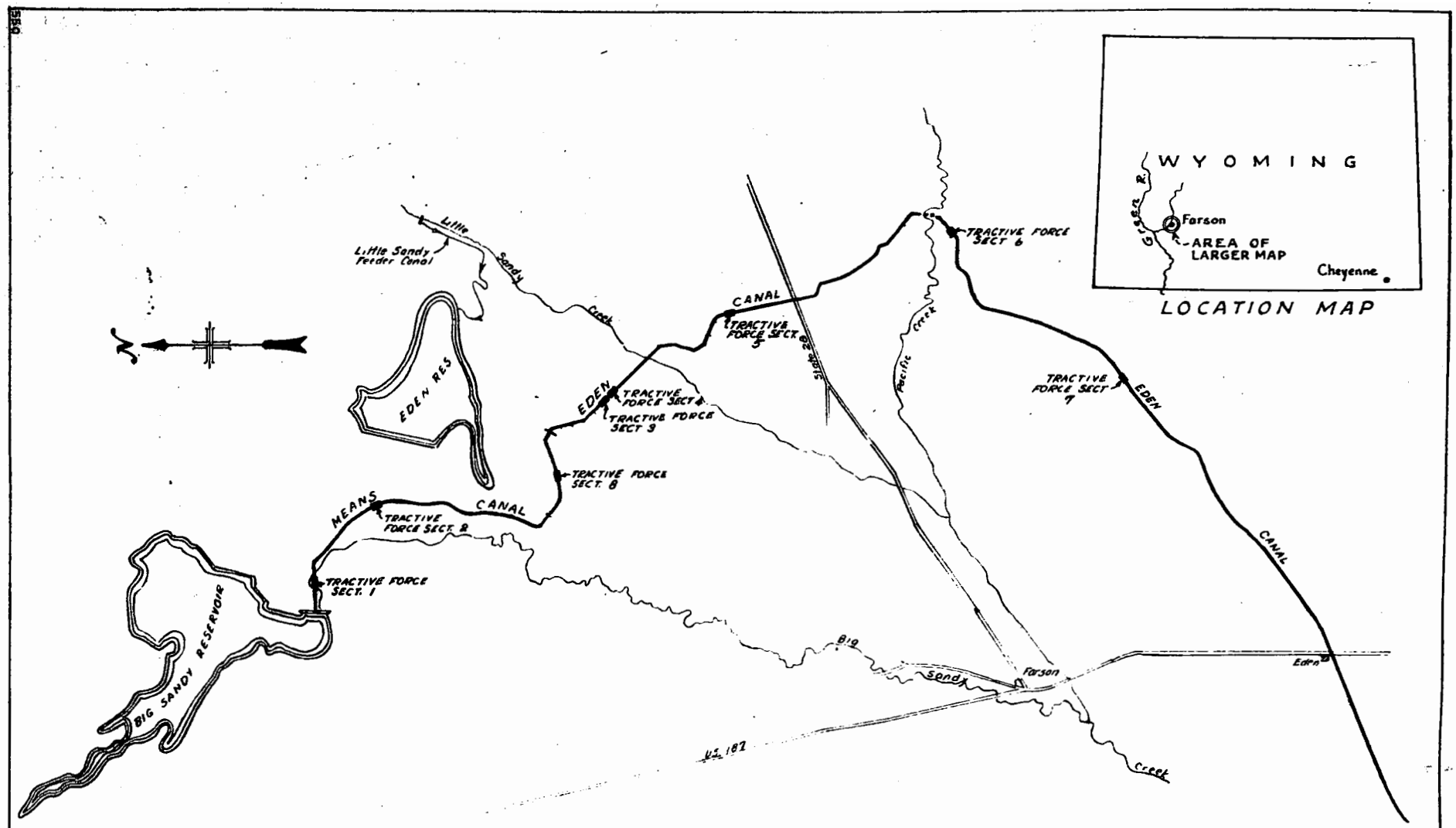
FIGURE 3



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

LOCATION OF TRACTIVE FORCE REACHES
COLUMBIA BASIN PROJECT, WASHINGTON

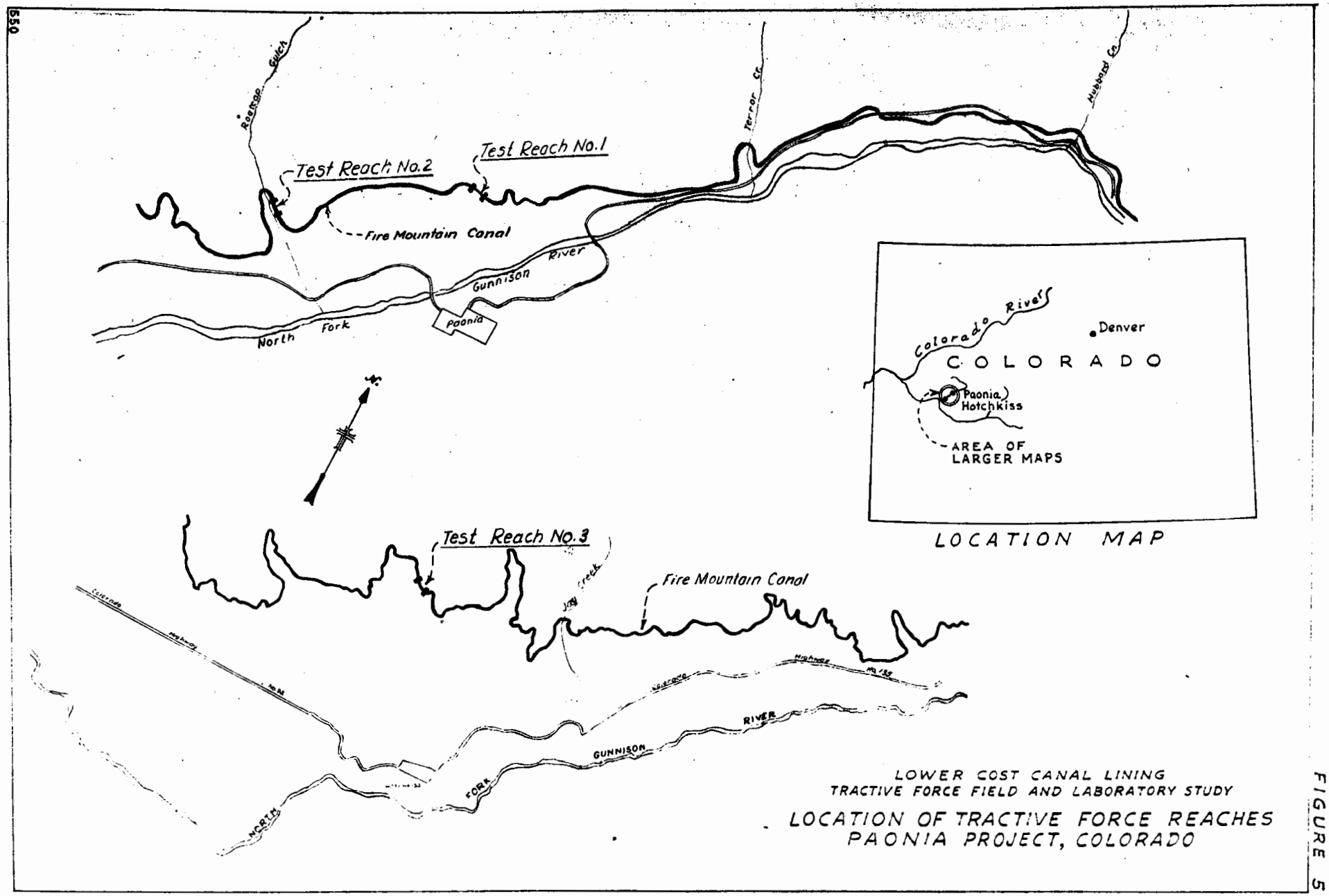
550



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

LOCATION OF TEST REACHES
EDEN PROJECT, WYOMING

FIGURE 4

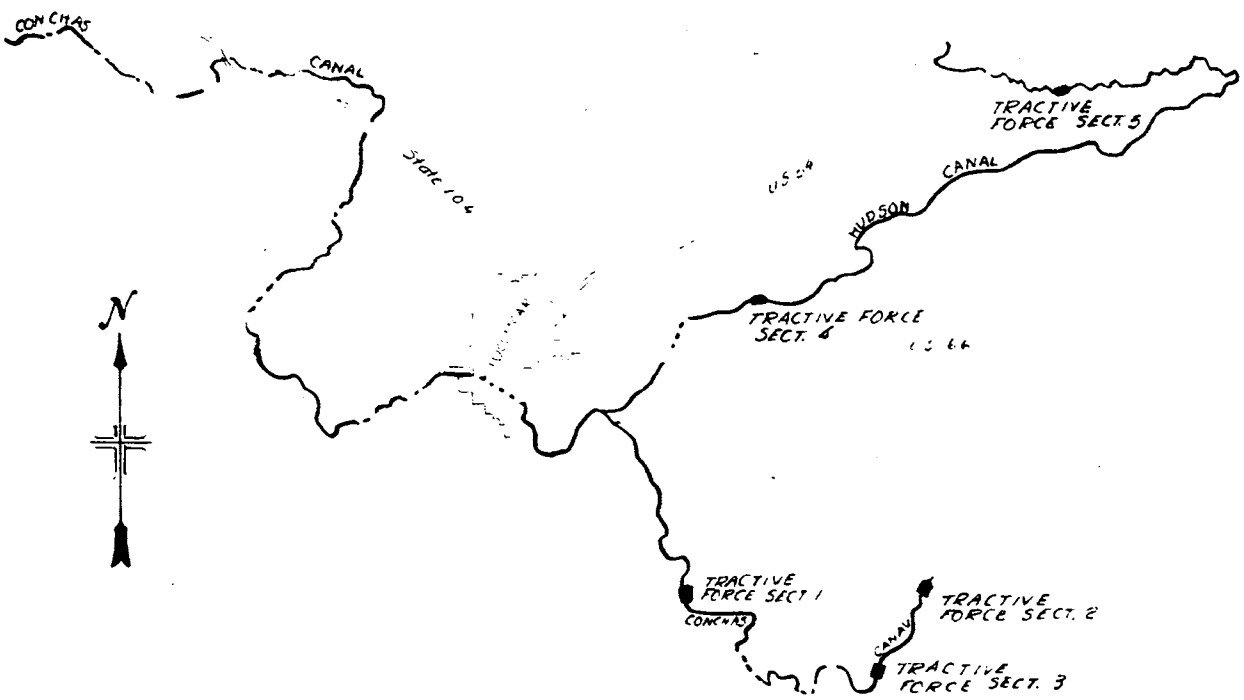


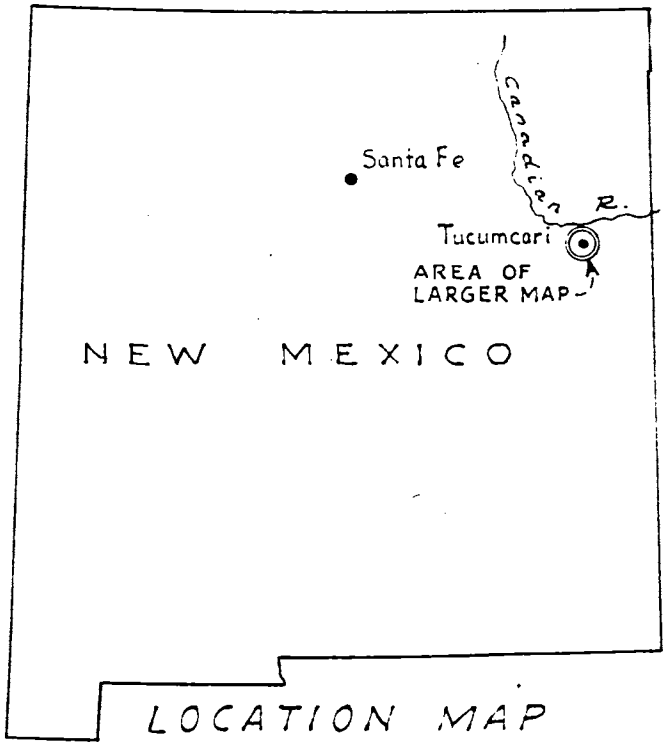
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

LOCATION OF TRACTIVE FORCE REACHES
PAONIA PROJECT, COLORADO

FIGURE 5

FIGURE 6



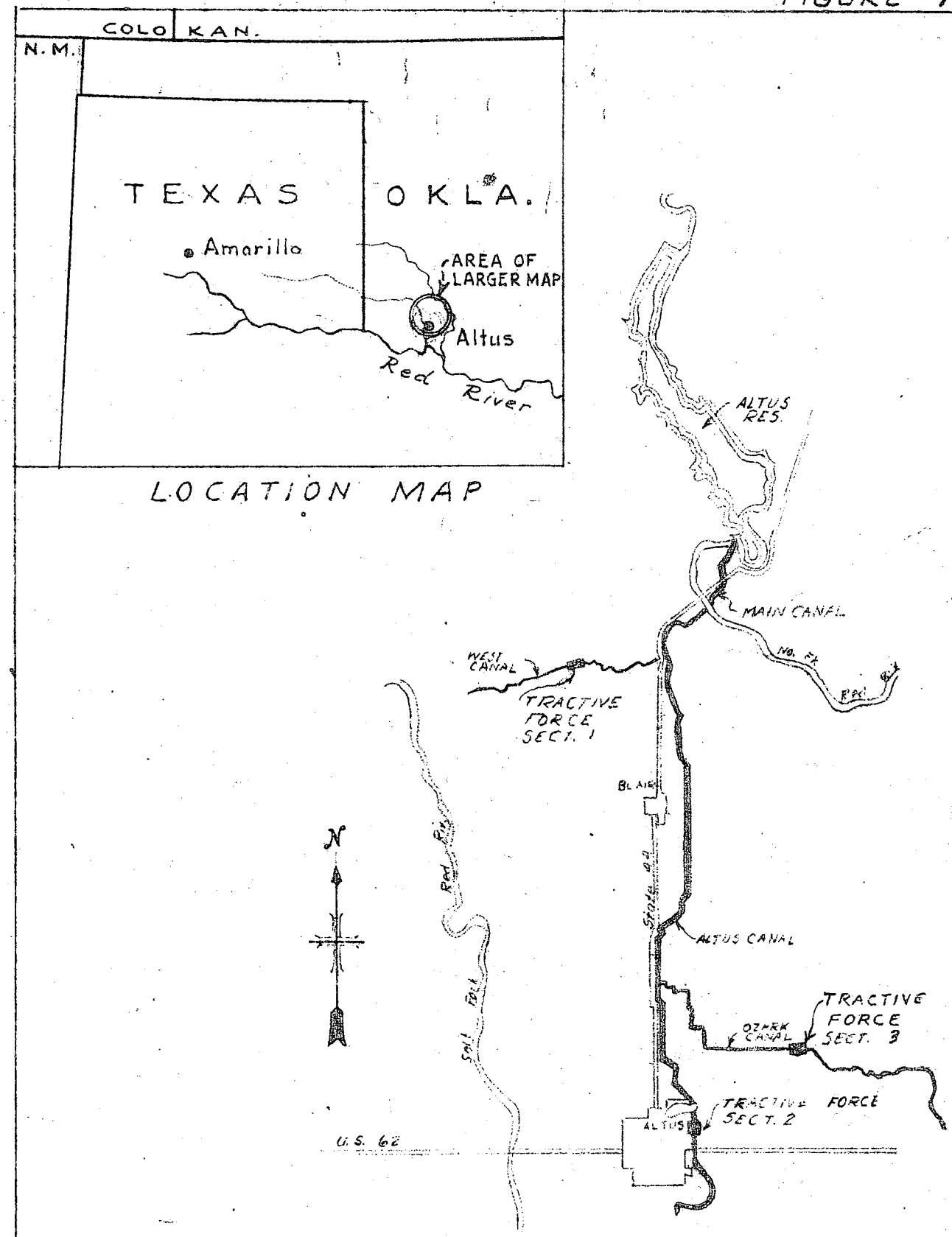


LOCATION MAP

LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

LOCATION OF TEST REACHES
TUCUMCARI PROJECT, NEW MEXICO

FIGURE 7



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

LOCATION OF TEST REACHES
W. C. AUSTIN PROJECT, OKLAHOMA

550

Reach Dry | Lateral PL 10A-824S | Discharge 3.79 cfs

Reach Dry | Millner-Gooding Canal | Discharge 1540 cfs

Reach Dry | P. A. Lateral | Discharge 67.7 cfs

Photographs of Reaches on Minidoka Project, Idaho

Reach Dry | Lateral PL No. 14 | Discharge 18.6 cfs

Reach Dry | Lateral PL No. 13 | Discharge 18.4 cfs

Reach Dry | Roza Main Canal | Discharge 514 cfs

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on Yakima Project, Washington

Reach Dry W.C. Lateral W27B Discharge 26.4 cfs

Reach Dry W.C. Lateral W26A Discharge 47 cfs

Reach Dry E.L. Lateral 68T5 Discharge 5.81 cfs

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on Columbia Basin Project, Washington

