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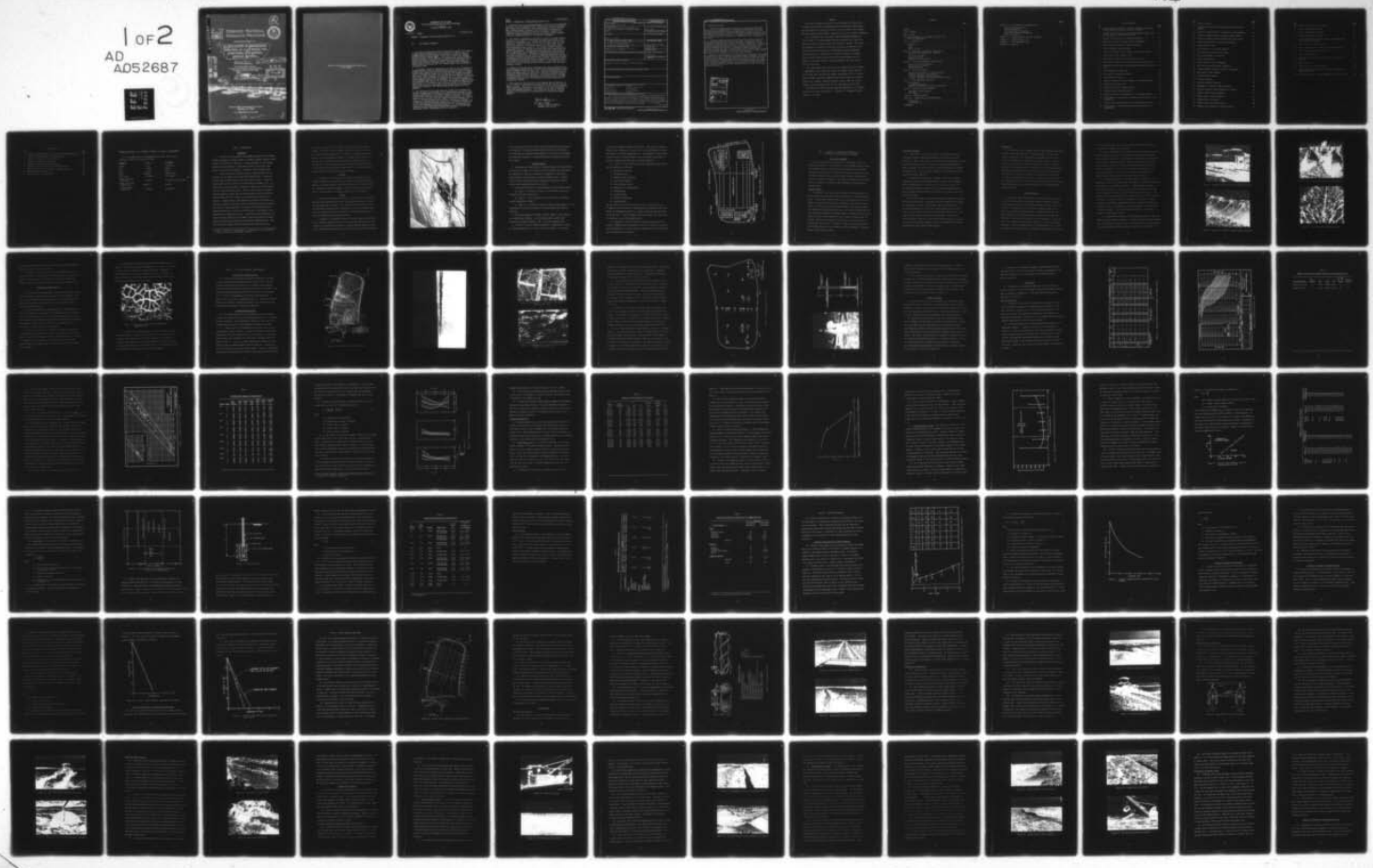

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DREDGED MATERIAL RESEARCH PROGRAM

MISCELLANEOUS PAPER D-77-4

(6)

AN EVALUATION OF PROGRESSIVE TRENCHING AS A TECHNIQUE FOR DEWATERING FINE-GRAINED DREDGED MATERIAL

by

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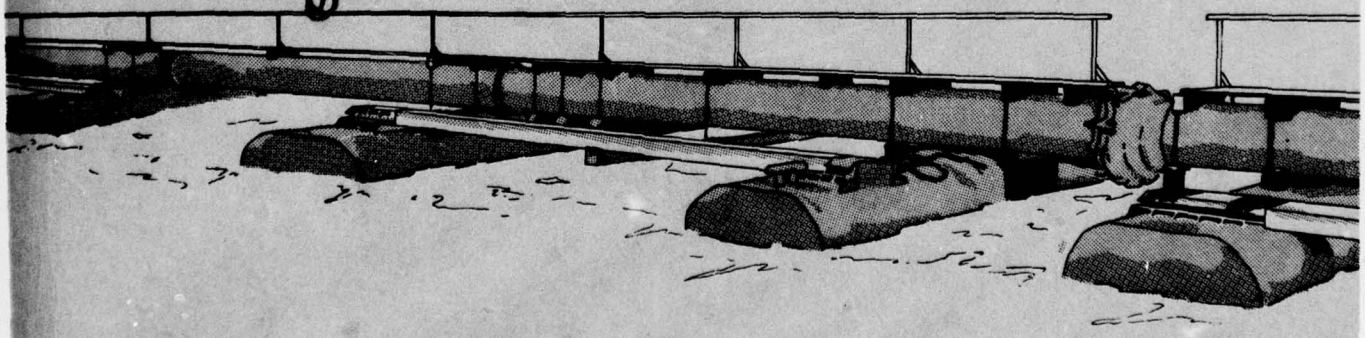

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under DMRP Work Unit No. 5A08

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IN REPLY REFER TO: WESYV

31 January 1978

SUBJECT: Transmittal of Miscellaneous Paper D-77-4

TO: All Report Recipients

1. The report transmitted herewith represents the results of a study of a dredged material dewatering concept evaluated as part of Task 5A (Dredged Material Densification) of the Corps of Engineers' Dredged Material Research Program (DMRP). This task is part of the Disposal Operations Project of the DMRP and is concerned with developing and/or testing promising techniques for dewatering and/or densifying (i.e., reducing the volume of) dredged material using physical, biological, and/or chemical techniques prior to, during, and/or after placement in containment areas.

2. The rapidly escalating requirements for land for the confinement of dredged material, often in urbanized areas where land values are high, dictated that significant priority within the DMRP be given to research aimed at extending the useful life of existing or proposed containment facilities. While increased life expectancy can be achieved to some extent by improved site design and operation and to a greater extent by removing dredged material for use elsewhere, the attractive approach being considered under Task 5A is to densify the in-place dredged material. Densification of the material would not only increase site capacity but also result in an area that would be more attractive for various subsequent uses because of the improved engineering properties of the material.

3. The objective of this study (Work Unit 5A08) was to evaluate the effects of progressive trenching on the dewatering and drying of fine-grained dredged material in confined disposal areas using the Riverine Utility Craft (RUC) and conventional trenching equipment. The study consisted of an initial field and laboratory testing program, construction of a surface drainage system within a disposal area using the progressive trenching approach, evaluation of trenching equipment, and a field instrumentation and monitoring program to test the effectiveness of the progressive trenching technique. The investigation was conducted by the Environmental Engineering Division of the Waterways Experiment Station, Environmental Effects Laboratory.

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4. Laboratory tests included determination of physical and engineering properties of the dredged material. Conventional consolidation tests were successfully performed on undisturbed dredged material samples, and a linear shrinkage laboratory test procedure was developed to evaluate potential shrinkage effects due to drying. Results of the laboratory testing program were used in estimating potential densification of dredged material due to progressive trenching.

5. The concept of progressive trenching is simply to provide drainage trenches for the removal of rain water and other surface water that may enter a containment area. Removal of this water allows the total evaporation potential available at the site to remove water from the material as opposed to the net evaporation (net evaporation equals total evaporation minus rainfall). The surface drainage system was constructed within a 28-hectare study area using both conventional and specialized equipment. Trenches were initially constructed using the RUC, an amphibious vehicle employing the Archimedean screw principle as a means of propulsion. Conventional draglines and flotation draglines that employed a special pontoon tracking mechanism were also used. A progressive trenching approach was used to deepen the surface drainage system using the various types of equipment as conditions warranted as the depth of desiccation cracks increased. It was found that construction of surface drainage systems within disposal areas was operationally feasible.

6. Effects of the progressive trenching efforts were evaluated by monitoring dredged material surface elevations and dredged material groundwater elevations within the study area. Field data indicated that the surface drainage system was effective in lowering the dredged material groundwater table through evaporation. An average surface settlement of approximately 0.23 m was achieved through the study area. Economic evaluations indicated that the progressive trenching operations were economically feasible.

7. The results of this study will be included as part of the site report for all tests conducted at the Upper Polecat Bay Disposal Site in Mobile, Alabama. The results of this study were also used in preparing final dewatering guidelines to be contained in the Task 5A synthesis report and engineering manual. This report may be used for interim guidance on the progressive trenching method for densifying dredged material.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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Polecat Bay, AL	Surface drainage
Dredged material	Trenching

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of a study conducted within a confined disposal area concerning the effects of progressive trenching on dredged material dewatering and drying are documented. The study consisted of an initial field and laboratory testing program, construction of a surface drainage system within the disposal area using a progressive trenching approach, evaluation of trenching equipment, and a field instrumentation and monitoring program.

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20. ABSTRACT (Continued).

Laboratory testing included determination of physical and engineering properties of the dredged material. Conventional consolidation tests were successfully performed on undisturbed dredged material samples and a linear shrinkage laboratory test procedure was developed to evaluate potential shrinkage effects due to drying. Results of the laboratory testing program were used in estimating potential densification of dredged material due to progressive trenching.

A surface drainage system was constructed within a 60-acre study area using both conventional and specialized equipment. Trenches were initially constructed using the Riverine Utility Craft (RUC), an amphibious vehicle employing the Archimedes screw principle as a means of propulsion. Conventional dragline equipment and flotation draglines which employed a special pontoon tracking mechanism were also used. A progressive trenching approach was employed to deepen the surface drainage system using the various types of equipment as conditions warranted. It was found that construction of surface drainage systems within disposal areas is operationally feasible.

Effects of the progressive trenching efforts were evaluated by monitoring dredged material surface elevations and dredged material groundwater elevations within the study area. Field data indicated that the surface drainage system was effective in lowering the dredged material groundwater table. An average surface settlement of approximately 0.75 ft was achieved throughout the study area. Economic evaluations indicated that progressive trenching operations were economically feasible with both comparatively low unit cost and favorable benefit/cost ratio.

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PREFACE

This report presents the results of an investigation of the effects of progressive trenching on dredged material dewatering and densification. The investigation was conducted as part of Work Unit 5A08 of the Dredged Material Research Program (DMRP) sponsored by the Office, Chief of Engineers.

This investigation was performed by the Environmental Engineering Division (EED) of the Environmental Effects Laboratory (EEL) during the period June 1975 to February 1977 by Mr. Michael R. Palermo. The trenching operations and portions of the data collection were carried out by the Mobility Systems Division of the WES Mobility and Environmental Systems Laboratory. Appreciation is expressed to Messrs. Pat Langan, Forrest Pruitt, Harvey Corey, Paul Warren, Harvey Blakney, and Pat Douglas of the Mobile District, Corps of Engineers, for their assistance with the study.

This study was prepared under the direct supervision of Mr. Raymond L. Montgomery, Chief, Design and Concept Development Branch, and Mr. A. J. Green, Chief, EED, and under the general supervision of Dr. T. A. Haliburton, Manager, Task 5A, Dredged Material Densification, Mr. Charles C. Calhoun, Jr., Manager, Disposal Operations Project, DMRP, Dr. Roger T. Saucier, Special Assistant, EEL, and Dr. John Harrison, Chief, EEL.

The Directors of WES during the study and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

	Page
PREFACE	1
LIST OF FIGURES	4
LIST OF TABLES	7
CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT	8
PART I: INTRODUCTION	9
Background	9
Purpose	10
Scope	10
Related Studies	12
PART II: OVERVIEW OF PROGRESSIVE TRENCHING AS A DEWATERING AND DENSIFICATION TECHNIQUE	15
Open Trench Drainage	15
European Practice	17
Mechanism for Densification	21
PART III: FIELD AND LABORATORY INVESTIGATIONS	23
Disposal Area Characterization	23
Dredged Material Borings	23
Laboratory Testing	30
PART IV: PREDICTIVE ANALYSIS	57
Potential Consolidation of Dredged Material	57
Potential Foundation Consolidation	61
Potential Shrinkage of Dredged Material	62
Potential Settlement Versus Drawdown Relationship	64
PART V: FIELD TRENCHING OPERATIONS	66
RUC Trenching	68
Conventional Trenching	80
Summary of Progressive Trenching Methodology	90
PART VI: RESULTS OF FIELD TRENCHING	94
Groundwater Table Drawdown	94
Settlement	96
PART VII: ECONOMIC ANALYSIS	100
PART VIII: CONCLUSIONS AND RECOMMENDATIONS	103
Conclusions	103
Recommendations	107
REFERENCES	109

	Page
APPENDIX A: SITE HISTORY AND CHARACTERISTICS	A1
Source of Dredged Material Site Investigations Containment Area Construction After Construction Investigations Disposal Operations	
APPENDIX B: DREDGED MATERIAL TEST DATA SUMMARIES	B1
APPENDIX C: OBSERVATION WELL DATA	C1
APPENDIX D: FIELD SETTLEMENT DATA	D1
APPENDIX E: NOTATION	E1

LIST OF FIGURES

No.		Page
1	Aerial photograph of Upper Polecat Bay disposal area showing dredged material dewatering studies in progress.	11
2	Dredged material dewatering field demonstrations, Upper Polecat Bay disposal area, Mobile District.	14
3	Amphirol vehicles used for trenching operations.	19
4	Depressions formed in dredged material by Amphirol.	19
5	Wheel trenching implements towed by Amphirol.	20
6	View of trenches formed by wheels.	20
7	Desiccation cracks found in Mobile River dredged material.	22
8	General plan of UPB disposal area.	24
9	Photograph of initial site conditions, July 1975.	25
10	Photograph of desiccation crack pattern within surface crust.	26
11	Photograph of high water content material beneath the surface crust.	26
12	Dredged material boring plan.	28
13	Photograph of sampling procedure.	29
14	Observation well detail.	29
15	Composite boring log and data summary for dredged material.	32
16	Composite grain-size curve.	33
17	Plasticity chart for dredged material.	36
18	Atterberg Limits trend with depth.	39
19	Typical void ratio log pressure plot for dredged material.	43
20	Relationship of consolidation pressure and coefficient of consolidation.	45
21	Typical linear shrinkage curve for dredged material tested.	47
22	Relationship of consolidation pressure and coefficient of permeability.	50

No.		Page
23	Wellpoint detail.	51
24	Average consolidation and shrinkage data for settlement analysis.	58
25	Potential dredged material consolidation versus drawdown.	60
26	Potential dredged material shrinkage versus drawdown.	64
27	Potential settlement versus drawdown and field results.	65
28	General plan progressive trenching study area.	67
29	Specifications of RUC.	70
30	RUC trenches in soft dredged material.	71
31	RUC trenches in thickly crusted area.	71
32	High area adjacent to north wier.	74
33	Trench intersections.	74
34	Specifications of wheel implements.	75
35	RUC trench formed with wheel implements.	77
36	Dredged material re-slurry with wheel implements.	77
37	Desiccation of RUC trenches.	79
38	Progressive RUC trenches.	79
39	Flotation dragline.	82
40	Flotation dragline trenching.	82
41	Appearance of flotation dragline trench C.	84
42	Flotation dragline trench deepening of trench H.	84
43	Lateral trench E after deepening.	87
44	Feeder trench I after deepening.	87
45	Slough failure in trench F.	88
46	Matting with conventional dragline.	88
47	Deepening with dragline at lateral trench B.	91

No.		Page
48	Deepening with dragline at trench H.	91
49	Average drawdown versus time.	95
50	Surface settlements by station.	97
51	Average settlement versus time.	99
A1	Location of channels, disposal areas, and dredged areas, Polecat Bay and vicinity.	A2
A2	Layout and log of boring SS-3-70.	A4
A3	Logs of borings SS-1-70, SS-2-70, SS-4-70, and SS-10-70.	A6
A4	Log of borings SS-11-71 and SS-12-71	A7
A5	Log of borings SS-13-71	A8
A6	UPB disposal area after dike construction, September 1971 survey.	A10
A7	Dike sections.	A11
A8	Layout and log of boring MP-SS-76.	A13
A9	Generalized foundation conditions prior to placement of dredged material.	A15
A10	UPB disposal area, following dredging A, July 1972 survey.	A18

LIST OF TABLES

No.		Page
1	Summary of Grain-Size Data for Fine-Grained Dredged Material	34
2	Atterberg Limits Summary for Dredged Material	37
3	Summary of Consolidation Test Results	41
4	Summary of Shrinkage Test Results	48
5	Variable Head Permeability Test Results	53
6	Qualitative Mineral Composition of Dredged Material	55
7	Quantitative Mineral Composition of Dredged Material	56
A1	Pertinent Data of Dredging "A"	A16
A2	Pertinent Data of Dredging "B"	A19

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurements used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
yards	0.9144	metres
acres	4046.856	square metres
cubic yards	0.7645549	cubic metres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force) per square inch	6894.757	pascals
tons (force) per square foot	95.76052	kilopascals

PART I: INTRODUCTION

Background

1. Millions of cubic yards* of fine-grained sediment must be dredged annually throughout the United States to maintain navigation channel depths because of the effects of shoaling. A large percentage of this dredged material must be confined in land disposal sites, and each year large amounts of new land are required to accommodate these disposal needs.