Reach Dry | Means Canal Sta's 19+17 to 29+17 | Discharge 289 cfs

Reach Dry | Means Canal Sta's 98+00 to 106+00 | Discharge 253 cfs

Reach Dry | Means Canal Sta's 260+00 to 270+00 | Discharge 188 cfs

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on Means Canal, Eden Project, Wyoming

Discharge 176 cfs

Reach Dry Eden Canal Sta's 345+00 to 352+00

Discharge 160 cfs

Reach Dry Eden Canal Sta's 352+00 to 359+65

Discharge 176 cfs

Reach Dry Eden Canal Sta's 459+95 to 469+95

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on Eden Canal Stations 345+00 to 469+95
Eden Project, Wyoming

Figure 13

Reach Dry

Discharge 130 cfs

Eden Canal Stations
640+00 to 650+00

Reach Dry

Discharge 125 cfs

Eden Canal Stations
829+00 to 839+00

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on Eden Canal Stations 640+00 to 839+00
Eden Project, Wyoming

Reach Dry | Fire Mountain Canal Sta's 414+00 to 424+00 | Discharge 86.3 cfs

Reach Dry | Fire Mountain Canal Sta's 643+00 to 653+50 | Discharge 80.0 cfs

Reach Dry | Fire Mountain Canal Sta's 1338+00 to 1345+00 | Discharge 55.2 cfs

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on Paonia Project, Colorado

Reach Dry | Conchas Canal Sta's 3210+00 to 3220+00 | Discharge 68.6 cfs

Reach Dry | Conchas Canal Sta's 3957+86 to 3967+86 | Discharge 57.4 cfs

Reach Dry | Conchas Canal Sta's 4051+00 to 3967+86 | Discharge 39.0 cfs

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on Conchas Canal
Tucumcari Project, New Mexico

Reach Dry

Hudson Canal Sta's
269+57 to 279+57

Discharge 138 cfs

Reach Dry

Discharge 61.7 cfs

Hudson Lateral Sta's
1086+00 to 1096+00

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on Hudson Canal and Lateral
Tucumcari Project, New Mexico

Figure 17

West Canal

Reach Dry

Discharge 78.5 cfs

Altus Canal

Reach Dry

Discharge 160 cfs

Ozark Canal

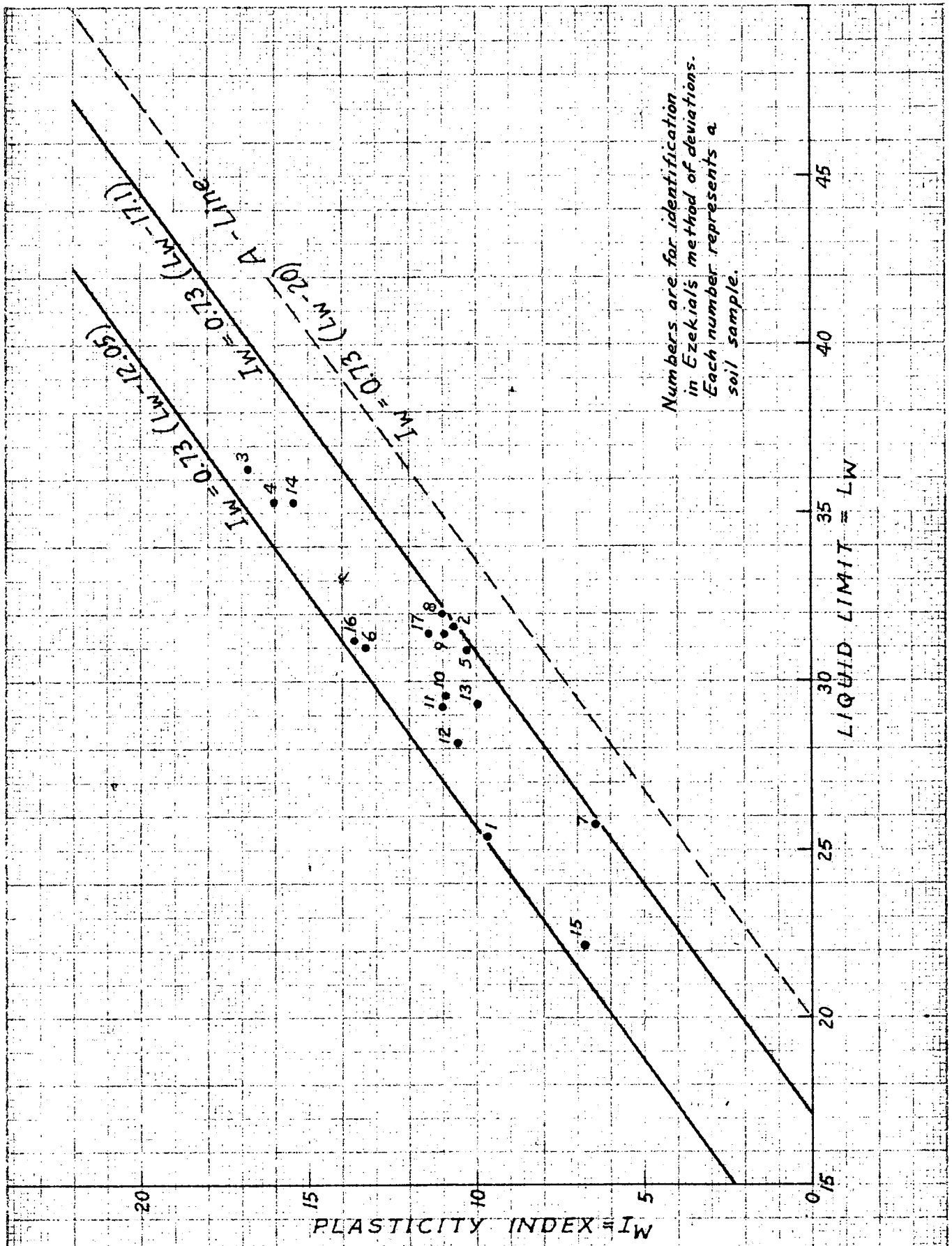
Reach Dry

Discharge 41.2 cfs

Lower-Cost Canal Lining
Tractive Force Field and Laboratory Study
Photographs of Reaches on W.C. Austin Project, Oklahoma

GPO 852039

FIGURE 18

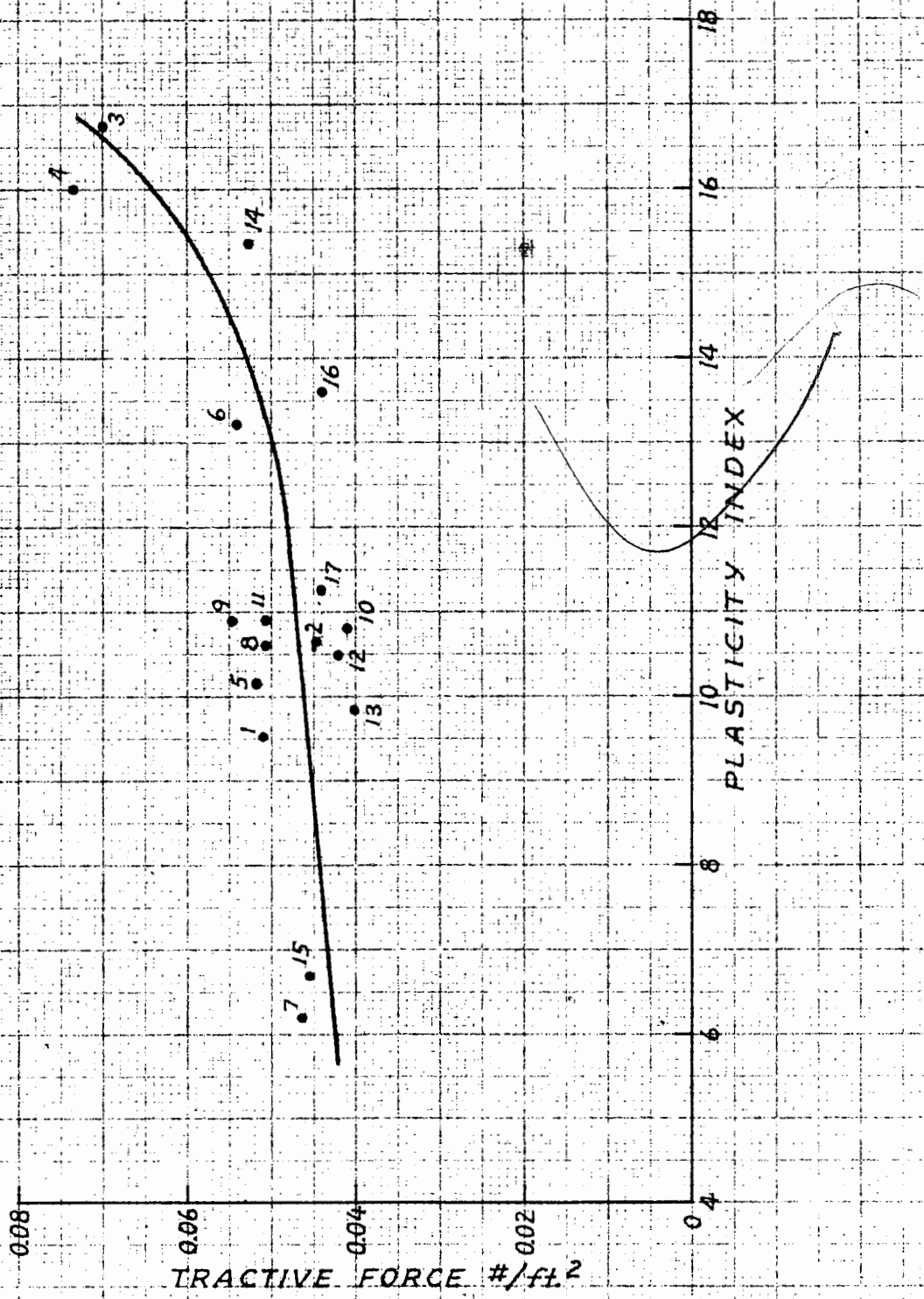


LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

AREA USED FOR PRELIMINARY ANALYSIS

55d

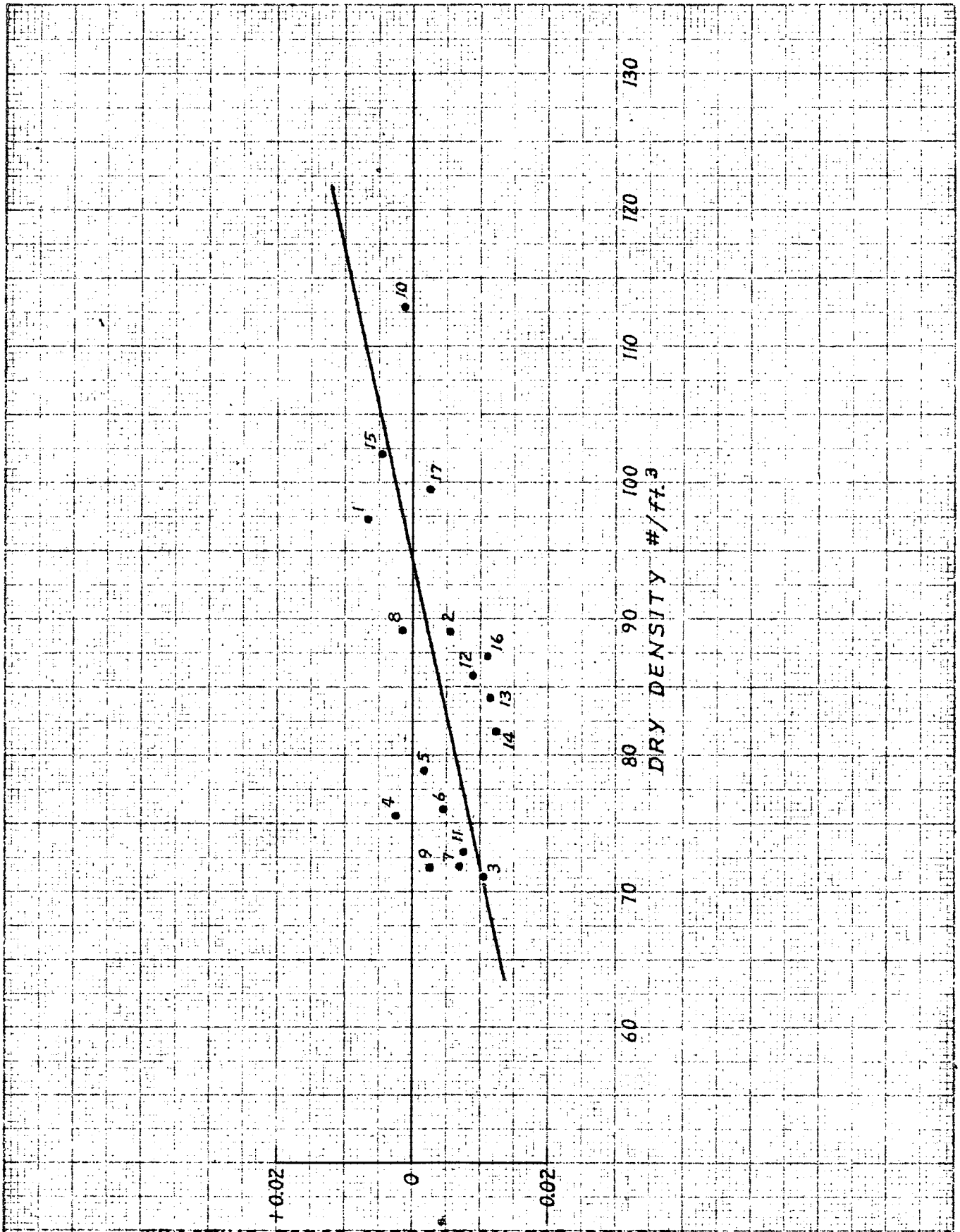
FIGURE 19



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

TRACTIVE FORCE VS. PLASTICITY INDEX

FIGURE 20

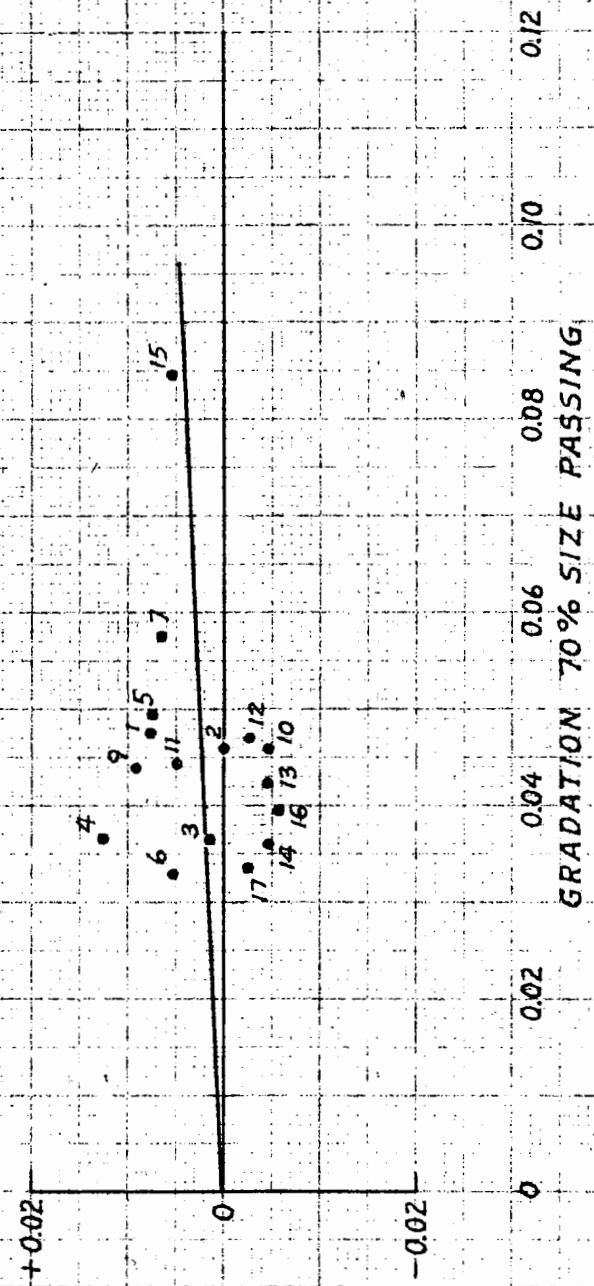


LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

CORRECTION NECESSARY FOR DENSITY

550

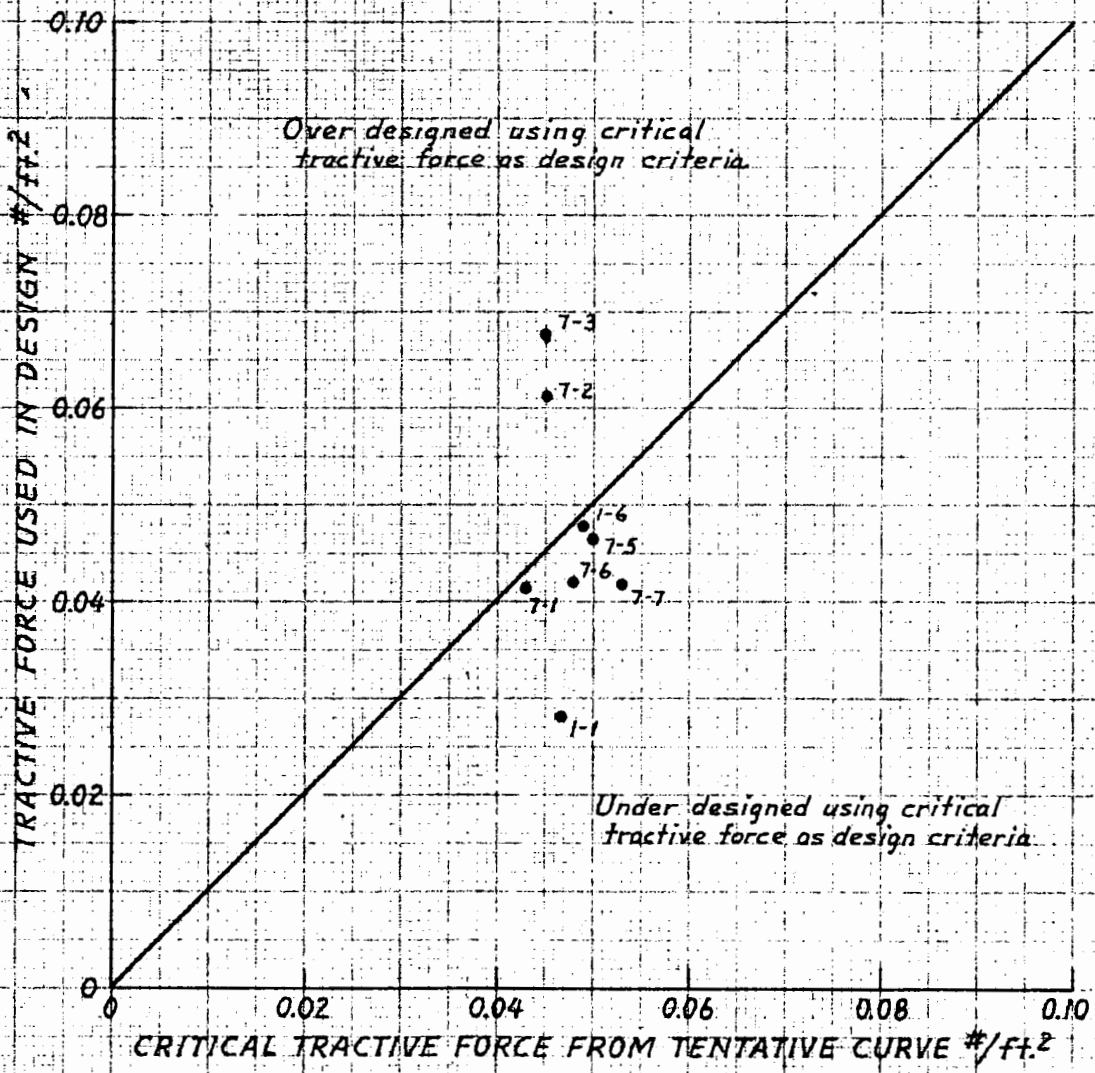
FIGURE 21



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

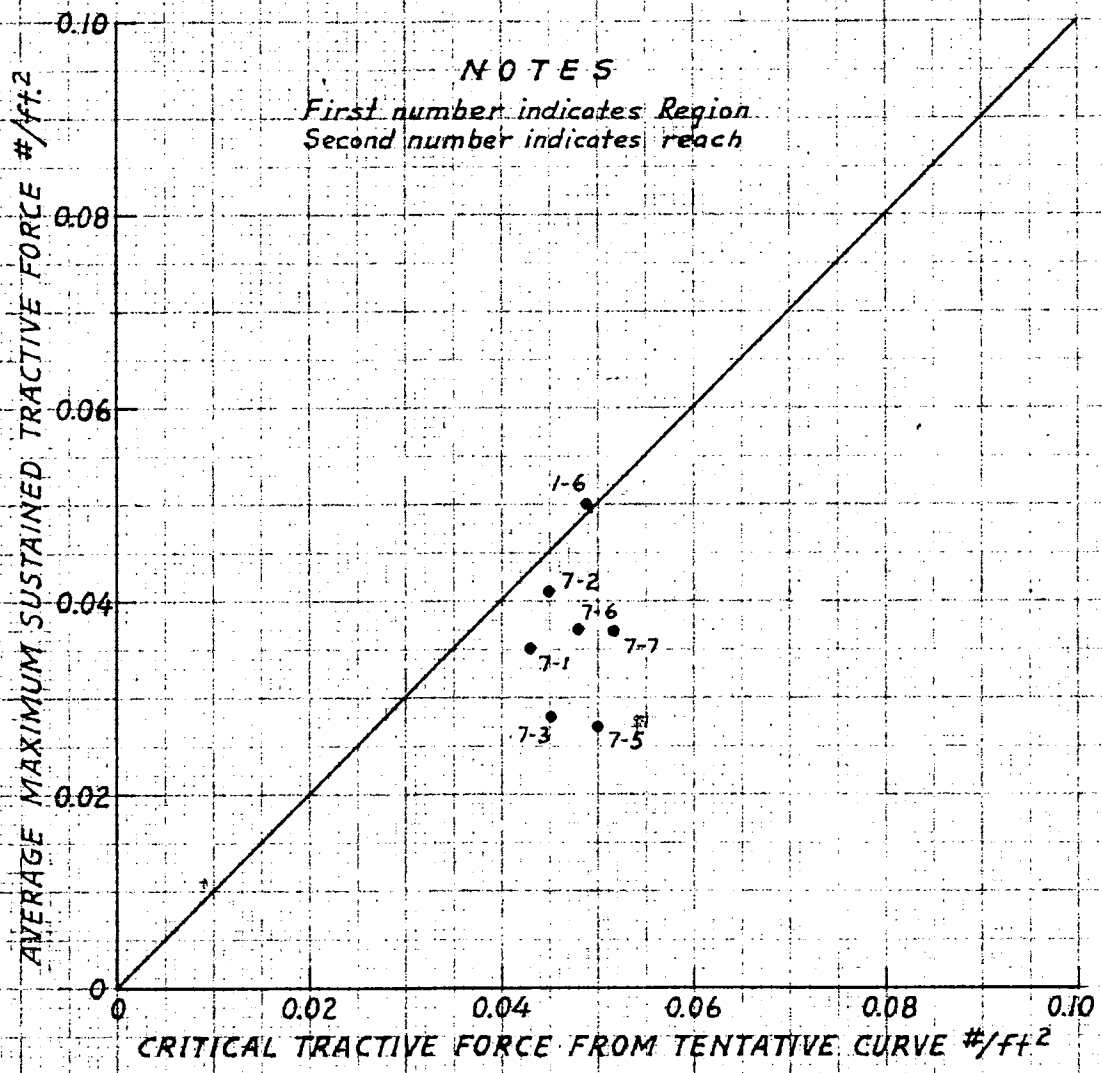
CORRECTION NECESSARY FOR PARTICLE SIZE

FIGURE 22



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

DESIGN TRACTIVE FORCES AND TRACTIVE FORCES SHOWN BY TENTATIVE CURVES COMPARED



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

AVERAGE MAXIMUM SUSTAINED TRACTIVE FORCES AND CRITICAL TRACTIVE FORCES FROM TENTATIVE CURVES COMPARED

APPENDIX I

Tentative Procedure for Performing Tractive-Force Test on Cohesive Materials

INTRODUCTION

Tractive force or boundary shear may be defined as the force per unit area exerted by a fluid flowing past a stationary boundary. The force, acting on the surface of the boundary in the mean direction of flow, is dependent on flow conditions and the roughness characteristics of the boundary material. In an earth canal, tractive force is the primary agent tending to cause erosion.

For every earth material there is a critical tractive force or range of tractive forces above which erosion will occur, and below which the material will remain essentially stable.

The magnitude of this critical tractive force is dependent upon the properties of the soil, including cohesion, the size and shape of the soil particles, and the range and distribution of the particle sizes. The determination of critical tractive forces has, in the past, depended to a considerable extent on the judgement of the observer. In some cases, initial movement of individual grains has been the criterion, whereas in other cases, the criterion has been the beginning of general bed movement. In calibrating the tractive-force tank, the experimenters tended toward the latter criterion.

During the last two decades, numerous experiments have established for non-cohesive materials a fairly consistent relationship between critical tractive force and the mean diameter of particles composing the bed material. The majority of these experiments have been performed with uniform sand and gravels. However, no satisfactory relationship between tractive force and soil properties has been obtained for cohesive materials, although it has been generally conceded that cohesive soils are generally more resistant to erosion than are non-cohesive soils.