2. Under current land disposal practice, retaining dikes are constructed and the disposal site filled with dredged slurry. Supernatant water is then released through sluice structures or weirs. In many instances water is left pooled in low areas within the disposal site. In areas where the slurry surface is exposed to evaporation, a thin surface crust is formed by natural drying. The water table within the dredged material generally remains near the dredged material surface preventing further drying and crust formation and is periodically recharged by rainfall. Dredged material lying beneath the surface crust remains at a high water content for long time periods following the disposal operation. The removal of this excess water is essential in the transformation of dredged material into a usable soil resource and is instrumental in the densification of disposal area life. A major area being addressed by the Dredged Material Research Program (DMRP) concerns the potential benefits gained by dewatering and densifying fine-grained dredged material. DMRP field studies on dredged material dewatering and densification were

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 8.

initiated in August 1975 at a confined land disposal site in Mobile, Alabama. The Upper Polecat Bay (UPB) disposal area, shown in Figure 1, is an 85-acre site primarily used for disposal of fine-grained dredged material from the maintenance dredging of the Upper Mobile River and Harbor areas. Progressive trenching operations conducted as part of the DMRP field study program have initiated drying and drainage within the UPB disposal area resulting in densification of the dredged material and an increase in the available disposal capacity.

Purpose

3. The purpose of this study was to evaluate the effects of progressive trenching on the dewatering and drying of fine-grained dredged material in confined disposal areas using the Riverine Utility Craft (RUC) and conventional trenching equipment. The effectiveness and production rates of various types of trenching equipment are also evaluated.

Scope

4. This report documents the results of a study conducted at the UPB disposal area concerning the effects of progressive trenching on dredged material dewatering and drying. The study consisted of an initial field and laboratory testing program, construction of a surface drainage system within the disposal area using a progressive trenching approach, and a field instrumentation and monitoring program.

5. Information is presented relative to the performance and effectiveness of trenching equipment within confined disposal areas and the overall evaluation of progressive trenching as a dredged material dewatering technique. The magnitude and efficiency of water removal through the trenching

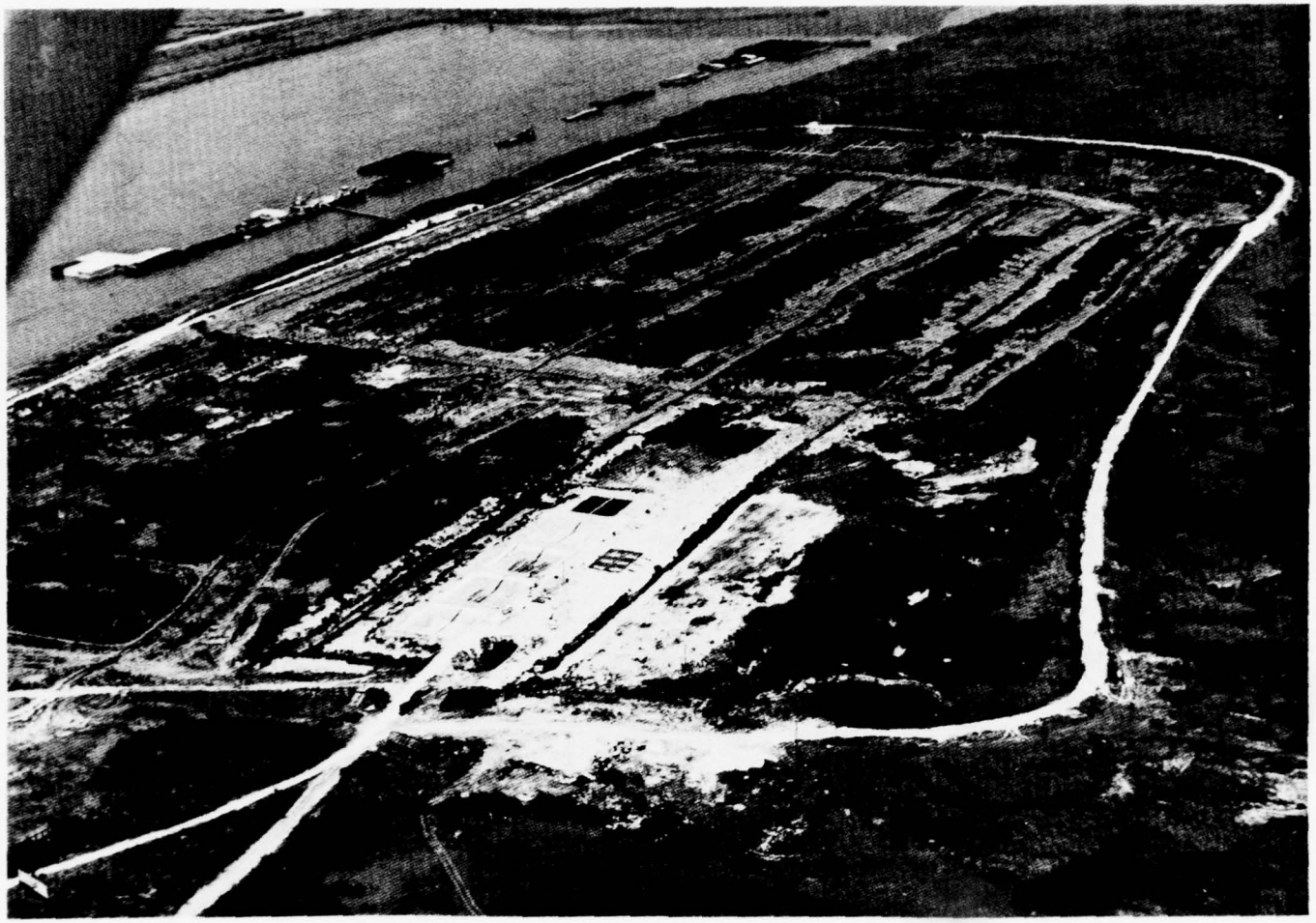


Figure 1. Aerial photograph of Upper Polecat Bay disposal area showing dredged material dewatering studies in progress

system and the densification effects gained through dewatering and drying are documented. The data presented include the results of laboratory tests performed to determine dredged material consolidation and shrinkage properties and correlation of laboratory predictive analysis with actual field results.

Related Studies

6. Dewatering and densification of dredged material is being addressed by Task 5A of the DMRP. This research task is concerned with development and evaluation of promising techniques for dewatering or densifying dredged material after placement in diked containment areas. Primary research efforts are directed toward dewatering fine-grained material produced from maintenance dredging activities.

7. Task Area 5A research is being developed by a three-phase approach:

a. Phase I - Preliminary evaluation of dewatering concepts for technical and economic feasibility.

b. Phase II - Field demonstration and evaluation of promising concepts identified in Phase I.

c. Phase III - Evaluation of Phase II data and development of design alternatives for use by CE Districts in routine dredging and disposal operations.

8. Following completion of Phase I studies, Phase II field demonstration studies were initiated. All field demonstration studies were evaluated in the Mobile District (MD) at the UPB disposal area.

9. Because of time and funding constraints, a comprehensive study of all field demonstrations at one test site was preferable to evaluating

individual techniques at numerous test sites. Also, better comparisons among various techniques are possible if all are evaluated at a similar environment for similar dredged material. Extrapolation of field demonstration results to other potential sites can be made on the basis of material properties and known laws of material behavior.[1]

10. A total of 10 field demonstrations and supporting field studies were initiated at the UPB site:

1) Progressive Trenching
2) Vacuum Wellpoints
3) Windmill Power Feasibility
4) Sand Slurry Injection
5) Meteorological Station
6) Mechanical Crust Stabilization
7) Underdrainage
8) Electro-Osmosis
9) Vegetative Dewatering
10) Capillary Wicks

The demonstrations are located within the site as shown in Figure 2. In addition to field studies on dredged material dewatering, field evaluations of equipment performance in disposal areas are being performed at the UPB site. A Task 5A summary report will present the results and an evaluation of each field demonstration.

11. Comparison of results from the feasibility studies and field studies on dredged material dewatering will aid CE Districts in possible field implementation of Task 5A research considering both cost effectiveness and operational constraints.

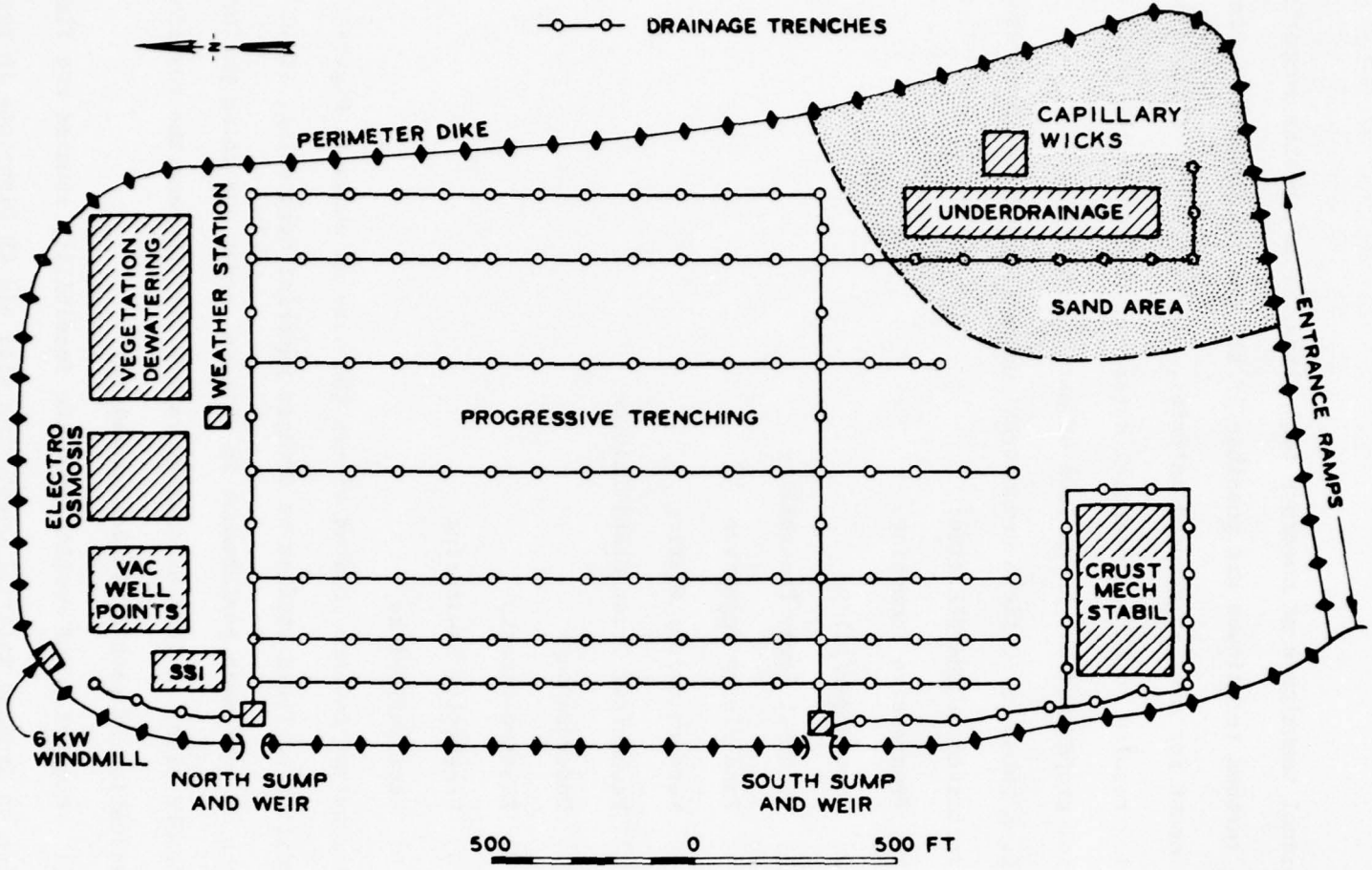


Figure 2. Dredged material dewatering field demonstrations, Upper Polecat Bay disposal area, Mobile District

PART II: OVERVIEW OF PROGRESSIVE TRENCHING AS A DEWATERING AND DENSIFICATION TECHNIQUE

Open Trench Drainage

12. Open trenches have long been used for drainage of land for agricultural purposes.[2] The objectives of such drainage systems include the efficient removal of surface water from fields and the effective evaporation and initiation of subsurface drainage to draw down or maintain the groundwater table at desired levels below the ground surface in order to prevent crop damage. These basic principles are also applicable to drainage and groundwater table drawdown in dredged material disposal areas.

Surface drainage

13. Retention of surface water accumulated from precipitation is a major problem associated with effective dewatering of confined disposal areas. In many cases disposal areas are not continuously inspected and managed to ensure that surface water completely drains from the area as runoff. Since the sites are essentially dammed by the retaining dikes, the trapped surface water eventually percolates into the dredged material. This effectively recharges the dredged material groundwater table and may offset a portion of the evaporative loss of water occurring during dry periods. Reduction in infiltration rates due to efficient removal of surface water is difficult to quantify. However, the benefits derived by efficient removal of surface water are a major advantage of trenching within confined disposal areas.

Sub-surface drainage

14. Theoretical solutions for design of open trench systems for sub-surface drainage have been developed by both engineers and soil scientists.[2] Many of the solutions are related to a steady-state approach in which the drainage system is designed to maintain the groundwater table at a given level while the level is being recharged by a constant infiltration rate. The most widely accepted of these solutions is the so-called "Ellipse Equation."[3]

15. Steady-state conditions do not apply to the case of actual dewatering in which the groundwater table is lowered. Such conditions must be analyzed using a nonsteady state solution that accounts for the changing gradients associated with a falling groundwater table. A widely accepted solution based upon nonsteady state conditions has been developed by Dumm.[4]

16. The effectiveness of subsurface drainage as determined by these and similar relationships is dependent upon the permeability or porosity of the material, spacing of the trenches, and the effective head. If fine-grained material is involved, the trench spacings must be quite close to allow effective subsurface drainage under gravity flow. Only slight removal of water by subsurface drainage will be possible in confined disposal areas due to the limited gradients that can be practically achieved by surface trenching and the low permeabilities normally associated with fine-grained dredged material.

Evaporation

17. Research has been conducted under the DMRP regarding evaporation of water from dredged material.[5] Evaporative water loss from a soil surface is dependent upon dredged material permeability, net solar radiation, windspeed, air temperature, and vapor pressure. Formation of desiccation cracks also influences evaporation rates, as does the presence of a groundwater table to recharge the loss through evaporation. Evaporative rates from the dredged material surface are slightly less than that from a free water surface and are reduced as a dried crust is formed. Trenching systems can serve to increase the efficiency of the evaporative process by effectively removing surface water accumulated through precipitation and preventing recharge of the dredged material groundwater table.

European Practice

18. Trenching within dredged material disposal areas in the United States has been restricted to periphery trenches constructed adjacent to the retaining dikes to improve dredged material for use in dike construction. Trenching within the interior of disposal areas for the purpose of dewatering and densification of dredged material has only been accomplished in European practice, primarily in the Netherlands.[6] Siltation of harbors in this region due to the interaction of river and tidal flow is severe and considerable dredging is required to maintain navigation. However, dredged material in the Netherlands is not looked upon solely as a disposal problem. Reclamation of material as a resource

for creating additional land for agricultural and industrial expansion is considered a primary dredging purpose.

19. Since dredged material confinement areas are planned and acquired with a future use as a prime consideration, provisions are implemented in the disposal operation to enhance potential dewatering and densification of the material through trenching. Disposal areas are usually smaller and rectangular in shape and layers of newly placed material are kept as thin as possible (3 to 4 ft) to allow maximum effectiveness of the trenching operation. In this way more material may eventually be placed per unit area yielding the greatest density possible.

20. Trenching operations in the Netherlands are carried out in a progressive fashion, allowing gradual improvement of trenches and increased effectiveness of the dewatering process.[7] Approximately two months following placement of a new layer, small parallel depressions are made with an amphibious vehicle called the Amphirol, shown in Figure 3. The Amphirol utilizes twin pontoons with spiral blades that rotate in opposite directions to propel the vehicle. Trenching is initiated by creating the parallel depressions approximately 8 feet on centers throughout the containment area. The depressions formed are usually 2 to 4 inches deep as shown in Figure 4. This process may be repeated to progressively deepen the newly formed trenches.

21. Approximately six months following material placement, twin disc wheels are towed behind the Amphirol to deepen the trenches to approximately one foot as shown in Figures 5 and 6. Manual dressing is usually required to link the trenches and allow efficient drainage of surface water. In

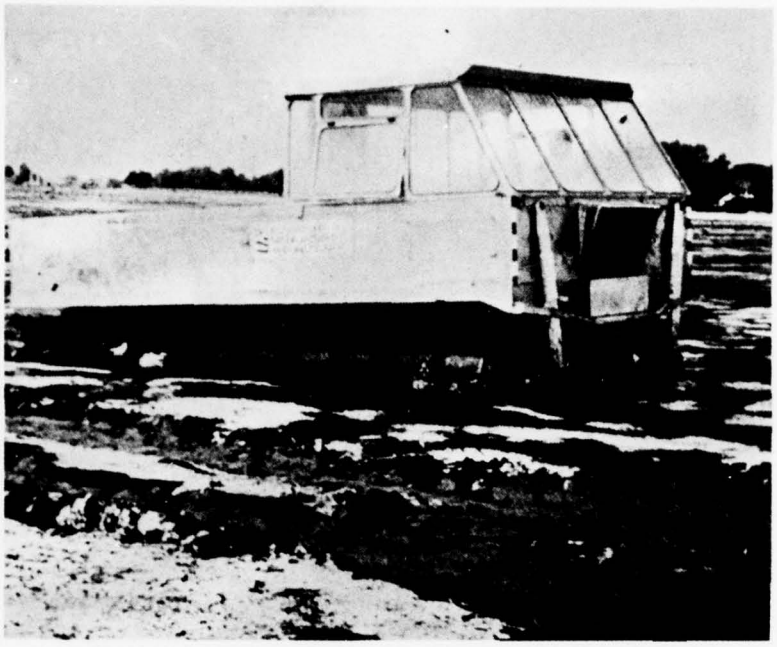


Figure 3. Amphirol vehicle used for trenching operations

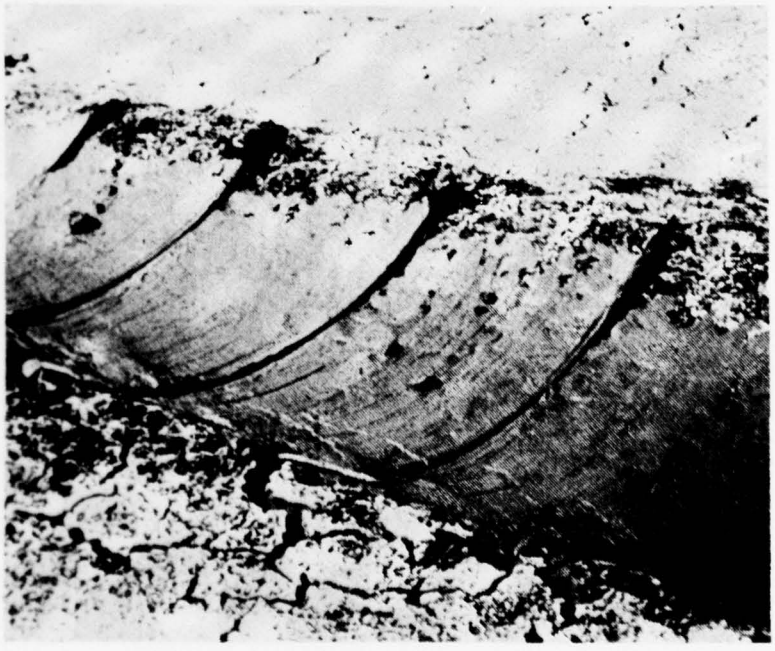


Figure 4. Depressions formed in dredged material by Amphirol

Figure 5. Wheel trenching implements towed by Amphirol

Figure 6. View of trenches formed by wheels

some cases larger cable-towed wheels are later used to deepen alternate trenches to depths of two feet or more.