Purpose of Tests

The initial reason for testing soil samples in this apparatus is to obtain sufficient data to permit the development of canal design criteria based on tractive forces. Theoretically, such a design will result in more stable canals than those designed in accordance with the criteria presently used.

In the future, the test will be used as a standard test to determine the erosion resistance of soils, especially those soils proposed for canal linings and embankments.

Samples of soils which have been stabilized with chemical or other additives may also be subjected to erosion tests, thus, determining the benefit obtained by use of the stabilizing agent.

A progressive study relating to the soil properties (Atterberg Limits etc.) with the resistance to tractive forces is also a use to which this test can be applied.

Equipment

The tractive-force test tank including the tank, motor, plastic lid, impeller blades, pressure gage, and pressure regulator is shown as a unit in Figure 1. Pertinent data for each of the components is listed below:

1. Tank

   a. Diameter = 35 inches
   b. Total height = 24 inches
   c. Height from sample surface to tank top = 13-3/8 inches
   d. Height from sample surface to bottom of plastic lid = 9 inches
   e. Depth of water used = 12 inches

2. Three-bladed impeller

   a. Blade width = 3 inches
   b. Blade length = 7 inches

3. Sample test well

   a. Width = 12 inches
   b. Length = 15 inches
   c. Depth = 10 inches

4. Sample container is a standard 8-inch diameter plastic percolation test cylinder

5. Plastic lid is made of 3/8-inch clear plastic

6. Pressure gage reads from 0 to 100 psi

7. Pressure regulator variable from 0 to 70 psi

8. The power source is a converted air powered drill

Additional equipment required for this test includes two stop watches, one for accurate determination of the rotational velocity and the other for determining the time required for testing at each velocity increment. A thermometer for reading the water temperature, and various tools such as trowels, screwdrivers, etc. also are needed.

PROCEDURE

The procedures recommended for performing the tractive-force test on samples of cohesive soil are based primarily on experience gained by performing the test on granular materials during the course of

calibrating the tractive-force tank. It is known that the process and pattern of erosion occurring in cohesive soils differs markedly from that occurring in granular soils. Three trial runs with cohesive soils were made, however, these constitute insufficient experience for anticipating all the operational problems which may arise in connection with performing the test on cohesive materials. Consequently, the recommended procedures should be considered as tentative, and subject to revision pending the gaining of additional experience. The foregoing reservation applies particularly to some of the quantitative testing criteria.

The recommended procedure together with a sample data sheet are presented in the following pages.

Preparation for Test

Preparation of the sample involves saturation of the material and smoothing the surface prior to beginning the test. Approximately 1 week total immersion should be sufficient to saturate most samples. After removing the sample from the immersion tank, the surface should be smoothed off so as to be flush with the flange of the 8-inch percolation settlement cylinder. A trowel, putty knife, straight edge or other suitable instrument may be used for this purpose. The cylinder may now be placed in the sample well of the tractive-force tank. Care should be taken to fill cracks such as those between the cylinder flange and the sample well cover with plasticine so as to obtain a smooth transition between the floor of the tank and the surface of the sample.

The tank may now be filled with water to the level indicated by the black line on the wall of the tank. At this point, the water temperature should be taken.

Performing the Test

The ultimate aim of the test is to determine in terms of the rotational velocity of the impeller blade, the tractive force required to cause erosion of the sample. The test procedure consists essentially of approaching the critical rotational velocity in systematic steps between which the velocity is held constant over specified intervals of time. Rotational velocities are expressed in rpm, and are determined by counting the number of revolutions of the impeller blade occurring in a period of from 30 to 60 seconds as indicated by a stopwatch. A second stopwatch is used to provide a continuous time record of the test. The rotational velocity may be set fairly accurately to a predetermined magnitude by means of the pressure-regulator valve and pressure gage in accordance with the calibration curve shown in Figure 2. Velocities should always be varied by turning the pressure-regulator valve. The line valve is left wide open for the duration of the test.

The way in which the critical rotational velocity is approached constitutes the important part of the test. Increasing the velocity by large steps precludes the possibility of accurately determining the critical rotational velocity. On the other hand, if the velocity increments are too small, excessive time is consumed in performing the test. It is

recommended that velocity increments be varied from a maximum of 5 to a minimum of 1 rpm, the increments becoming progressively smaller as the critical condition is approached. Between steps, the velocity should be increased gradually, because a sudden acceleration may prematurely precipitate an unstable condition. Upon attainment, the desired rotational velocity should be held constant for a period of from 5 to 10 minutes before increasing the velocity another step.

The three trial runs with cohesive soils indicated that upon reaching the critical rotational velocity, erosion tended to begin quite suddenly and to progress rapidly. The trial samples included a sandy clay, a lean clay, and a plastic clay. There should be little question as to whether or not the critical condition has been reached.

When it becomes apparent that the critical rotational velocity has been attained or surpassed, the test should be stopped. The valve should be closed, the tank drained, and the lid removed. The distance from the outer edge of the sample to the center of the eroded area should be measured in inches and recorded as shown on the sample data sheet.

Summary of Procedure

In performing a laboratory test, it is easy to overlook details or to omit steps which may have a significant bearing on the outcome of the test. Errors or omissions can sometimes be avoided by frequent reference to a check list which summarizes the test procedure. It is recommended that the following outline be used as such a check list.

A. Preparations for test

1. Preparation of sample

   a. Saturate (2 to 3 days immersion)
   b. Smooth surface of sample
   c. Place cylinder in sample well
   d. Insure smooth transition between tank floor and surface of sample by filling cracks with plasticine

2. Fill tank to indicated level

3. Take temperature of water

B. Performing the test

1. Open line valve

2. Start Stopwatch No. 2

3. Open pressure regulator valve gradually until gage registers 3 psi (about 10 rpm)

   a. Check rpm with Stopwatch No. 1
   b. Observe sample 5 to 10 minutes, writing down pertinent observations

c. Record cumulative time registered on Stopwatch No. 2, and increase velocity gradually to next step

4. Repeat Step 3, each time increasing the velocity by increments varying from 5 down to 1 rpm, as many times as necessary until critical condition is reached and ~~con-~~ continued erosion begins

5. Record time on Stopwatch No. 2, shut off valve, drain tank and remove lid

6. Measure x distance (from outer edge of sample to center of eroded area)

SAMPLE DATA SHEET
Material Description--CL Mod. Plasticity
Laboratory Sample No.
Temperature, 16.5° C.

Vr rps	Vr rpm	P psi	Cum. time min.	Observations
10/56.0 10/55.4	10.7	3.0	5	No perceptible movement.
10/41.3 10/41.0	14.5 14.6	4.0	10	Not much change. A few loose sand particles leaving at first. Surface of sample still stable.
10/31.1 10/32.0	19.3 18.8	6.0	18	No significant change. A few loose sand particles left at first
20/52.2 20/51.9	23.0 23.1	8.0	26	No perceptible movement. All loose sand particles seem to have left
20/48.8 20/48.8	24.6 24.6	9.0	36	No perceptible change
20/45.8 20/46.0	26.2 26.1	10.0	46	No perceptible change
20/43.8 20/43.6	27.4 27.5	10.8	52	Surface of sample appeared stable at first. Small chunk broke loose after 3 minutes. Chunks continued to leave. Water becoming cloudy. Sizeable cavity formed after 5 minutes at this speed. Past critical. Test stopped after 6 minutes. Critical Vr = 27 rpm

ANALYSIS OF RESULTS

Having determined by experiment the critical rotational velocity and the distance from the outer edge of the sample at which erosion occurred, the purpose of the analysis is to determine the critical tractive force.

Theory and experimental results indicate that for the conditions anticipated in the tractive force tank, the tractive force should be proportional to the square of the velocity of flow near the floor of the tank. Determination of flow velocities near the floor of the tank by means of a bank of Pitot tubes showed that the flow velocity is directly proportional to the rotational velocity of the impeller blade at any point along a line extending radially outward from the center of the tank. Consequently, it becomes apparent that at any point of the sample, the tractive force should be directly proportional to the square of the rotational velocity of the blade. The proportionality factor is dependent on the radial distance from the center of the tank, which for the purpose of the test may be more conveniently expressed as the distance from the outer edge of the sample. The relationship between tractive force and the rotational velocity of the impeller blade is expressed by the formula:

Where $To = C\,Vr^2$

To = Tractive force in lb/ft^2

Vr = Rotational velocity of impeller blade in rpm

C = Proportionality factor dependent upon x - distance, which is measured from outer edge of sample along a line projected toward the center of the tank

The variation of C with x is shown on Figure 3.

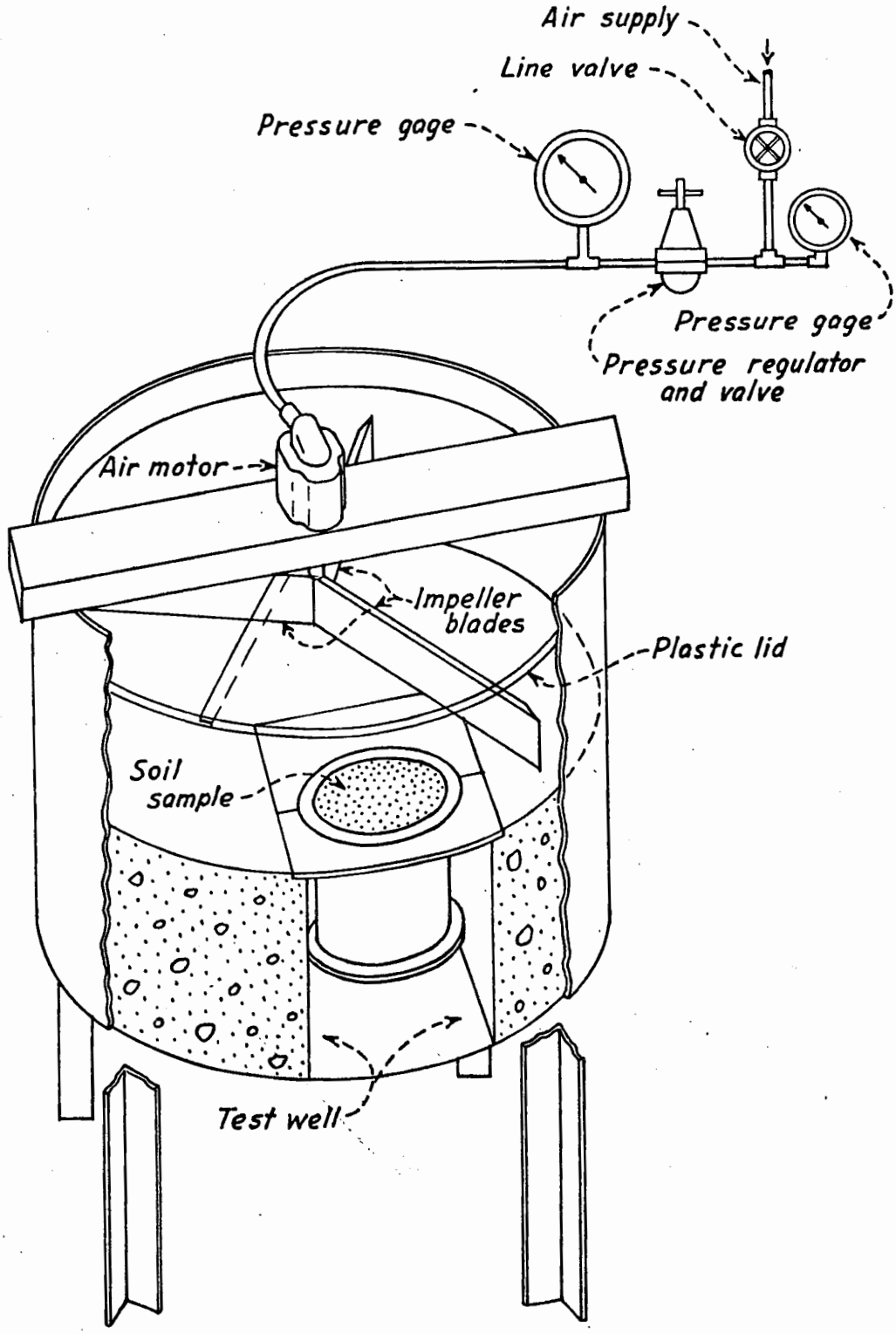
Upon completion of a tractive force test the critical rotational velocity and the x - distance are known. The critical tractive force may now be determined with the aid of Figure 3. Suppose for example, that the critical rotational velocity for a particular sample was 34 rpm, and that the distance from the outer edge of the cylinder to the center of the eroded area measured 3 inches. According to the foregoing definitions, $Vr = 34$ rpm and $x = 3$ inches. The value of C in Figure 3 corresponding to $x = 3$ inches is 0.00013. Using Eq. 1, the critical tractive force would then be:

$$To = C\,Vr^2$$
$$= 0.00013 \times (34)^2 = 0.150\ lb/ft^2$$

Figure 4 may be used for a direct estimation of the critical tractive force. In Figure 4, the sample is divided into four zones which correspond closely to 2-inch increments of the x - distance. Repeating the above example with $Vr = 34$ rpm and $x = 3$ inches, it is seen that the center of the eroded area lies in the center of Zone 2. Entering Figure 4 with $Vr = 34$ rpm, the tractive force at the center of Zone 2 is seen to be 0.15 lb/ft^2 which agrees with the method based on Figure 3. Considering the assumptions made in evaluating the calibration data, it would seem that the critical tractive force can be estimated with sufficient accuracy from Figure 4.

Interior - Reclamation - Denver, Colo.