22. Trenching operations as performed in the Netherlands serve to efficiently remove the surface water allowing evaporation to improve the material. The creation of the trenches also serves to increase the effective evaporative surface area further speeding the drying process.

Mechanism for Densification

23. The construction and maintenance of an efficient surface trenching system within a dredged material disposal area can initiate a drawdown of the dredged material groundwater table. Increased evaporation efficiency will mainly contribute to the loss of subsurface water in fine-grained dredged material.

24. As the dredged material groundwater table is lowered, material within the transition zone changes from a submerged state to a saturated state. This imposes effective loads on the underlying material equal to the difference between submerged and saturated unit weight of the material. The additional loading initiates drainage of the dredged material according to accepted theories of consolidation.

25. Similar consolidation of foundation soils due to a watertable drawdown within the dredged material can significantly add to potential gains in disposal area capacity. However, the potential for consolidation of foundation soils is dependent on the interaction of the dredged material material groundwater table with that initially present within the foundation.

26. Dredged material lying above the lowered groundwater table is subject to loss of water through evaporation, and considerable reductions in volume can occur through the shrinkage mechanism. Shrinkage of dredged material also results in formation of desiccation cracks, as shown in Figure 7, which further increase the evaporative surface area and drainage efficiency of the dried crust.

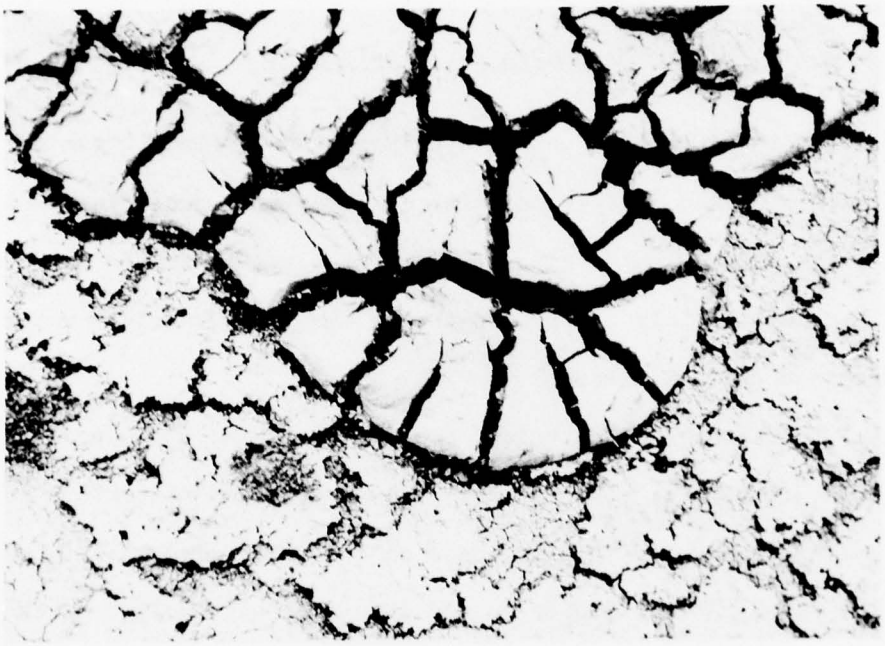


Figure 7. Desiccation cracks formed in Mobile River dredged material

27. A combination of dredged material consolidation and shrinkage and consolidation of foundation soils can result in considerable gains in disposal area capacity. The field and laboratory investigations, trenching operations, and site monitoring programs conducted at the UPB study area were designed to evaluate the effects of progressive trenching on dredged material densification due to these mechanisms.

PART III: FIELD AND LABORATORY INVESTIGATIONS

Disposal Area Characterization

28. Disposal site history and background information for the UPB site was accumulated from available sources within the MD. The UPB disposal area was constructed in 1970 by end-dumping sand retaining dikes in an existing marsh area inclosing a total area of 85 acres. Two subsequent disposal operations filled the area with a total thickness of 8 to 12 feet of predominantly fine-grained dredged material. A general plan of the site is presented in Figure 8. Detailed information regarding site history, foundation conditions, dike construction, and dredged material disposal is presented in Appendix A.

Dredged Material Borings

29. Field investigations at the UPB disposal area were conducted initially to characterize the site and obtain information on the dredged material properties. The investigations consisted of site surveys and dredged material borings to obtain samples for laboratory testing.

30. A general view of site conditions at the time of the field investigations is shown in Figure 9. Initial site surveys indicated some ponded water, but a thin surface crust of dried material 2 to 8 inches thick existed over a majority of the progressive trenching study area shown in Figure 2. Desiccation cracks throughout the surface crust exhibited a typical polygonal pattern shown in Figure 10. In most areas the thin crust would not support a man's weight. A layer of fine-grained dredged material approximately 8 feet thick was present beneath the crust

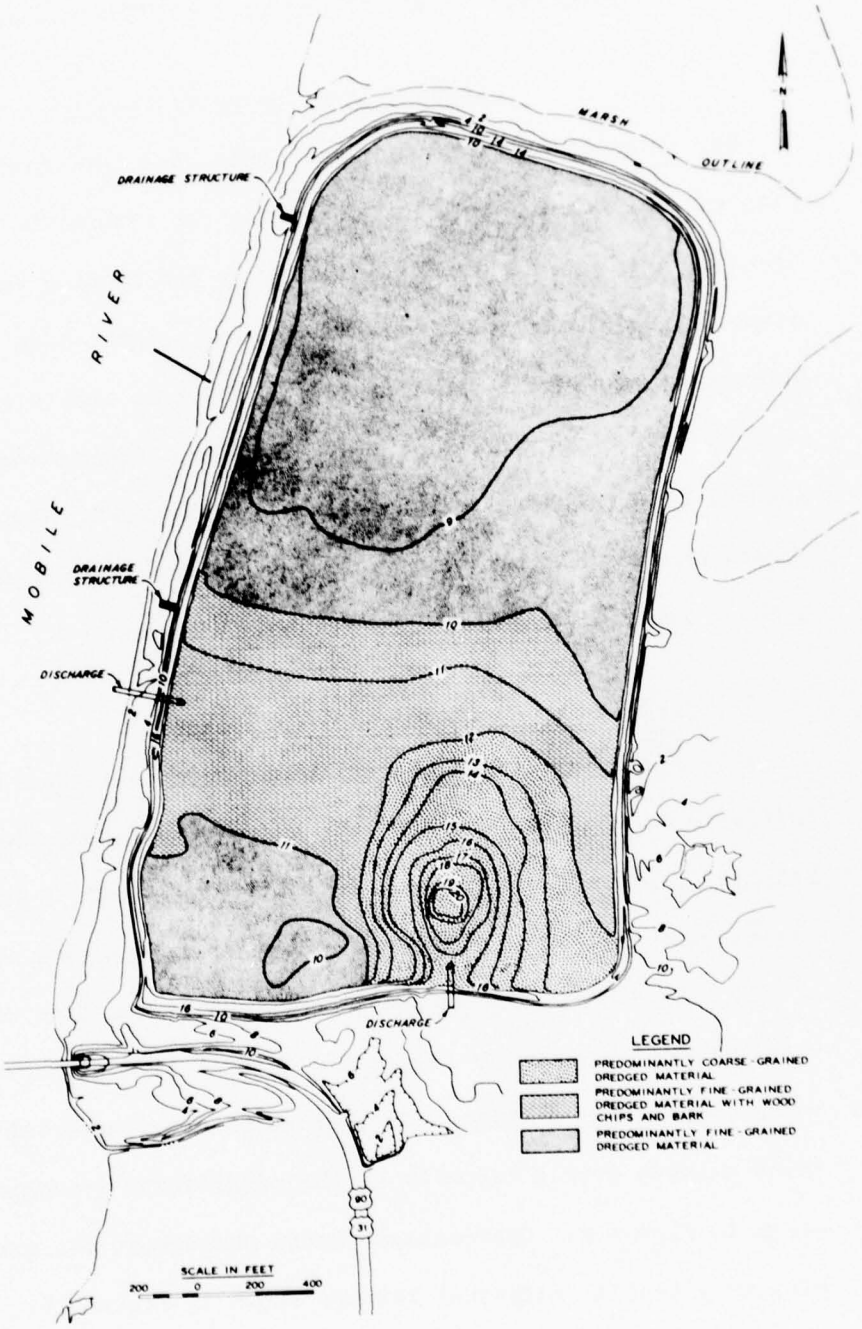


Figure 8. General plan of UPB disposal area

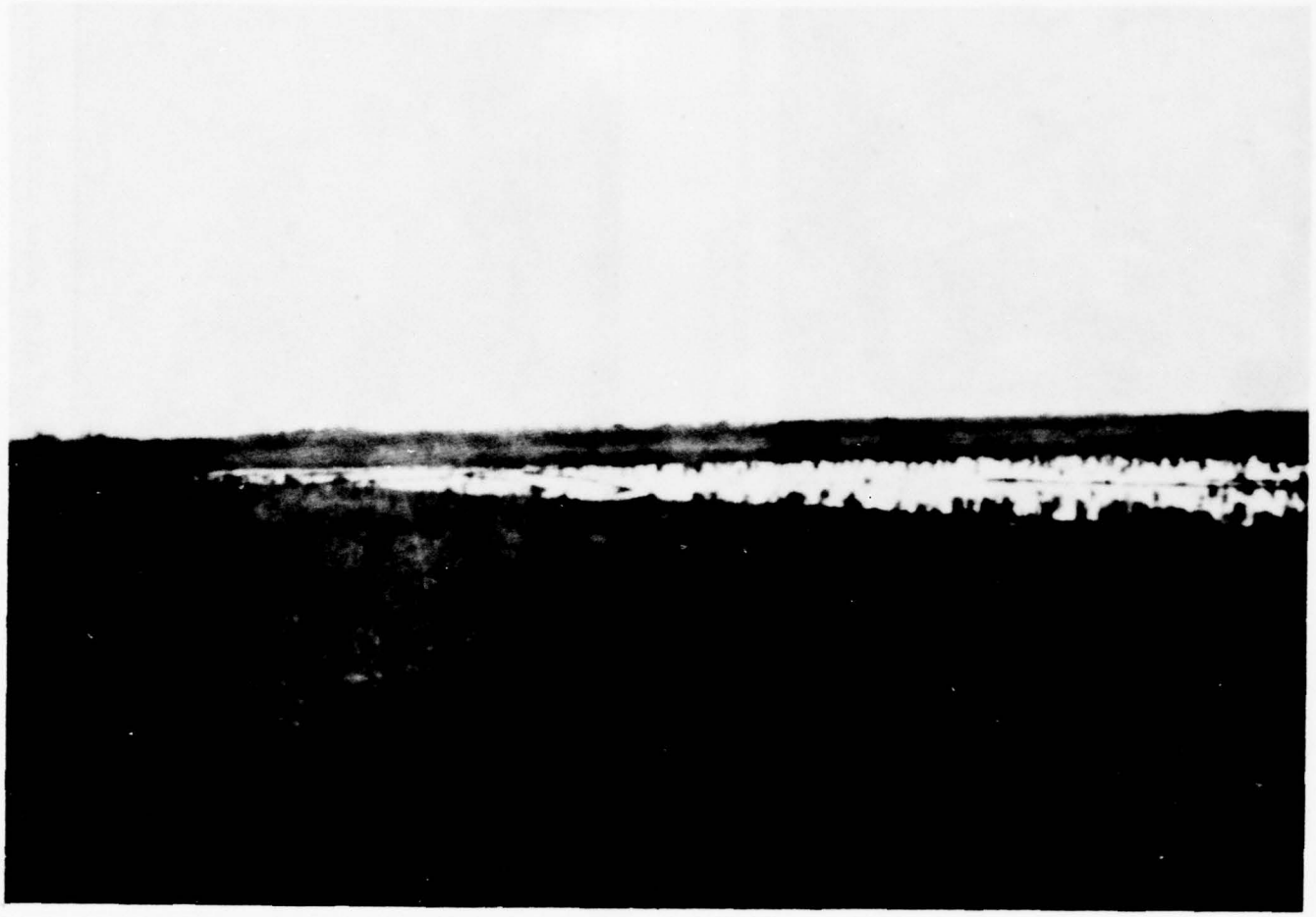


Figure 9. Photograph of initial site conditions, July 1975

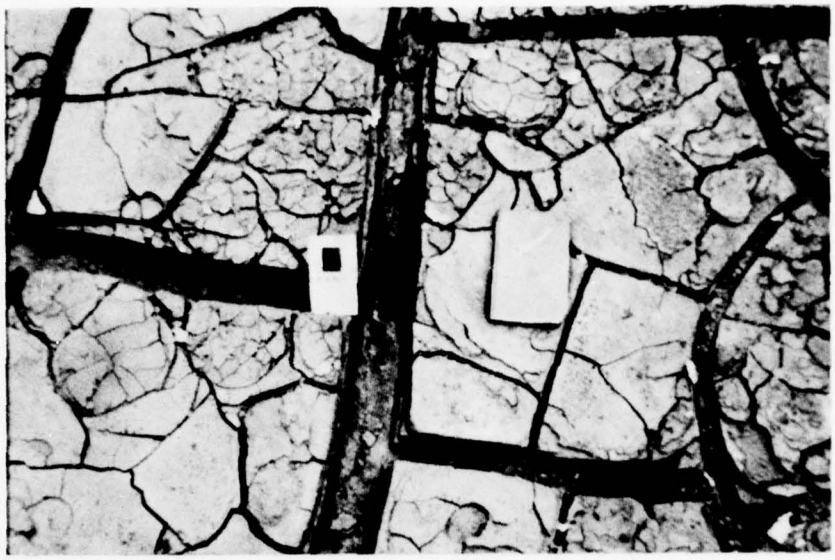


Figure 10. Photograph of desiccation crack pattern within surface crust

Figure 11. Photograph of high water content material beneath the surface crust

having the consistency similar to that of warm axle grease. This material was generally at water contents above the liquid limit. Appearance of the wet material is shown in Figure 11. Topography was generally flat, grading slightly lower from south to north.

31. One undisturbed boring was taken in the UPB disposal area by the MD in May 1975. The boring was located 500 feet east of the north weir as shown in Figure 12 to initially define the physical properties of the fine-grained dredged material. This boring was made prior to drainage of surface water from the area. Access of boring equipment was impossible due to presence of only a thin surface crust; therefore, samples were taken by hand-pushing a 5-inch I.D. push tube to a depth of 10 feet.

32. Twenty-six (26) borings were taken within the disposal area during July and August 1975 and in connection with initial DMRP field studies. The borings were designated BI-1 through BI-26 and are located as shown in Figure 12. Locations of the borings were chosen to generally define conditions within the entire disposal area and to define more detailed information along a central axis through the disposal site.