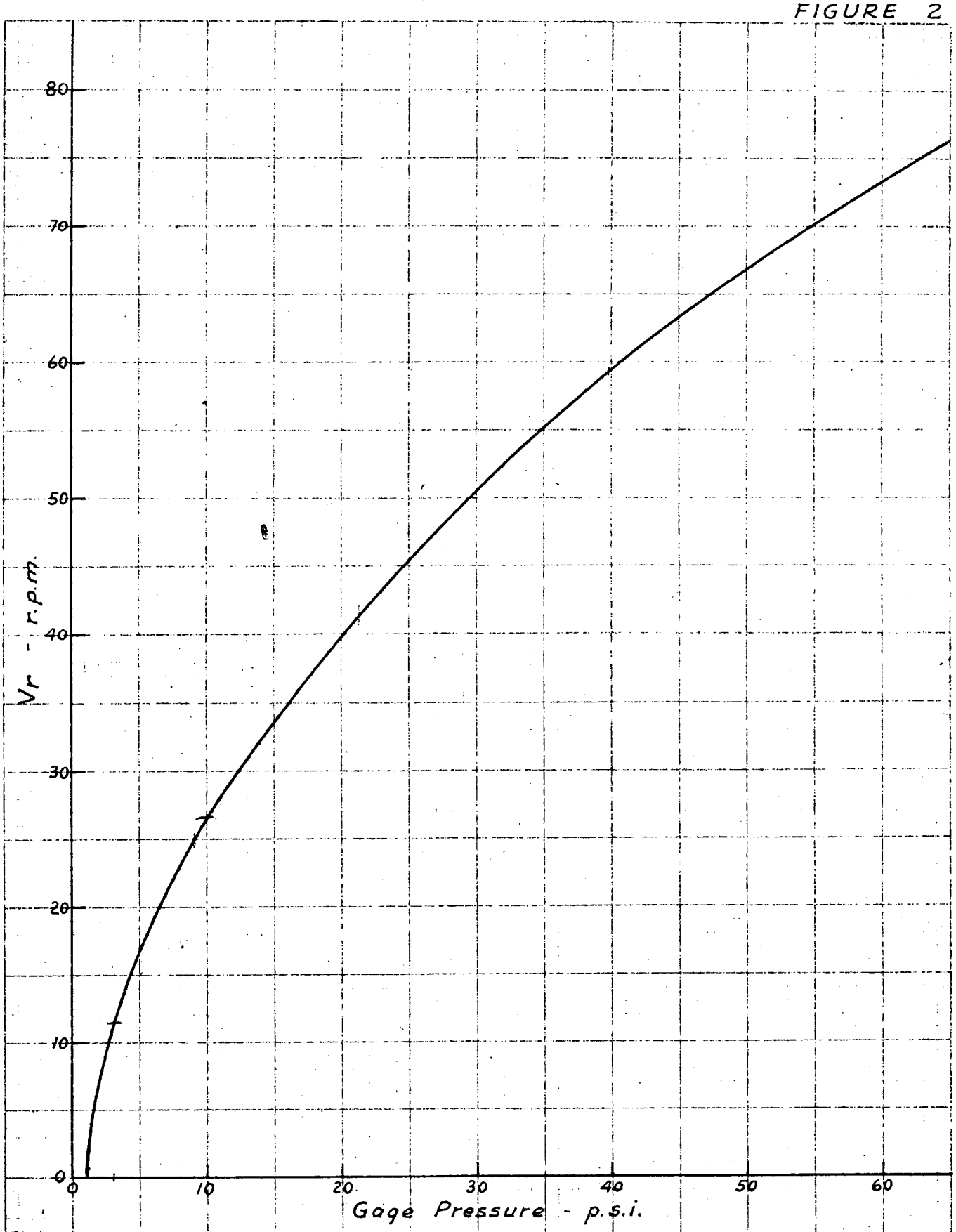
FIGURE 1



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

TRACTIVE FORCE TEST TANK

FIGURE 2



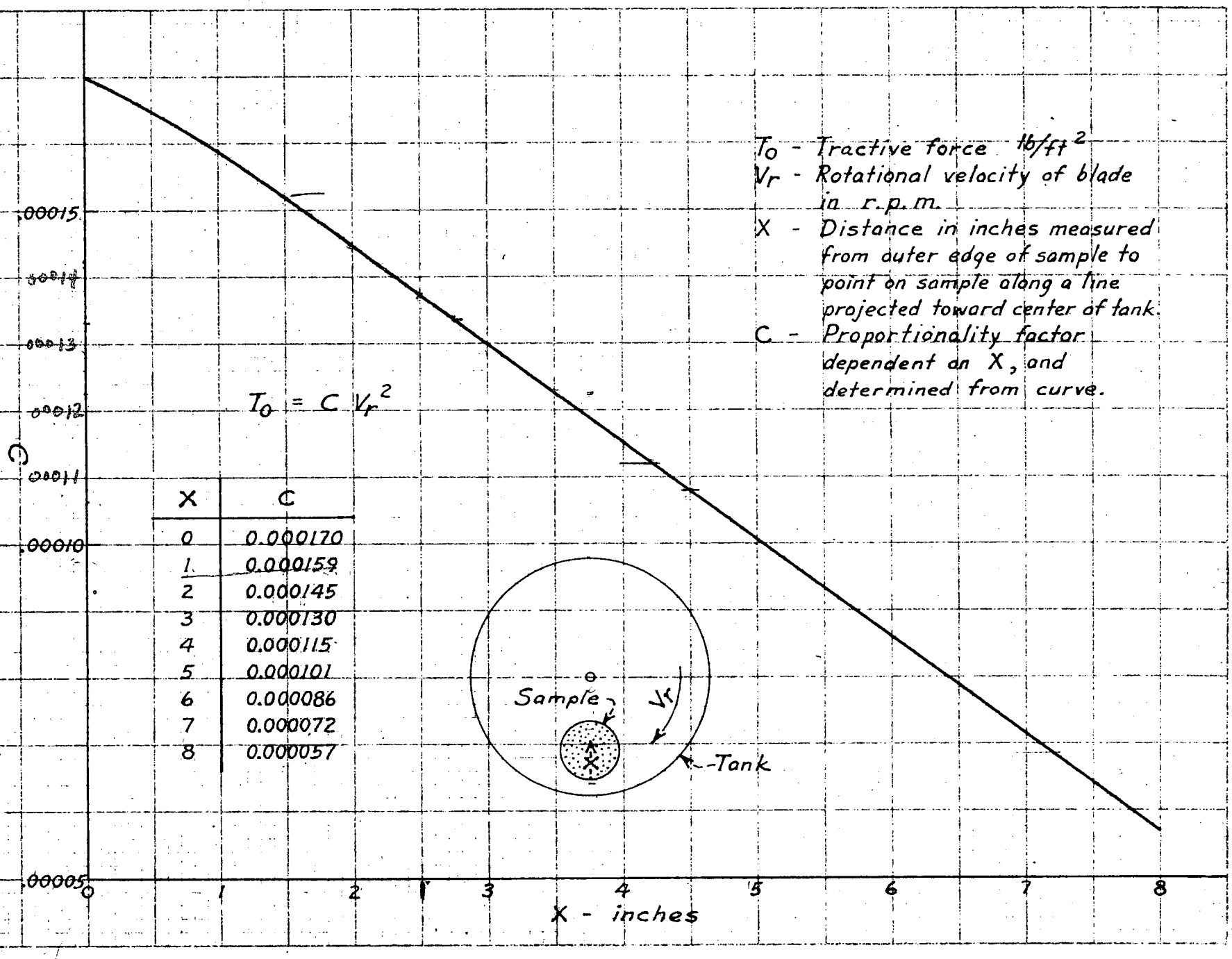
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

VARIATION OF IMPELLER BLADE SPEED WITH GAGE PRESSURE

550

DISTRIBUTION OF TRACTIVE FORCE ACROSS SAMPLE

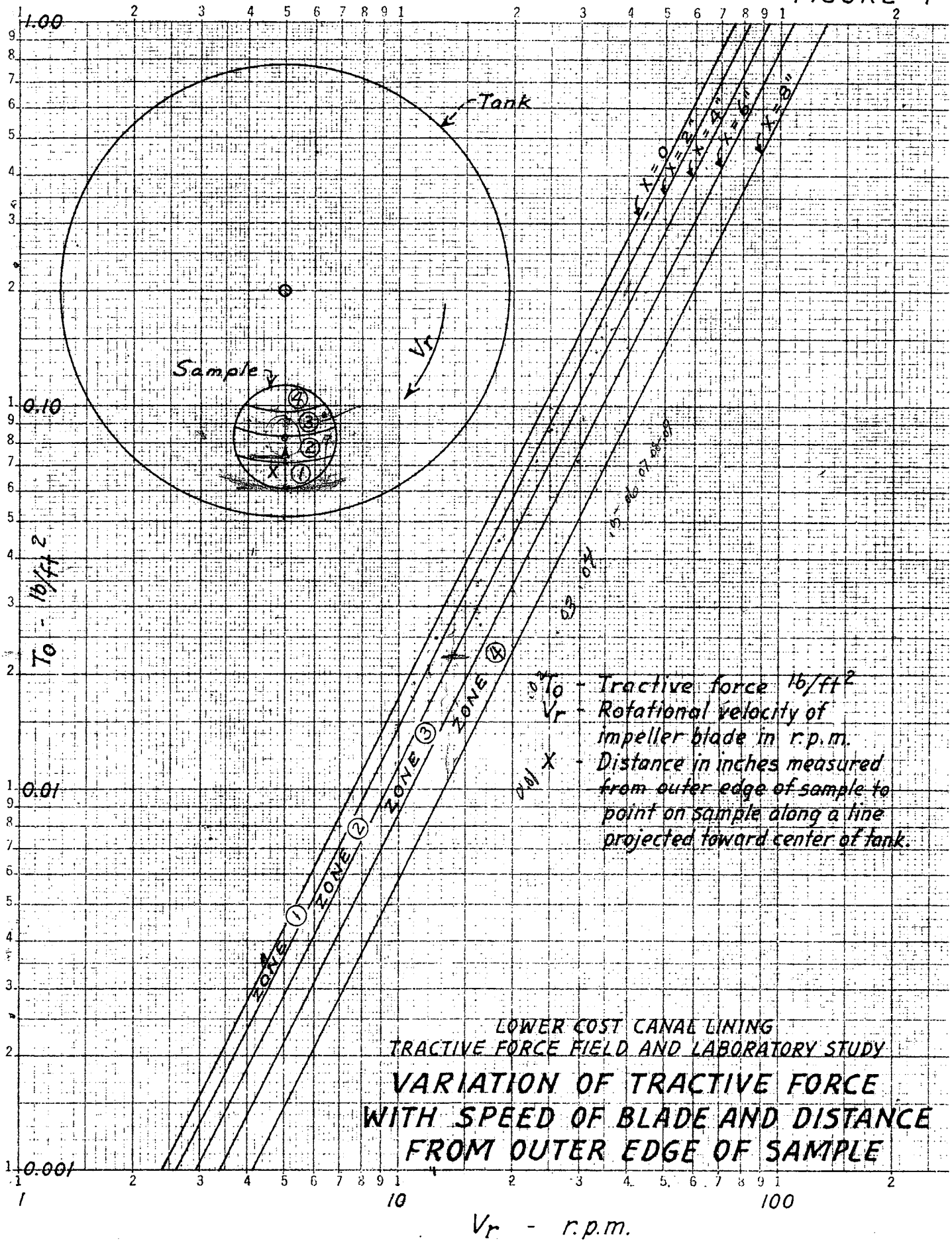
LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY



X	C
0	0.000170
1	0.000159
2	0.000145
3	0.000130
4	0.000115
5	0.000101
6	0.000086
7	0.000072
8	0.000057

FIGURE 3

FIGURE 4



LOWER COST CANAL LINING
TRACTIVE FORCE FIELD AND LABORATORY STUDY

VARIATION OF TRACTIVE FORCE WITH SPEED OF BLADE AND DISTANCE FROM OUTER EDGE OF SAMPLE