33. The borings were taken by hand-pushing a 3-inch I.D. piston-type sampler. Continuous samples were taken to a maximum depth of 12.5 feet below the dredged material surface. This procedure allowed sampling completely through the dredged material layer into the foundation soils for most of the borings. A photograph of the sampling operation is shown in Figure 13. Two of the borings, BI-5 and BI-25, were attempted in the southeast corner of the disposal area, but the sandy material exhibited

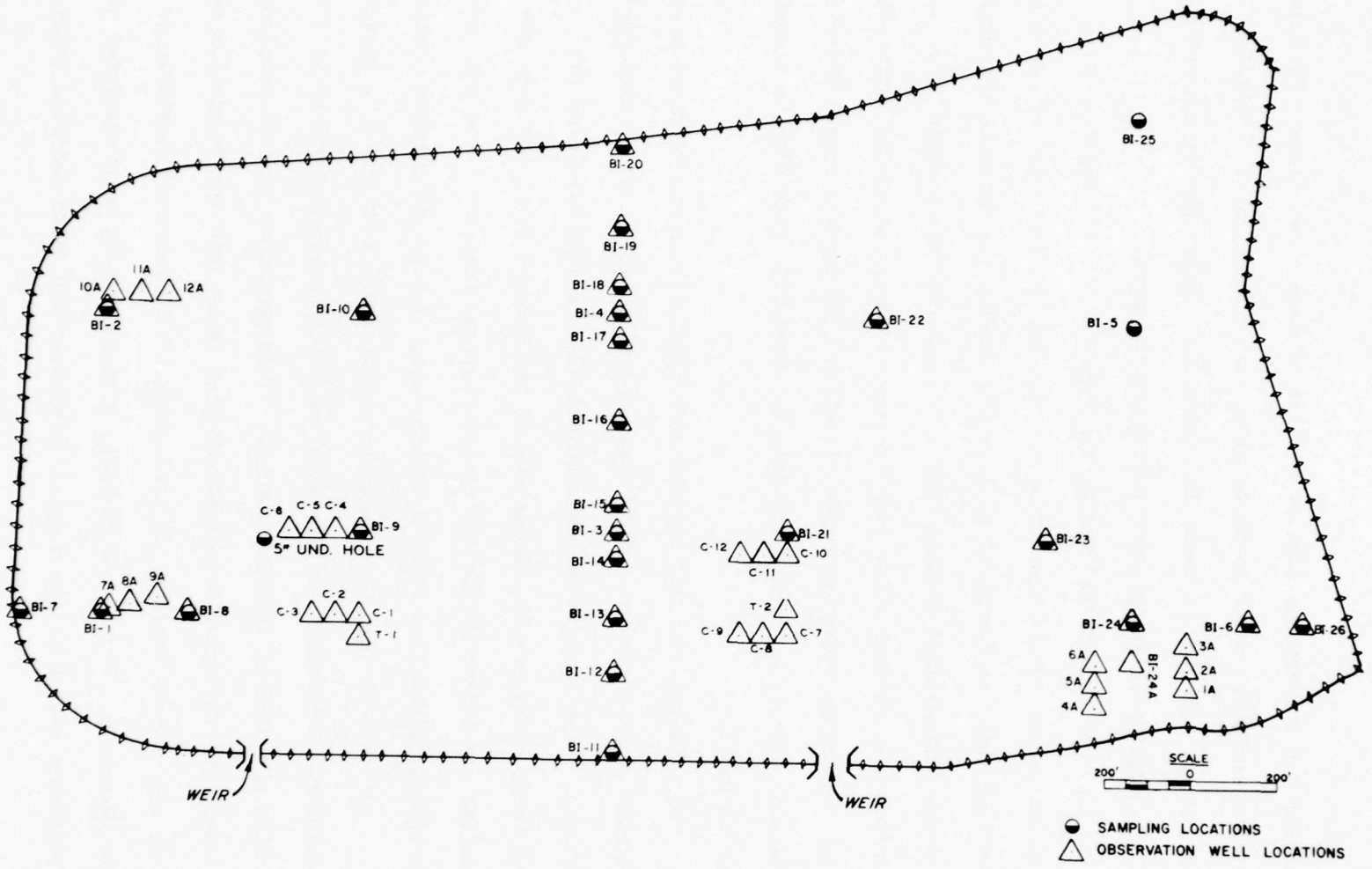


Figure 12. Dredged material boring plan

Figure 13. Photograph of sampling procedure

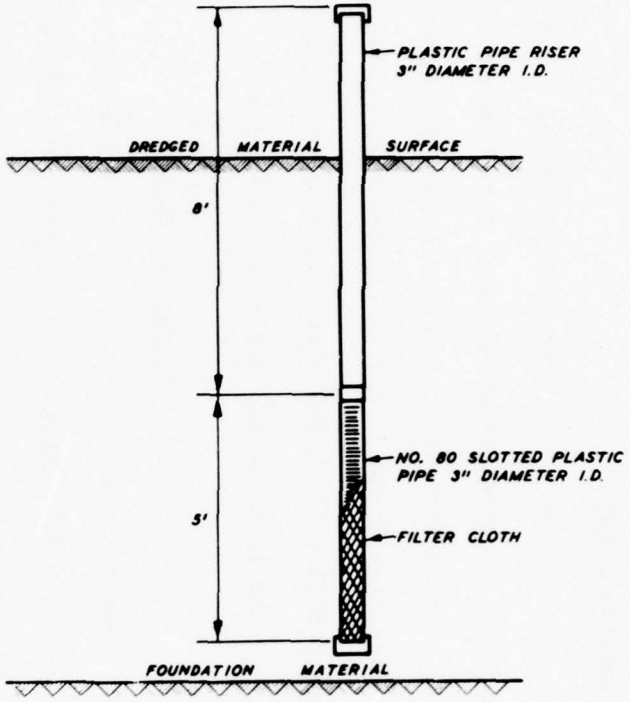


Figure 14. Observation well detail

penetration resistance and allowed only surface sampling. A total of 102 undisturbed dredged material samples were taken during this field investigation phase.

34. Observation wells were also installed in 24 boreholes as indicated in Figure 12 to determine groundwater table conditions within the dredged material. The wells were fabricated from 5-foot sections of No. 80 slotted plastic pipe connected to 8-foot plastic pipe risers. The points were wrapped in filter cloth and seated to a depth of approximately 10 feet. Details of the installation are shown in Figure 14.

Laboratory Testing

35. Samples from the 5-inch undisturbed boring were tested by the Mobile District Soils Laboratory to determine initial dredged material properties. Testing included laboratory classifications under the Unified Soil Classification System (USCS),[8] water content determinations, in situ densities, Atterberg Limits determinations, and gradation analyses.

36. Laboratory tests performed on the 3-inch undisturbed dredged material samples from borings BI-1 through BI-26 included USCS classifications and water content determinations on all samples and density determinations, gradation, specific gravity tests, Atterberg Limits, vane shear, consolidation tests, and laboratory shrinkage tests on selected samples. The overall testing program was designed to determine the existing physical and engineering properties of the dredged material for use in estimating potential shrinkage and consolidation. Conventional laboratory testing was performed by the WES Soils and Pavements Laboratory according to accepted CE procedures.[9]

37. Methods used to determine shrinkage characteristics were developed specifically for this study and are described in paragraph 59. The laboratory shrinkage tests were performed by the WES Environmental Effects Laboratory.

Test Results

38. Test results are summarized graphically for all undisturbed borings in Figure 15. Logs of individual borings and individual graphical data are presented in Appendix B. Individual test data results are available in reference 10.

Physical properties

39. Eighty-two of the total 102 dredged material samples from the 3-inch undisturbed borings were fine-grained and classified as a clay (CH), dark grey to black in color. The fine-grained material is considered to hold the most importance regarding the consolidation and shrinkage characteristics of the UPB site. The dredged material typically contained approximately 5 percent organic material.

40. Grain-size analysis and Atterberg Limits were performed on 34 fine-grained samples. A composite grain-size curve is presented in Figure 16. A total of 21 samples were very fine-grained with an average of 93% by weight passing the #200 sieve and 41% finer than one micron (.001mm). The remaining fine-grained samples were described as sandy clay with an average of 78% passing the #200 sieve and 31% finer than one micron. Grain-size data for the fine-grained samples are summarized in Table 1.

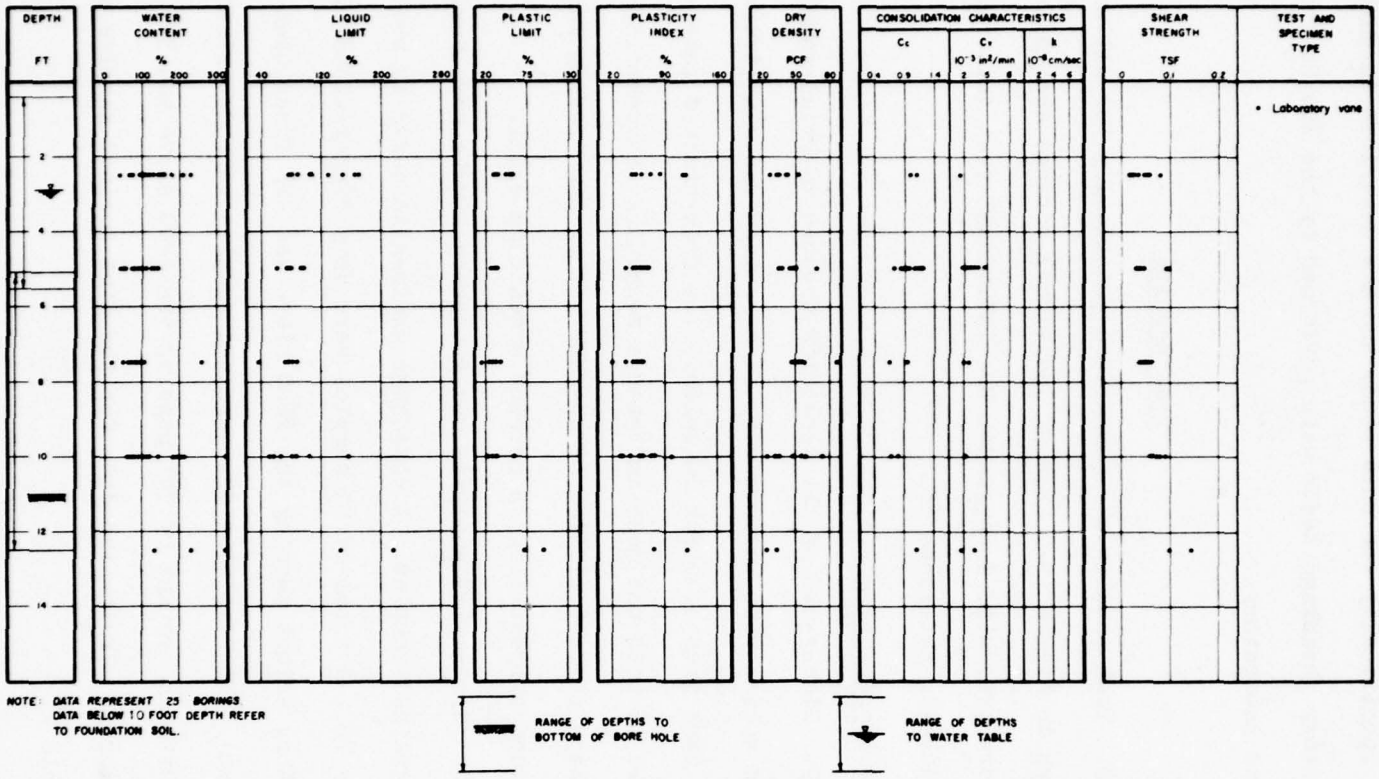


Figure 15. Composite boring log and data summary for dredged material

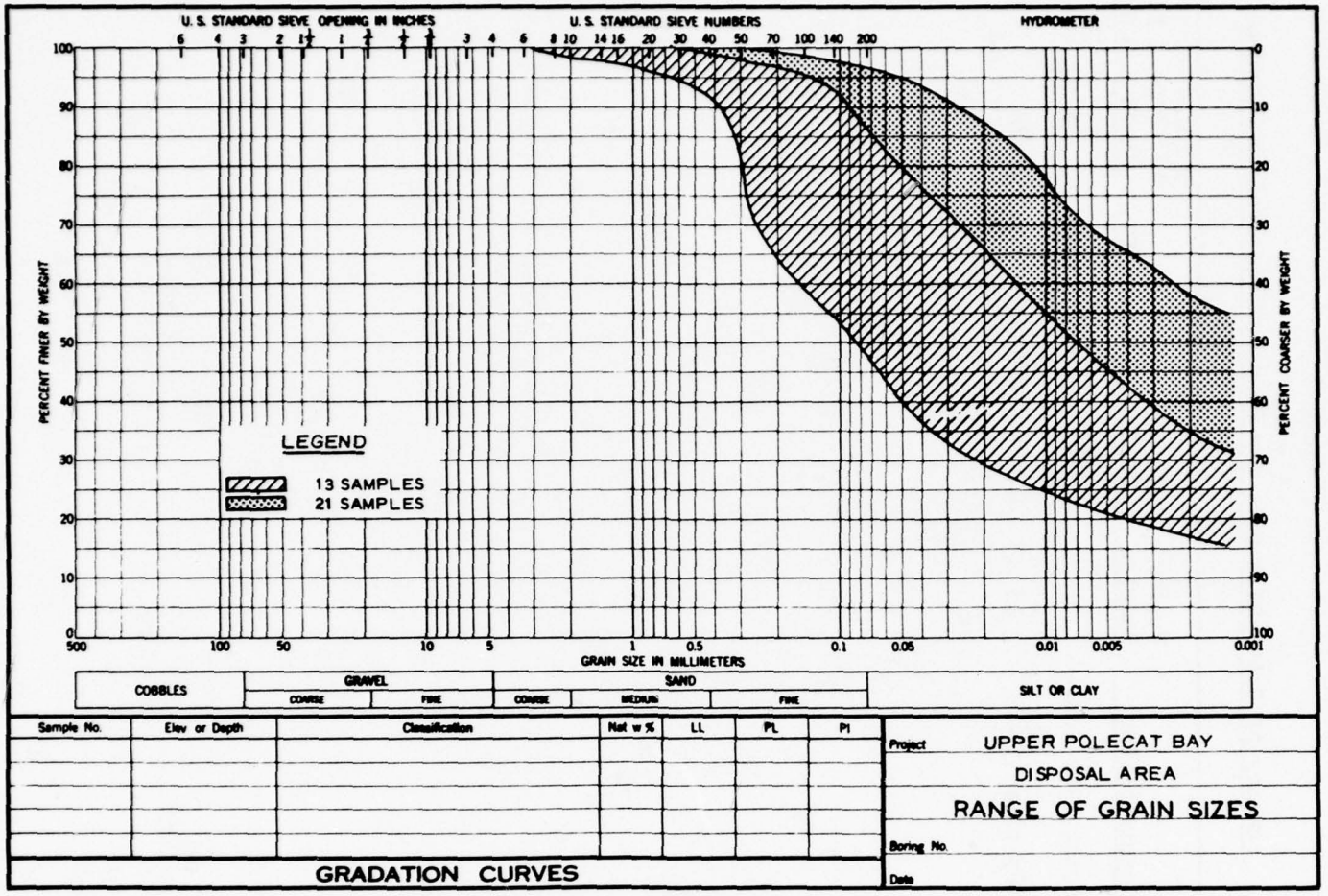


Figure 16. Composite grain-size curve

Table 1

Summary of Grain-Size Data for Fine-Grained Dredged Material

Classification	No. of Samples	D_{90}	D_{60}	D_{50}	% Finer No. 200 Sieve	% Finer 0.001 mm
Plastic clay (CH)	21	0.058	0.0087	0.004	93	41
Sandy clay (CH)	13	0.123	0.0360	0.014	78	31

41. A few of the samples classified as a silty sand (SM), clayey (SC), or poorly graded sand (SP). This reflects the variable nature of material encountered in a confined disposal area caused by the sedimentation process of dredged material having significant amounts of both coarse-grained and fine-grained material. Coarse-grained material generally settled near the discharge location while finer material was carried toward the weirs.

42. Some of the samples taken from the 7.5- to 10.0- and 10.0- to 12.5-foot depths classified as organic clay (OH). This material is the natural foundation material later overlain by dredged material.

43. Atterberg Limits were determined for 33 dredged material samples and are shown plotted on the plasticity chart presented in Figure 17. The data are also summarized in Table 2. The Atterberg Limits tests included determination of the sticky limit, the water content above which the mixture of soil and water will adhere to a steel spatula, in addition to the usual liquid and plastic limits. The limits for the UPB material plotted parallel to and slightly above the "A" line, the arbitrary boundary between the inorganic clays (CL and CH) and inorganic silts and organic clays (ML, MH, OL, and OH). Materials that plot parallel to the "A" line are usually of similar geologic origin and composition. The fact that the trend was above the "A" line indicates that the material behaves and classifies as inorganic clay CH though it contains significant amounts of organic material and exhibits the characteristic black color and odor of organic clays.

44. The liquid limit of the material was generally well above

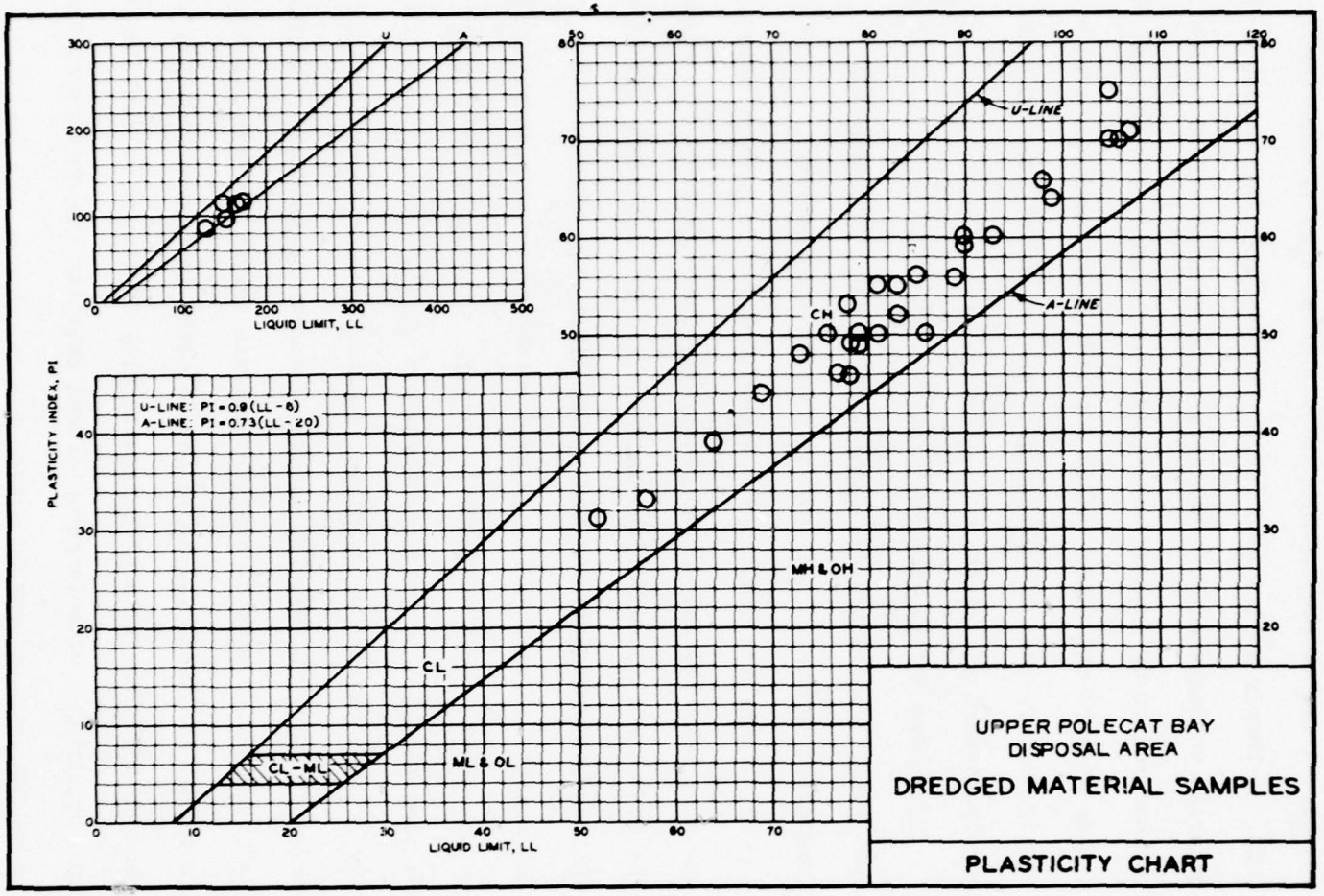


Figure 17. Plasticity chart for dredged material

Table 2

Atterberg Limits Summary for Dredged Material

Boring	Sample	USCS Classification	Liquid Limit LL	Plastic Limit PL	Sticky Limit StL	Plasticity Index PI	Water Content w_n	Liquidity Index I_L
BI-3	1	CH	150	33	95	117	135	0.87
	2	CH	99	35	49	64	130	1.48
	3	CH	86	36	48	50	77	0.82
	4	CH	89	33	50	56	91	1.03
BI-4	1	CH	105	35	51	70	103	0.97
	2	CH	77	31	46	46	86	1.20
	3	CH	79	30	36	49	75	0.92
	4	CH	105	30	49	75	149	1.59
BI-8	1	CH	165	52	115	113	183	1.16
	2	CH	98	32	42	66	113	1.23
	3	CH	78	25	40	53	98	1.38
	4	CH	69	25	52	44	73	1.09
BI-9	1	CH	106	36	53	70	180	2.06
	2	CH	76	26	33	50	134	2.16
	3	CH	85	29	44	56	83	0.96
	4	CH	57	24	33	33	194	5.15
BI-12	1	CH	130	47	74	83	131	1.01
	2	CH	81	26	40	55	89	1.15
	3	CH	79	29	40	50	78	0.98
	4	CH	52	21	30	31	40	0.61
BI-16	1	CH	171	56	97	115	109	0.46
	2	CH	93	33	50	60	88	0.92
	3	CH	83	31	46	52	87	1.08
	4	CH	107	36	50	71	180	2.03
BI-19	1	CH	90	31	47	59	96	1.10
	2	CH	78	27	41	51	79	1.02
	3	CH	90	30	48	60	81	0.85
BI-22	1	CH	81	31	48	50	77	0.92
	2	CH	64	25	35	39	44	0.49
BI-24	1	CH	107	36	71	71	126	1.26
	2	CH	78	29	44	49	99	1.43
	3	CH	73	25	36	48	71	0.96
	4	CH	83	28	42	55	65	0.67

50 percent indicating a high degree of compressibility. This fact was substantiated by the consolidation tests. Generally high values of both the liquid limit and plasticity index indicate that the UPB dredged material should exhibit a high degree of shrinkage when water is evaporated.[11]

45. Values for Liquidity Index, I_L,* were computed for the UPB dredged material using the following relationship:

$$I_L = \frac{w_n - PL}{LL - PL} = \frac{w_n - PL}{PI} \qquad (1)$$

where

I_L = Liquidity Index, in percent

w_n = Natural water content, in percent

LL = Liquid Limit, in percent

PL = Plastic Limit, in percent

PI = Plastic Index, in percent

46. As can be seen from the above equation, material with a natural water content equal to the Liquid Limit (LL) has a Liquidity Index of unity. A majority of the samples had a Liquidity Index close to and above unity, indicating material behavior similar to a viscous liquid. This was later substantiated during the trenching activities when problems were encountered with dredged material flowing back into the excavated trenches.

47. Trends of liquid limit, plastic limit, and natural water content versus depth for dredged material samples are shown in Figure 18. Both the high and low value and the average value of the parameters are shown plotted versus sample depth. All of these parameters have

* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix E).

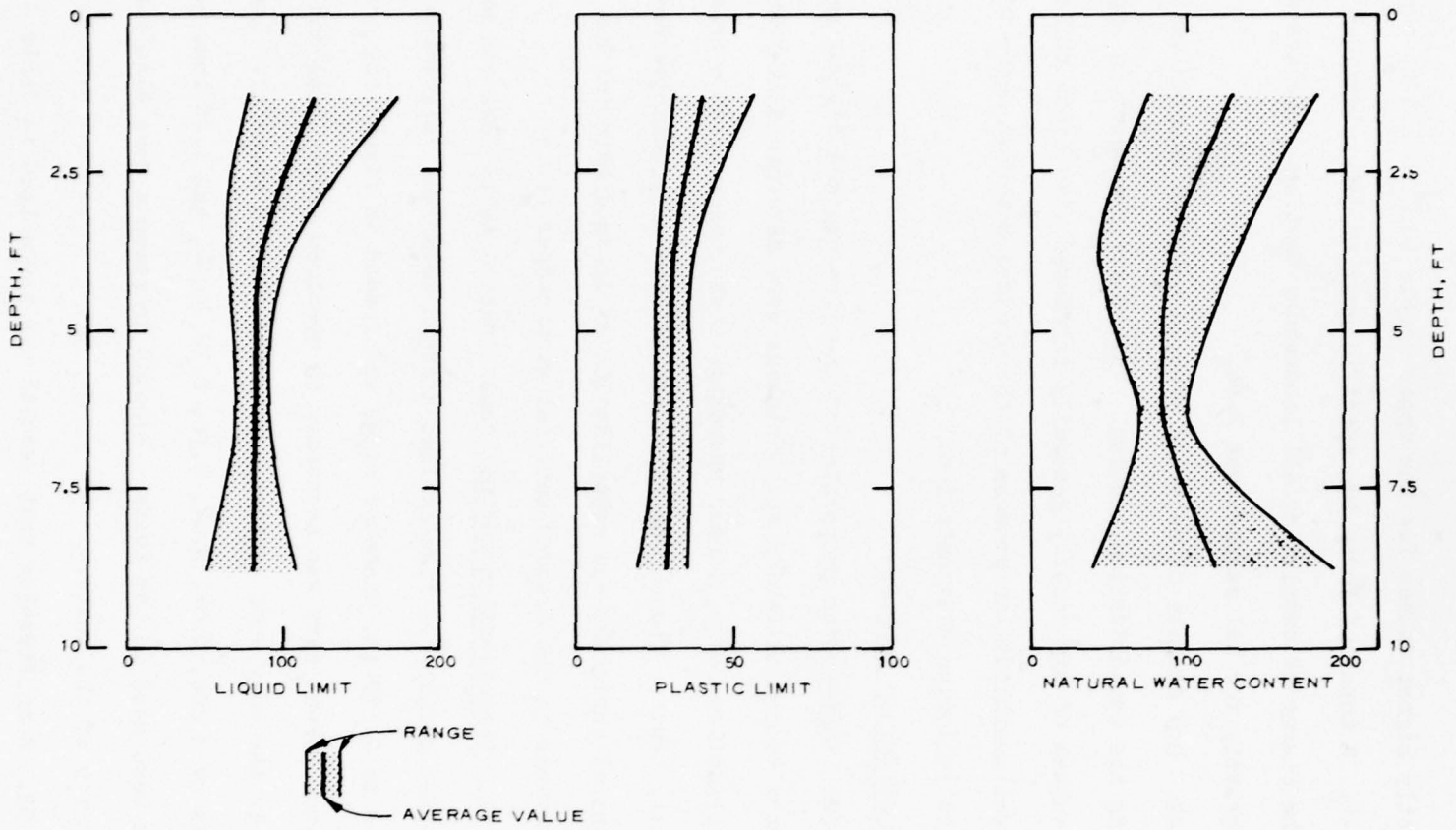


Figure 18. Atterberg Limits trend with depth

slightly higher values for the upper sample (0.0 to 2.5 ft depth).

48. A total of forty two specific gravity determinations were made in the course of completing all laboratory testing. The average specific gravity for all samples was 2.66.

49. Dry density of selected dredged material samples was determined during the consolidation testing. Values are presented in Appendix B. The values of dry density generally increased with depth reflecting the natural consolidation process of the dredged material under its own weight following sedimentation.

Engineering properties

50. Engineering properties of the fine-grained dredged material as related to consolidation and shrinkage were determined by results of consolidation tests, linear shrinkage tests, and variable head permeability tests. These properties can be used in predictive analysis of potential shrinkage and consolidation of dredged material due to possible reductions in the dredged material groundwater table.

51. Consolidation tests. Consolidation tests were run on twenty selected samples of fine-grained dredged material. Specimens were prepared in 2-1/2-in. diameter rings and loaded in fixed ring consolidometers. Great care was necessary in specimen preparation and loading due to the very soft consistency of the dredged material. Load increments of 0.004, 0.04, 0.08, 0.16, 0.32, 0.64, and 1.28 tons per square foot were used in the tests. Rebound increments were also run on a majority of the tests.

52. Consolidation test results are summarized in Table 3 and

Table 3

Summary of Consolidation Test Results

Sample No.	Classification	C_c	P_c psf	e_o	Natural w_o	Dry Density pcf	G_s
BI-2-2	CH	1.084	220	3.44	126.4	38.0	2.70
BI-3-1	CH	1.139	270	3.27	119.8	36.0	2.46
BI-3-2	CH	1.148	168	3.45	128.9	37.3	2.66
BI-3-3	CH	0.956	270	2.82	99.6	44.8	2.74
BI-3-4	CH	0.785	248	2.58	88.2	47.8	2.74
BI-3-5	OH	2.099	580	4.04	158.5	29.5	2.38
BI-4-1	CH	1.259	322	3.64	133.1	36.4	2.70
BI-4-2	CH	1.013	228	3.14	117.4	40.0	2.65
BI-4-3	CH	0.600	190	2.10	76.9	53.7	2.67
BI-4-4	CH	0.707	244	2.20	77.7	53.2	2.73
BI-4-5	OH	1.460	520	2.90	111.6	39.2	2.45
BI-8-2	CH	1.036	140	3.20	115.3	40.4	2.72
BI-9-2	CH	1.103	106	3.71	133.0	35.9	2.71
BI-10-2	CH	0.770	236	2.59	92.2	47.1	2.71
BI-12-2	CH	0.860	222	2.83	103.3	44.5	2.73
BI-16-2	CH	1.243	172	3.87	138.6	35.0	2.73
BI-19-2	CH	0.945	276	2.78	100.3	44.7	2.71
BI-21-2	CH	1.041	264	3.12	108.9	41.2	2.72
BI-23-2	CH	0.966	284	2.80	99.7	44.6	2.72
BI-24-2	CH	0.948	186	2.57	90.8	47.2	2.70

Appendix B. Individual test results including plots of void ratio versus log of load (e-log P) and time-consolidation data are available in Reference 10.

53. Values of the compression index, Cc, and preconsolidation pressure, Pc, were determined from plots of void ratio versus pressure and are presented in Table 3. Laboratory consolidation tests on sedimented material usually indicate an overconsolidated condition until the effective overburden stress is exceeded.[12] This behavior was exhibited by the UPB dredged material with the higher load increments for all tests yielding straight-line relationships and clearly defined values for Cc. A typical void ratio-log pressure curve for the dredged material tested is shown in Figure 19.

54. Values for preconsolidation pressure, Pc, were determined by accepted graphical construction methods.[13] For the samples from shallow depths (0.0 to 2.5 feet) Pc values were generally higher than present overburden pressures. This difference could possibly be due to desiccation of the upper layers occurring during natural surface drying and crust formation. Also, previous laboratory consolidation testing on dredged material indicates that Pc values greater than overburden may be attributable to sample disturbance during trimming and frictional resistance of the rings during the conventional consolidation test.[14]

55. Values of the compression index, Cc, varied between 0.60 and 1.26 for the clay (CH) dredged material, with an average value of 0.916. Organic clay (OH) samples yielded higher values representative of the natural marsh foundation material. Compression index is normally

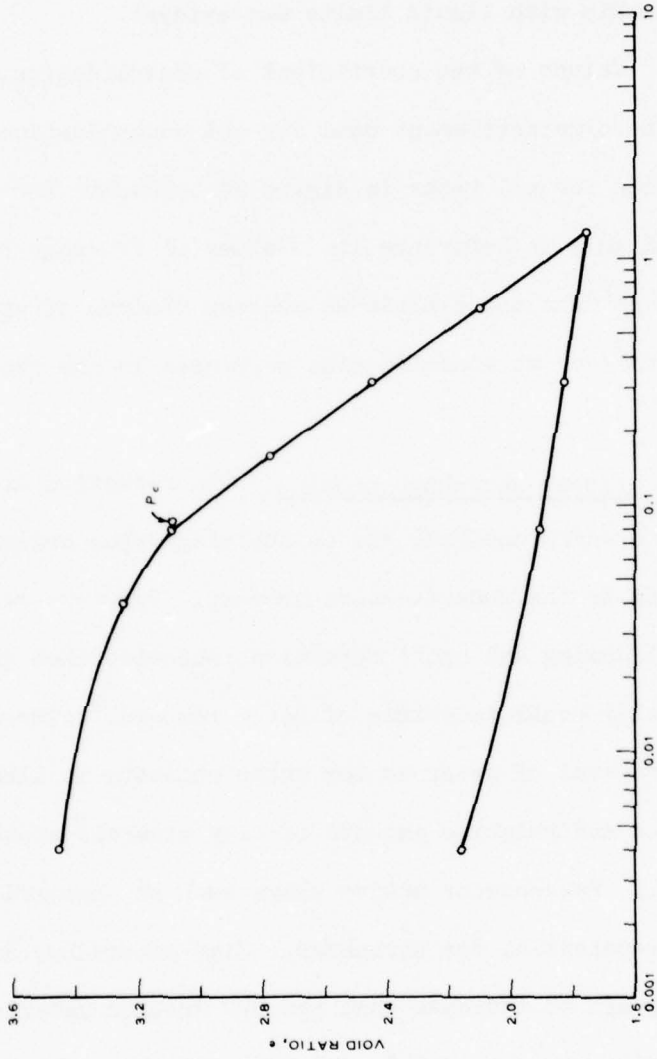


Figure 19. Typical void ratio log pressure plot for dredged material

related with the liquid limit for natural soils. The UPB dredged material did not cover a significant range of liquid limits and no relationship with liquid limits was evident.

56. Values of the coefficient of consolidation, Cv, were computed using the time settlement data for 50% consolidation. These values are summarized for all tests in Figure 20. Results for individual tests are available in Reference 10. Values of Cv range between 0.00004 and 0.00130 cm^2/sec and exhibit an average minimum of approximately 0.0003 cm^2/sec at consolidation pressures in the range of 0.08 to 0.16 tsf.

57. *Linear shrinkage testing*. The reduction in volume of a fine-grained dredged material due to shrinkage upon drying is a major contribution to the densification process. Previous research on dredged material drying and crust formation indicated that volume reduction is essentially equal to volume of water removed.[5] The change in volume due to removal of water at low water contents is also dependent upon the types and relative amounts of clay minerals present in the dredged material. Presence of active clays such as montmorillonite indicate a higher potential for shrinkage. Clay mineralogy analyses as described in paragraph 68 indicate that the UPB dredged material has a montmorillonite content of 25%, and therefore has a high shrinkage potential.

58. In a field site the actual volume of water removed through evaporation would be impossible to determine. Further, if the actual volume reduction is equal to volume of water removed, the magnitude of reduction in terms of original volume is dependent on the initial water

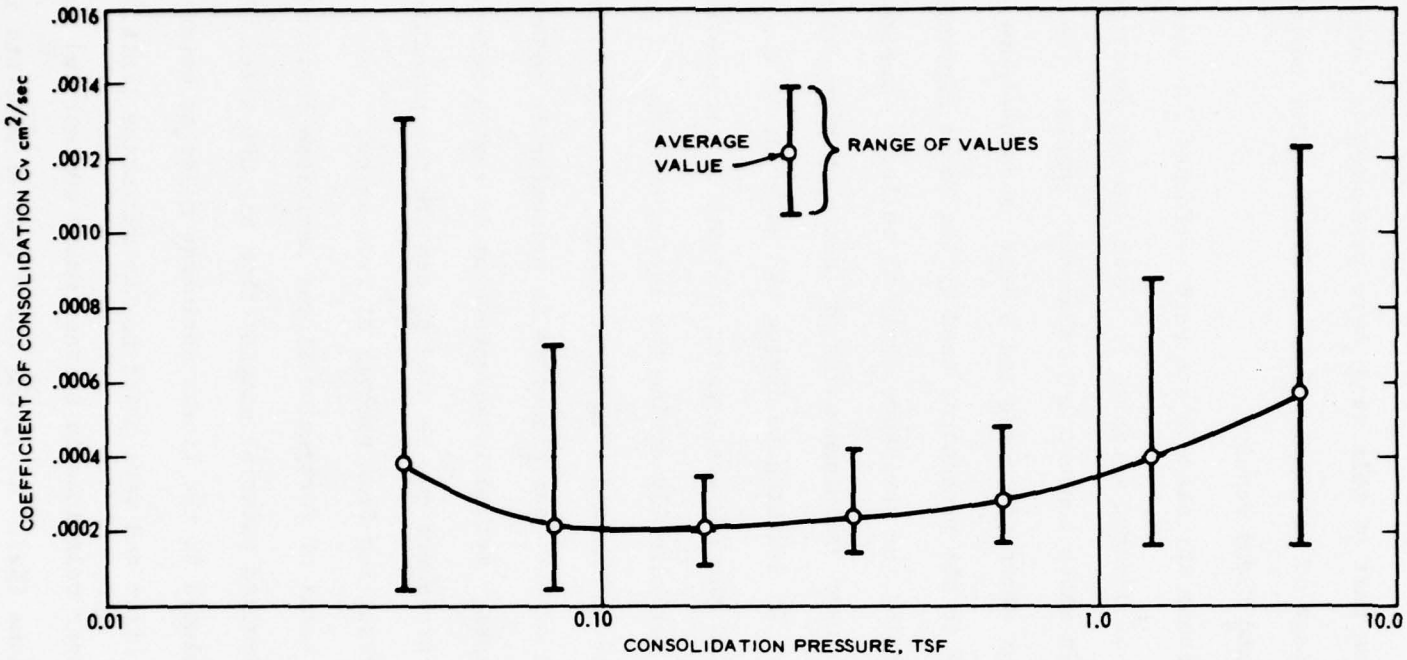


Figure 20. Relationship of consolidation pressure and coefficient of consolidation

content or void ratio. Therefore, results of linear shrinkage tests performed as part of this study were presented in terms of water content and percentage of original volume to allow easier comparison of laboratory data and field results.

59. Linear shrinkage tests were performed for this study on selected samples of dredged material to establish the relationship of reduction in water content and volumetric change. The tests were run using linear shrinkage molds and a test procedure developed for this study based on the procedures used by the Texas Highway Department (THD) for determining the shrinkage limit of soils.[15] Dredged material was placed in linear shrinkage molds at initially high water contents and oven-dried. In addition to drying the material to the shrinkage limit as called for in the THD test, water contents and volumetric changes were determined periodically during the drying process. A correlation between water content and volumetric change was then determined. A full description of the test procedure is presented in reference 10. The linear shrinkage method is advantageous in that a relatively simple laboratory procedure can be used to confirm the potential volumetric reduction resulting from removal of free water.

60. A total of forty-nine linear shrinkage tests were performed on clay (CH) dredged material samples from the UPB site. The samples were initially placed in the linear shrinkage molds at water contents above the Liquid Limit and were dried to the shrinkage limit. All tests indicated a linear relationship between water content (w) and percent of initial volume (%v). A typical curve from these tests is presented in

Figure 21. This behavior can simply be expressed as:

$$\Delta V\% = \frac{\Delta W}{C_s} \qquad (2)$$

where

$\Delta V\%$ = Change in volume expressed on a percent of original volume

ΔW = Change in water content, percent

C_s = Coefficient of shrinkage

The coefficient at shrinkage, C_s, is simply the slope of the straight-line curve relating water content and percent of initial volume. The average value for C_s for all tests was 2.34. Average volume reduction was equal to the volume of water removed for all tests. Differences in the values of C_s were therefore directly attributed to differences in the initial water content of the samples. Summary of results for all tests are summarized in Table 4.

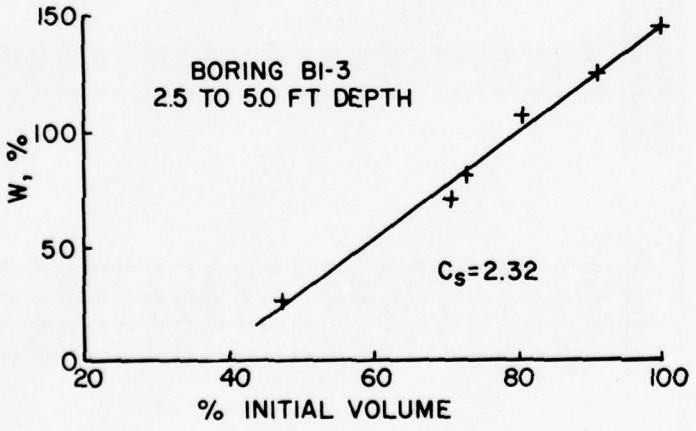


Figure 21. Typical linear shrinkage curve for dredged material tested

Table 4

Summary of Shrinkage Test Results

Boring	Depth, ft	Coefficient of Shrinkage, C_s	Boring	Depth, ft	Coefficient of Shrinkage, C_s
BI-1	2.5-5.0	2.66	BI-15	0.0-2.5	4.72
BI-2	2.5-5.0	2.22		2.5-5.0	1.91
BI-3	0.0-2.5	2.45		5.0-7.5	1.99
	2.5-5.0	2.32	BI-16	0.0-2.5	3.03
	5.0-7.5	2.43		2.5-5.0	2.23
BI-4	0.0-2.5	2.32		5.0-7.5	2.02
	2.5-5.0	1.97		7.5-10.0	2.09
	5.0-7.5	2.13	BI-17	0.0-2.5	2.32
	7.5-10.0	3.66		2.5-5.0	2.38
BI-6	2.5-5.0	1.91		5.0-7.5	2.00
BI-7	2.5-5.0	1.84	BI-18	2.5-5.0	1.96
BI-8	2.5-5.0	2.00	BI-19	2.5-5.0	2.01
BI-9	2.5-5.0	1.68		5.0-7.5	2.20
BI-10	2.5-5.0	2.22	BI-20	0.0-2.5	1.89
BI-11	0.0-2.5	5.51		2.5-5.0	2.08
	2.5-5.0	2.08		5.0-7.5	2.46
BI-12	2.5-5.0	2.19		7.5-10.0	2.71
	5.0-7.5	2.00	BI-21	2.5-5.0	2.25
	7.5-10.0	1.59	BI-22	2.5-5.0	1.75
BI-13	0.0-2.5	3.62	BI-23	2.5-5.0	1.88
	2.5-5.0	1.94	BI-24	2.5-5.0	2.13
	5.0-7.5	2.13	BI-26	2.5-5.0	1.93
	7.5-10.0	1.73			
BI-14	0.0-2.5	4.38			
	2.5-5.0	1.95			
	5.0-7.5	1.91			
	7.5-10.0	1.82			

61. At low water contents, repulsion between particles tends to limit volume reduction, slightly affecting the linear relationship. Previous research regarding soil drying and shrinking has also indicated a deviation from a straight linear relationship at low water contents.[5] However, since extremely low water contents cannot be achieved by dredged material dewatering and densification techniques now available, it was therefore concluded that a simple straight line relationship as shown by the typical shrinkage test in Figure 21 is more representative of the field drying that can be practically achieved.

62. Permeability. Values for the coefficient of permeability, k, for the dredged material were determined by laboratory consolidation test data and by variable head field permeability tests. Consolidation test data were used to compute values of k using the following relationship:[16]

$$k = \frac{0.2\gamma_w a_v H^2}{(1-e_o)t_{50}} \qquad (3)$$

where

γ_w = Unit weight of water, g/cm^3

a_v = Slope of the void ratio-pressure curve for the initial load increment, cm^2/g

H = One-half the specimen height, cm

e_o = Initial void ratio

t_{50} = Elapsed time for 50% consolidation for the initial load increment, sec

63. Computed values of k are shown plotted in Figure 22 for various consolidation pressures. This plot indicates an average value of 1×10^{-7} cm/sec.

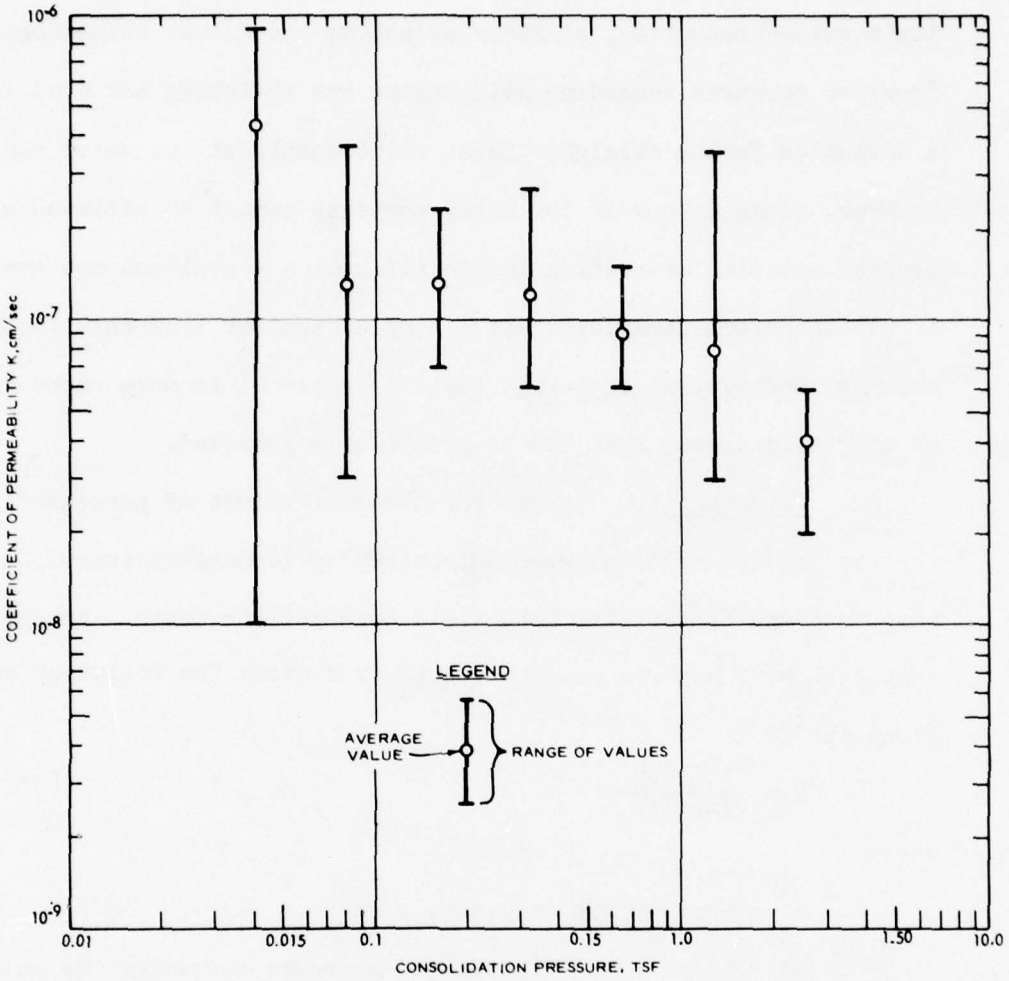


Figure 22. Relationship of consolidation pressure and coefficient of permeability

64. Variable head tests were run on fourteen small diameter wellpoints installed at the UPB site. Locations of the wellpoints are shown in Figure 12. The points were of the Casagrande type and were constructed using 6-in. lengths of 1-in.-I.D. x 1-1/2-in.-O.D. porous stone and 1/2-in.-I.D. Saran tubing risers encased in 3/4-in.-PVC pipe. Twleve of the points

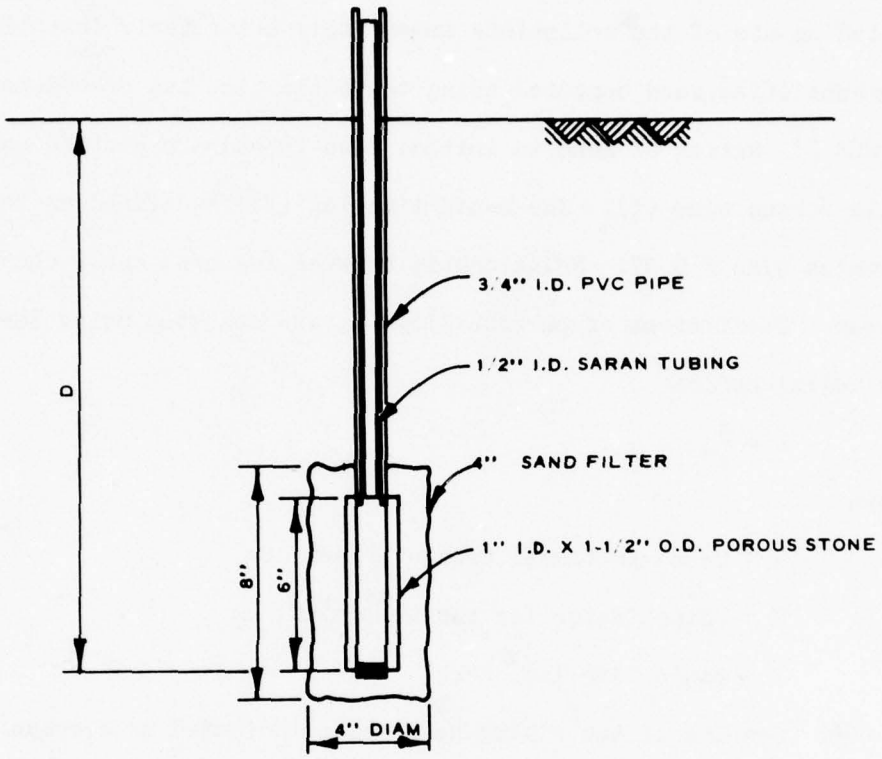


Figure 23. Wellpoint detail

were encased in 4-in.-diameter sand filters held in place by nylon meshing. This was done to avoid possible smearing of the porous stone by the fine-grained dredged material. Points were seated at various depths below ground surface by hand pushing a 4-in.-I.D. outer PVC pipe containing the tip and riser into the dredged material below the hardened crust, lifting the outer pipe, and leaving the riser, filter, and tip at the desired depth. Details of the installation are shown in Figure 23.

Depths of installation and other pertinent data are summarized in Table 5.

65. Ten falling head tests and seven rising head tests were conducted on six of the wellpoints immediately after their installation. Permeabilities were computed using the basic time lag procedure developed by WES.[17] Ratios of head to initial head (h/ho) are plotted on the log scale versus time (t). The basic time lag (T) is defined as the time t at which h/ho = 0.37. Relationship between log h/ho and t should be linear. Coefficient of permeability, k, was computed using the following relationship:

$$k = \frac{A}{FT} \tag{4}$$

where

A = Cross-sectional area of riser, cm^2

F = Shape factor for the wellpoint, cm

T = Basic time lag, sec

66. Results of the rising head tests indicated an average value for k of 2.5×10^{-5} cm/sec, significantly higher than permeability values as determined from consolidation test data. This indicates that the mass permeability of the UPB dredged material is significantly higher than that indicated by laboratory size specimens, probably due to the presence of organic material, wood chips, silt and sand lenses, etc. The rising head tests also indicated higher permeability at the southernmost wellpoints C-8, C-9, and C-12, located as shown in Figure 12.

67. Falling head test results indicated an average value for k of 2.5×10^{-4} cm/sec. In these tests the head could not be raised above 1.29 ft. Relationship of head ratios with time also appeared nonlinear,

Table 5

Variable Head Permeability Test Results

Well-point	Tip Depth ft	Filter	Type Test	Initial Head ft	Coefficient of Permeability k , cm/sec
C-1	7.6	Sand*	Falling head	0.84	7.7×10^{-5}
			Falling head	0.76	8.8×10^{-5}
C-2	5.0	Sand	Rising head	3.52	0.5×10^{-5}
			Falling head	0.58	10.3×10^{-5}
			Falling head	0.71	20.5×10^{-5}
C-3	3.0	Sand	Falling head	0.48	1.5×10^{-5}
			Falling head	1.29	12.3×10^{-5}
C-4	8.0	Sand	None	--	--
C-5	3.2	Sand	Rising head	1.76	1.0×10^{-5}
C-6	5.0	Sand	Rising head	4.35	0.4×10^{-5}
C-7	8.5	Sand	Falling head	0.48	20.5×10^{-5}
			Falling head	1.09	61.5×10^{-5}
C-8	7.0	Sand	Rising head	1.91	3.8×10^{-5}
			Falling head	0.49	61.5×10^{-5}
C-9	5.0	Sand	Rising head	2.21	1.4×10^{-5}
			Falling head	0.32	41.0×10^{-5}
C-10	8.3	Sand	None	--	--
C-11	6.9	Sand	Rising head	2.25	2.6×10^{-5}
C-12	5.0	Sand	Rising head	0.44	7.7×10^{-5}
T-1	8.0	None	None	--	--
T-2	7.9	None	None	--	--

* See Figure 23.

suggesting that hydraulic fracturing of the soft underlying dredged material might be occurring. Other research confirmed that hydraulic fracturing does occur in the UPB dredged material with heads of approximately one ft.[18] More reliance should therefore be placed on rising head test results.

Clay mineralogy

68. A petrographic analysis of six samples of clay (CH) dredged material from the UPB site was performed by the WES Concrete Laboratory.[19] X-ray diffraction methods were used to determine the mineralogical composition with special emphasis on clay mineralogy and clay content.[20,21] Four qualitative and two quantitative analyses were performed with results presented in Tables 6 and 7. The samples were generally composed of montmorillonitic and chloritic clays, clay mica, quartz, and traces of other nonclay minerals. Organic content determined by ignition loss was five percent.

Table 6

Qualitative Mineral Composition of Dredged Material*

Constituents**	Samples					
	CL-7 SS-1, BI-1 No. 33	CL-7 SS-2, BI-6 No. 3	CL-7 SS-3, BI-2 No. 3	CL-7 SS-4, BI-13 No. 2	CL-7 SS-5, BI-16 No. 2	CL-7 SS-6, BI-19 No. 2
Clays						
Montmorillonite	C	C	C	C	C	C
Chlorite	C	C	C	C	C	C
Clay-mica	M	M	R	M	M	M
Kaolinite	R	R	R	R	R	R
Nonclays						
Quartz	I	I	I	I	I	I
Potassium feldspar	R	R	N.D.†	R	R	R
Plagioclase feldspar	R	R	R	R	R	R
Halite	R	R	R	R	R	R
Hematite	N.D.	N.D.	R	M	N.D.	R
Calcite	N.D.	N.D.	R	R	N.D.	N.D.

* Determined by X-ray diffraction.

** Relative amounts are indicated in the table. Intermediate (I), 25-50 percent; common (C), 10-25 percent; minor (M), 5-10 percent; rare (R), <5 percent.

† Not detected.

Table 7

Quantitative Mineral Composition of Dredged Material

Constituents	Samples* CL-7 SS-1, BI-1 No. 3	CL-7 SS-2, BI-6 No. 3
Clays		
Montmorillonite	25	25
Chlorite	25	20
Clay-mica	10	10
Kaolinite	Trace	Trace
Subtotal	60	55
Nonclays		
Quartz	30	35
Feldspars	--	5
Calcite and hematite	5	Present
Halite	--	--
Organic material	5	5
Subtotal	40	45
TOTAL	100	100

* Amounts of constituents given as percentages.

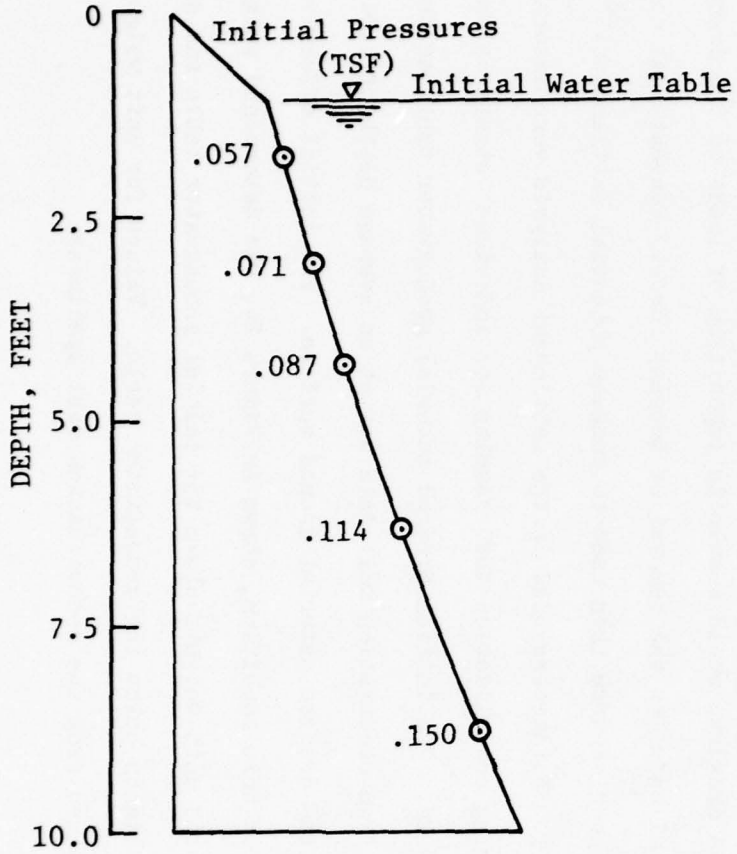
PART IV: PREDICTIVE ANALYSIS

69. Predictive analyses were conducted to determine potential surface settlement of the progressive trenching study area due to consolidation and shrinkage. Data accumulated from the field and laboratory investigations were used to perform the analyses and were then correlated with actual field results. Formulation of such an analysis will enable extrapolation of study results to other dredged materials and site conditions.

Potential Consolidation of Dredged Material

70. Results of consolidation tests performed on undisturbed samples were used to predict potential consolidation of dredged material due to drawdown of the dredged material groundwater table. The analysis assumed drawdown would result in imposition of loads on the dredged material equal to the removal of bouyant force. Conventional consolidation theories were then used to compute potential settlements.[22]

71. Parameters used in the settlement analysis were determined by averaging consolidation test results for individual strata as shown in Figure 24. The initial dredged material groundwater table as determined from observation well data was at an average depth of 1.24 feet below the dredged material ground surface. The initial effective stress plot for this condition, shown in Figure 24, was determined using saturated unit weights above the initial groundwater table and submerged unit weights below the groundwater table. Values for unit weights were determined from the consolidation test specimens.



H (ft)	e_1	C_c	C_s	LL %	PL %	PI %
1.25	3.45	1.20	3.35	123	39	83
1.25	2.92	1.01	2.06	83	29	53
1.25	2.83	1.01	2.06	83	29	53
2.50	2.30	0.78	2.12	81	29	52
2.50	2.17	0.75	2.26	80	28	52

Figure 24. Average consolidation and shrinkage data for settlement analysis

72. Individual settlements for each strata indicated in Figure 24 were computed using the relationship:

$$\Delta H = H \frac{C_c}{1 + e_1} \log \frac{P_2}{P_1} \qquad (5)$$

where

ΔH = Settlement of the strata under consideration, ft.

H = Thickness of strata, ft.

C_c = Compression index, average of all tests for respective strata

P_1 = Initial pressure at center of strata, tsf

P_2 = Final pressure at center of strata, tsf

e_1 = Initial void ratio at pressure P_1

73. Virgin consolidation curves were constructed for each test using the extended straight-line portion of the void ratio-log pressure plots. Values for the initial field void ratio, e_1, were determined using intersection of the initial pressure at the center of the strata, P_1, and the constructed virgin curve.

74. The total settlement due to consolidation for a given drawdown was determined by adding the contribution of each strata. The relationship of total settlement due to consolidation versus drawdown is shown plotted in Figure 25.

75. Laboratory consolidation test data indicated a permeability value of approximately 10^{-7} cm/sec for the fine-grained dredged material, while variable head tests indicated a value of approximately 10^{-5} cm/sec. Times required for various degrees of consolidation were estimated using

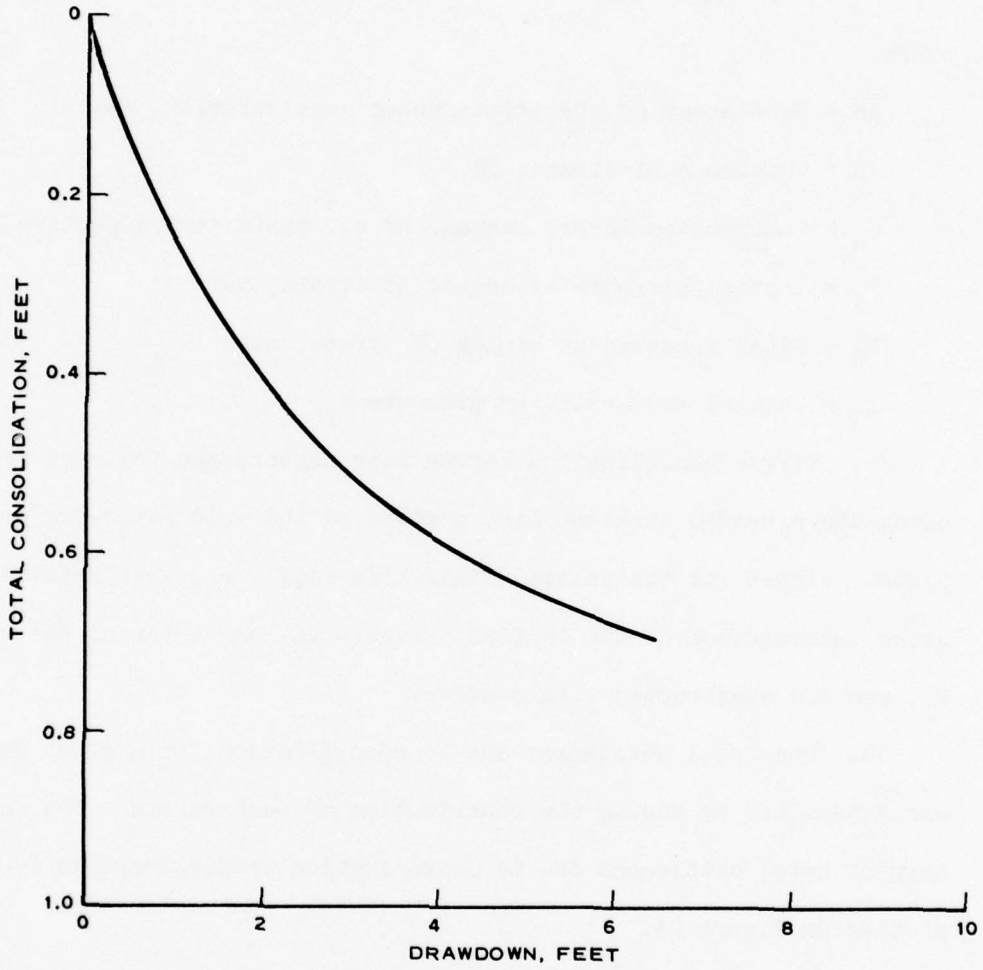


Figure 25. Potential dredged material consolidation versus drawdown

the relationship:

$$t = \frac{H^2 T}{c_v} \qquad (6)$$

where

t = Time required for consolidation, sec

H = Thickness of strata, ft

c_v = Coefficient of consolidation, cm^2/sec

T = Time factor, constant for various degrees of consolidation

76. The time relationship using variable head field permeability data reflects values of c_v of approximately 0.3 cm^2/sec which indicates that dredged material consolidation would reach 90 percent of total consolidation approximately two months following imposition of load. This time relationship is considered representative of field conditions and was used in the predictive analysis.

Potential Foundation Consolidation

77. Foundation conditions at the UPB site consist of compressible layers of organic clays (OH) and plastic clays (CH) over a majority of the progressive trenching study area. Detailed information concerning foundation conditions is presented in Appendix A. The potential for additional consolidation of foundation soils due to a water table drawdown within the dredged material is dependent upon the interaction of the dredged material water table with that initially present within the foundation soils.

78. Consolidation tests were performed on undisturbed samples of the compressible foundation soils taken both before and after placement of dredged material within the containment area. Results of these tests indicated that approximately 90% of total consolidation of the foundation soils has taken place.[10]

79. Piezometers were installed in both foundation soils and dredged material to determine possible interaction of the respective water tables. Locations of the piezometers are shown in Figure 12. Data from the piezometers presented in Appendix A indicate a perched water table condition at the UPB site. A drawdown of the water table within the dredged material would not impose higher loadings on the foundation soils with this condition in effect.[10]

80. Additional consolidation of the foundation soils induced by progressive trenching therefore was not considered in the predictive analysis and any rebound from reductions in load due to water evaporation is considered negligible.

Potential Shrinkage of Dredged Material

81. Laboratory shrinkage tests described in previous paragraphs indicate that densification of dredged material in the field will occur due to the drying and shrinkage process following a drawdown of the groundwater table. This is further substantiated by DMRP research conducted on crust formation and behavior for fine-grained dredged material.[5] This research determined that crust formation occurs down to the dredged material groundwater table.

82. Drawdown of the dredged material groundwater table in most confined disposal areas will occur over a period of a year or more as evidenced by field studies conducted at UPB site. Field experience has shown that drying and shrinkage of the dredged material keeps pace with the drawdown or lags slightly behind the drawdown, eventually forming a crust down to the lowered groundwater table. Average water contents within the crust material are usually near the plastic limit, with wetter material below the crust remaining at water contents near the liquid limit.

83. For the predictive analysis an average change in water content due to drying was assumed equal to the difference between the plastic and liquid limits at the initial groundwater table to a no change condition at the lowered dredged material groundwater table.

84. Since the area under consideration is large, the change in volumes due to shrinkage will be directly related to settlements. The coefficient of shrinkage, C_s, as defined in PART III was used to relate the average change in water content to settlement using the following relationship:

$$\Delta H = H \frac{\Delta w}{C_s} \tag{7}$$

where

ΔH = Settlement due to shrinkage, ft

H = Thickness of strata, ft

Δw = Average change in water content, percent

C_s = Coefficient of shrinkage

85. Parameters used in the analysis were determined by averaging results of laboratory shrinkage tests and Atterberg Limits tests for each

of several dredged material samples at different depths as shown in Figure 24. The relationship of potential settlement due to shrinkage versus drawdown is presented in Figure 26.

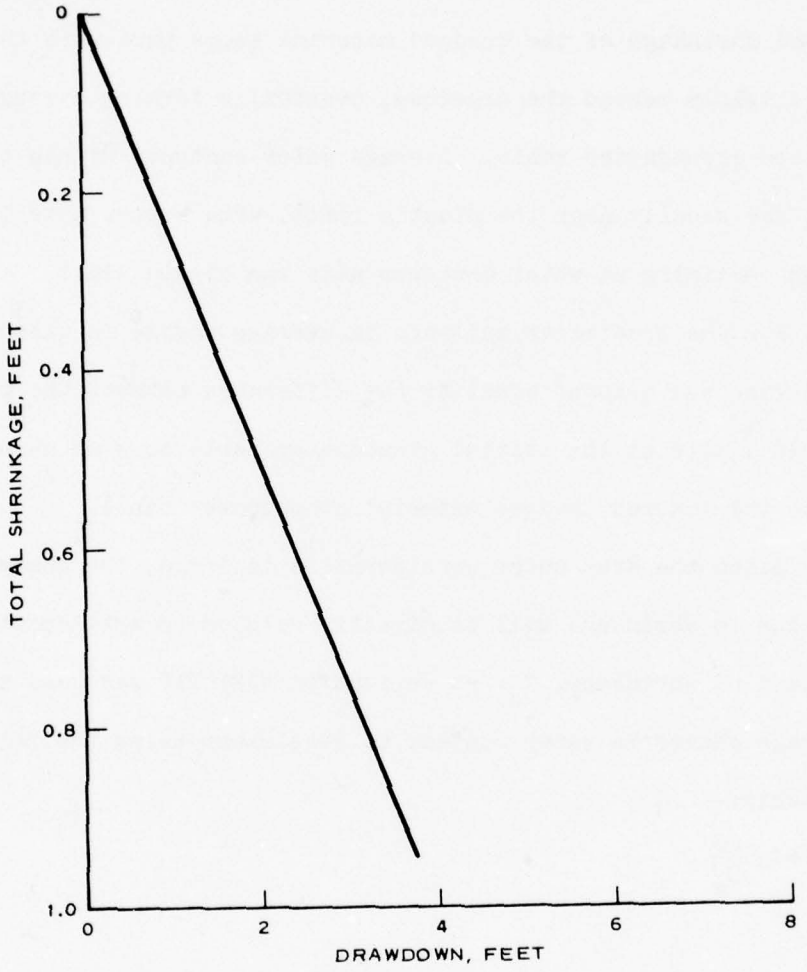


Figure 26. Potential dredged material shrinkage versus drawdown

Potential Settlement Versus Drawdown Relationship

86. The total potential settlements for various dredged material groundwater table drawdowns were determined by adding potential settlements

due to both shrinkage and consolidation. This relationship is presented in Figure 27.

87. Actual field settlements and groundwater table drawdowns in the progressive trenching study area were monitored as discussed in PART VII. The field results are also shown in Figure 27. Potential settlements determined by the predictive analysis compare favorably with actual field results.

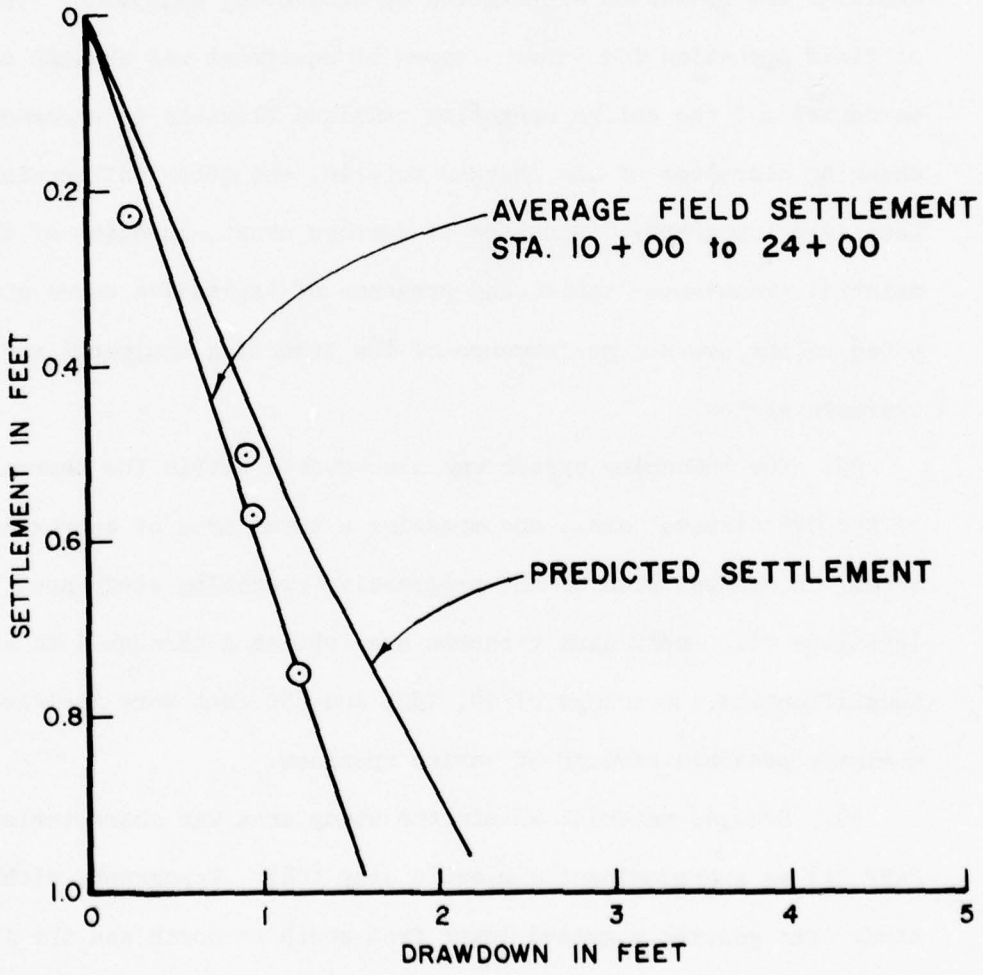


Figure 27. Potential settlement versus drawdown and field results

PART V: FIELD TRENCHING OPERATIONS

88. The field trenching program was designed to evaluate the overall effectiveness of a surface drainage system and to evaluate the trenching performance of both conventional and specialized equipment. Working conditions within a confined disposal area are unlike those encountered in any naturally occurring environment and present unusual problems for mobility and operation of vehicles or excavating equipment. The method of field operation for various types of equipment was changed as conditions warranted and the entire operation remained flexible to accommodate the changing character of the dredged material and other influencing factors. Localized topography, thickness of surface crust, location of the dredged material groundwater table, and presence of vegetative cover all contributed to the overall performance of the trenching equipment and trench drainage system.

89. The trenching system was constructed within the central portion of the UPB disposal area, encompassing a total area of approximately 60 acres. A general plan of the progressive trenching study area is presented in Figure 28. Individual trenches are labeled A through I to aid in identification. Spacings of 50, 150, and 250 feet were included to evaluate possible effects of varied spacings.

90. Dredged material within the study area was characterized in PART III as a predominantly plastic clay (CH). Topography within the study area generally graded lower from south to north and the initial crust thickness varied from approximately 8 inches opposite the south weir to approximately 2 inches opposite the north weir. The dredged

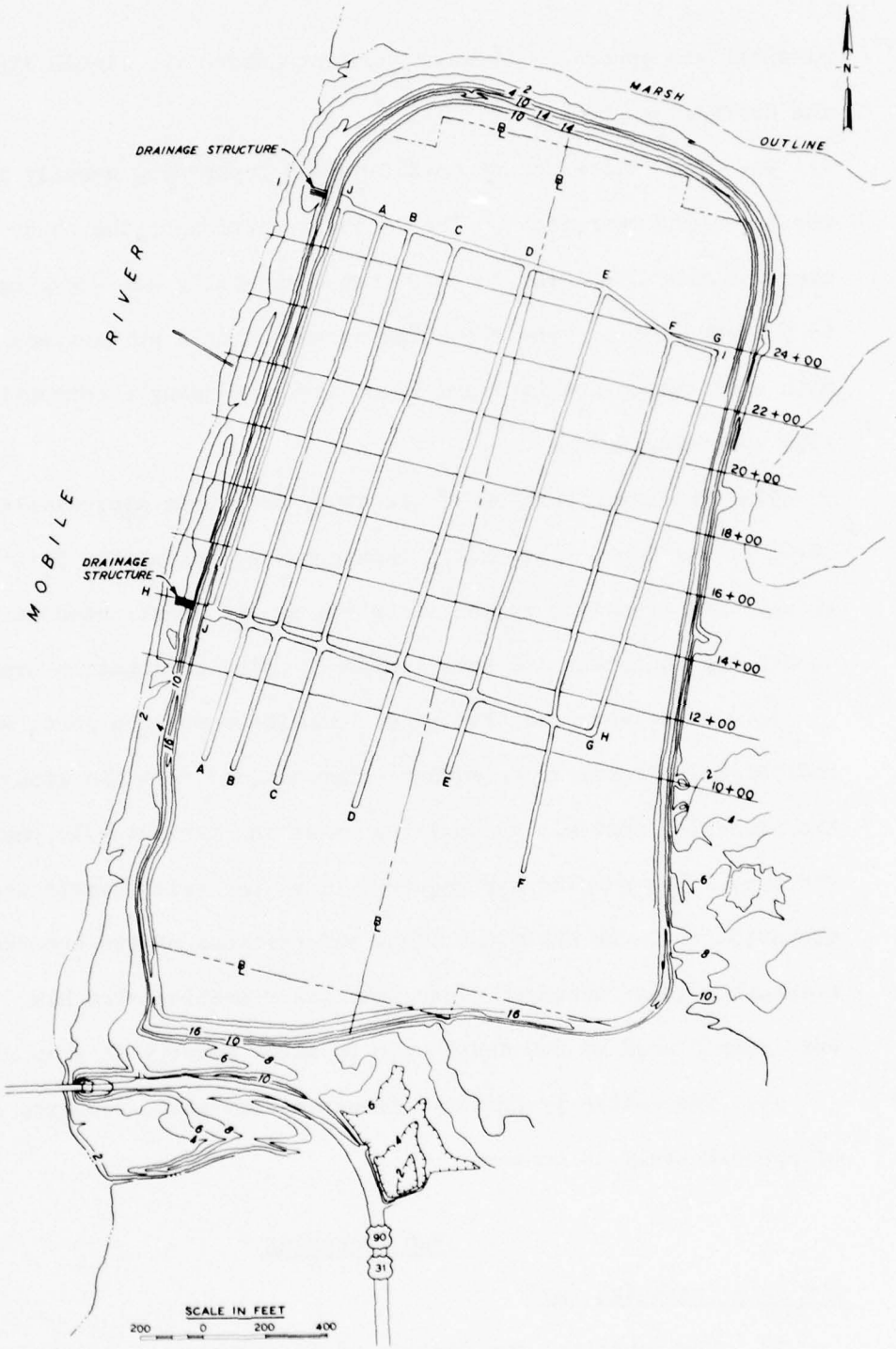


Figure 28. General plan progressive trenching study area

material was generally at water contents above the liquid limit beneath the surface crust.

91. The initial crust condition and topography greatly influenced the trenching operations. The southern portion of the study area from approximately Sta 10+00 to 16+00 had a generally well-developed crust up to 8 inches thick. The trenching system in this portion was constructed with a flotation dragline and later deepened using a conventional dragline operating on mats.

92. The north portion of the study area from approximately Sta 16+00 to 24+00 had a generally thin crust approximately 2 to 4 inches thick. The trenching system in this area was constructed using specialized amphibious equipment and later deepened using a flotation dragline.

93. Sumps were constructed at both the north and south weirs as indicated in Figure 28 to gather water drained from the study area by the trenching system. Accumulated water was periodically pumped from the area. The pumping was required since the weir inverts were set at elevation +5.0 MLW while the sumps and portions of the trenches were eventually constructed to river level at elevation +2.0 MLW. A culvert was later placed at the south weir to allow gravity flow at river elevation.

94. The entire progressive trenching operation occurred over a period of approximately 14 months.

RUC Trenching

RUC as a trenching tool

95. The potential for success of trenching as a dredged material dewatering and densification technique spawned efforts to acquire

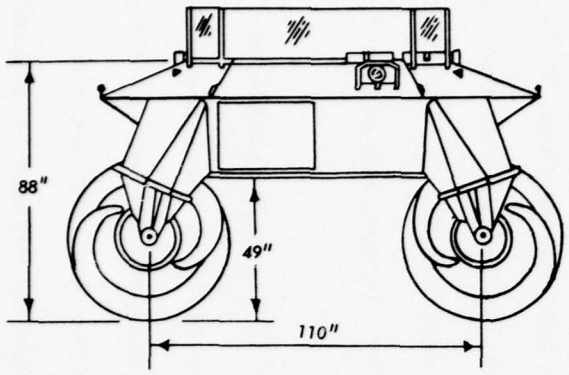
suitable equipment for use in DMRP field studies.

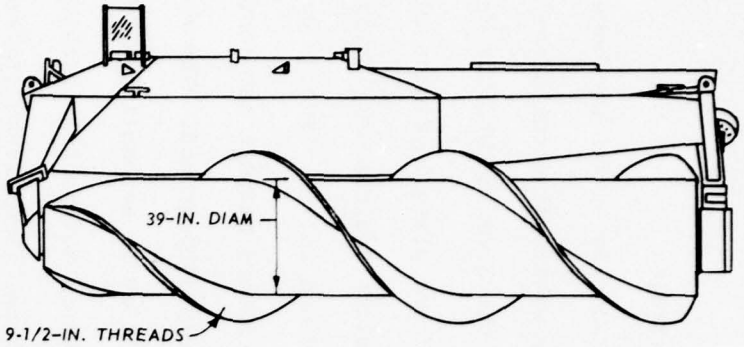
96. Several amphibious vehicles were considered for use based on preliminary data gathered for a DMRP study within disposal areas.[23] The vehicle that seemed the most suitable was the Riverine Utility Craft (RUC). General specifications for the RUC are given in Figure 29.

97. The RUC is an experimental amphibious vehicle originally developed for the U. S. Navy for reconnaisance use in the riverine environment of the Mekong Delta, South Vietnam. Twin rotors support the vehicle and serve as flotation in water or extremely soft ground. The rotors are fitted with a helical blade and propulsion is accomplished by rotation of the rotors in opposite directions. Lateral movement is possible by rotation of both rotors in the same direction. Trafficability studies for the RUC have previously been performed by the WES Mobility and Environmental Systems Laboratory (MESL).[24] Movement of the vehicle causes rutting or trenches to be formed in soft material as shown in Figure 30.

98. In many respects, the RUC is similar in appearance and operational characteristics with the Amphirol. However, the RUC is a much heavier vehicle and the rotors are over three times larger, making the RUC a much more effective trenching tool.

99. The original purpose of the RUC is its only inhibiting factor. Since the vehicle was designed solely for military reconnaisance, many features originally required serve to complicate its use for trenching. No heavy steel frame is used, and both frame and body are constructed of aluminum to lighten the vehicle. A heavier vehicle is desirable for





TO

RIVERINE UTILITY CRAFT

EMPTY WT (INCLUDING DRIVER & FUEL)	11,000 LB
GROSS WT (DRIVER, FUEL & PAYLOAD)	13,000 LB
LENGTH, FT (OVERALL)	246/12 = 20.5
WIDTH, FT (OVERALL)	168/12 = 14
HEIGHT, FT (OVERALL) (LESS WINDSHIELD)	92/12 = 7.67
ROTOR SPACING, CENTER TO CENTER, IN.	110
ROTOR DIAMETER (DRUM ONLY) IN.	39
ROTOR DIAMETER (OVER HELIX) IN.	58
ROTOR LENGTH (OVERALL) IN.	222
ROTOR LENGTH (IN CONTACT WITH GROUND, NO RUT) IN.	195
GROUND CLEARANCE, IN.	49
FLOATING DEPTH (EMPTY) IN. (WATER)	21.5
FLOATING DEPTH (LOADED) IN. (WATER)	24.0

Figure 29. Specifications of RUC

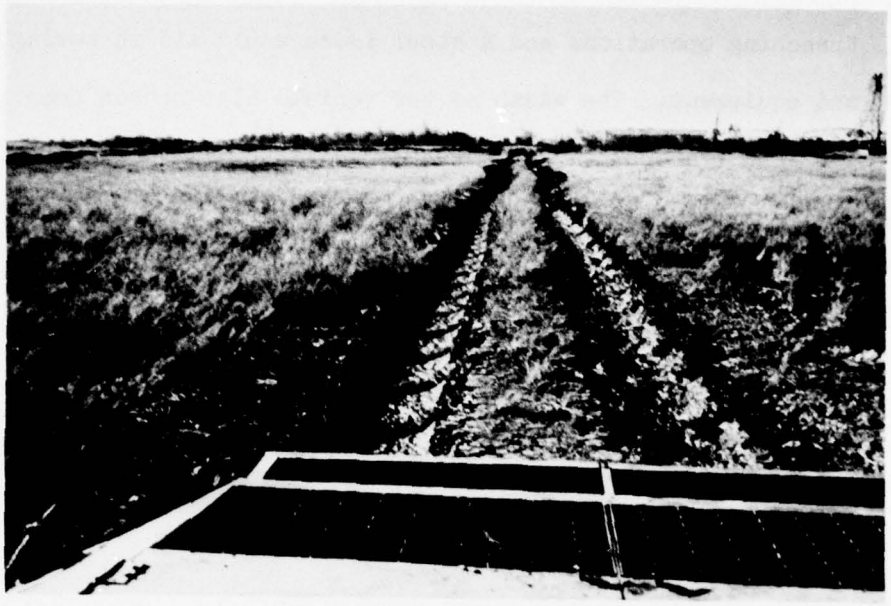


Figure 30. RUC trenches in soft dredged material

Figure 31. RUC trenches in thickly crusted area

trenching operations and a steel frame would aid in towing implements and equipment. The width of the vehicle also caused complications in overland transport. Since the legal width limit in most states is 12 feet and the vehicle width is 14 feet, the pontoons must be dismounted and the vehicle tilted during transport to meet these requirements. Disadvantages notwithstanding, the RUC proves itself as a valuable trenching tool and transportation vehicle in disposal areas. No other currently existing vehicle can hope to match the RUC's capabilities. Additional DMRP research concerning uses and performance of the RUC within disposal areas is currently underway.[25]

Operational considerations

100. Initial trenching with the RUC at the UPB study area was performed during October 1975. Trenching performance was evaluated in areas of various crust thicknesses between 2 to 8 inches between approximate stations 10+00 to 24+00 in the progressive trenching study area. Trenches A through I, shown in Figure 28, were initially constructed in this phase.

101. RUC trenching performance on thin crusted areas from approximately station 16+00 to 24+00 was good, with trench formation 4 to 8 inches deep. As crust thickness exceeded 6 inches, trenches 12 to 18 inches were formed, but the operation caused great mechanical strain on the vehicle. Typical appearances of RUC trenches in the two crust conditions are shown in Figures 30 and 31. Based on the initial evaluation, RUC trenching operations were restricted to only thinly crusted areas north of station 16+00 in all subsequent phases.

102. The efficiency of RUC-constructed trenches vary considerably with material consistency. Very wet material with water content at or in excess of the liquid limit tends to flow back into and fill the trenches after the vehicle has passed, inhibiting the efficiency of the trenches. Repeated passes of the vehicle in these trenches actually tend to re-slurry the dredged material and refill the trenches. The most effective trenching method in this environment proved to be two passes: the first to break the initially formed crust and the second to smooth and clear the trench forming a roughly semicircular depression as shown in Figure 30.

103. In stiffer material with thicker initial crusts and material near the plastic limit, repeated passes of the vehicle tended to deepen the trenches. However, the strain on the vehicle while operating in this environment prohibits extensive trenching.

104. RUC trenches are formed at generally constant depth and therefore tend to follow the natural contours of the disposal area. Bottom grading is impossible, thus efficiency of the RUC trenches is totally dependent on the topography.

105. The inability to grade RUC trenches presented some problems since isolated low areas within the UPB disposal area tended to pond surface water. A particularly troublesome area existed immediately adjacent to the north weir at the intersection of trenches A and I, located in Figure 28. The disposal area surface was generally lower near the north weir but a high spot near the weir prevented effective drainage from the RUC trenches. This condition is shown in Figure 32.

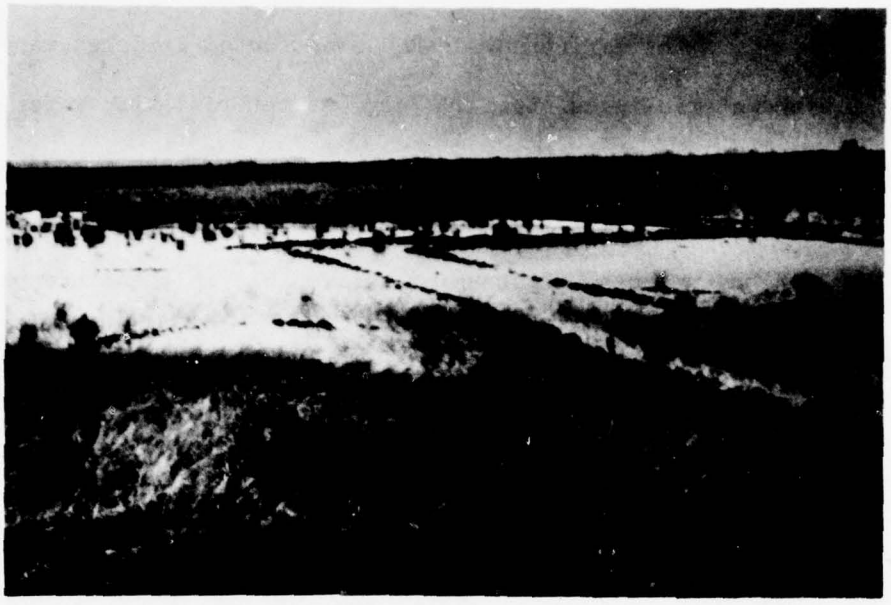


Figure 32. High area adjacent to north weir

Figure 33. Trench intersections

106. The intersection of RUC trenches also caused minor problems. The action of the pontoons that form the trenches also tend to block previously constructed trenches at the intersection as illustrated in Figure 33.

Design and use of implements

107. During December 1975 and January 1976 an extensive overhaul of the RUC was performed by the MESL at the WES. The purpose of this overhaul was to increase the general reliability and overall effectiveness of the RUC as a trenching tool. The vehicle was also fitted with an A-frame, winch, and fittings for towing various trenching implements.

108. The first implements were designed by MESL and were modeled after those successfully used in European practice. The basic configuration consisted of hollow wheels, four feet in diameter, and tapered in a V-pattern as shown in Figure 34. The wheels were designed to effectively grade and deepen the trenches and can be water-ballasted for deeper trenching capability.

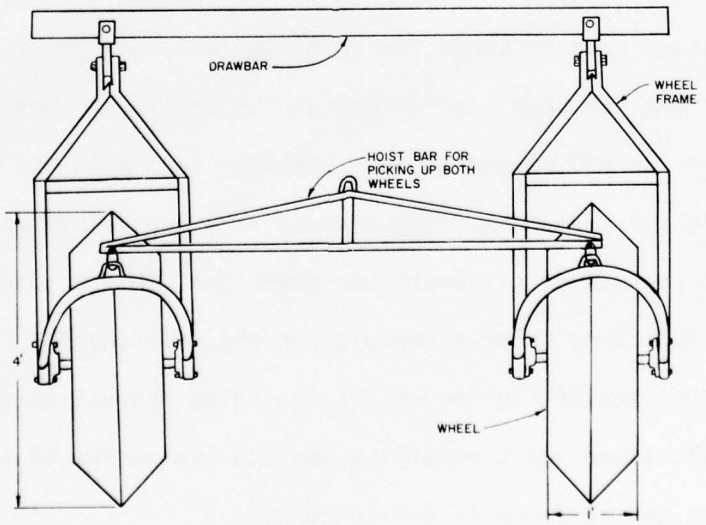


Figure 34. Specifications of wheel implements

109. RUC trenching operations with the wheel implements were performed at the UPB study area during February 1976. As in previous RUC operations, the efficiency of trenches constructed with the wheel implements was greatly dependent upon the consistency of the dredged material. The "V" formed by the wheels remained open in material well below the liquid limit, at times reaching a depth of 12 inches below the rotor depth. This condition is shown in Figure 35.

110. When operating in material at or above the liquid limit, the wheels sank below the axle level and a shearing motion tended to re-slurry the dredged material and flow material back into the trench. A view of this condition is shown in Figure 36.

111. Generally, the wheel implement did not significantly aid in deepening the trenches. The winching system also proved to have limitations in controlling the level of the wheels relative to the rotors and did not allow effective grading of the trench.

112. Other implements including discs and plows were evaluated at the UPB study area in later trenching operations. These implements generally had the same limitations as the ballasted wheels. The design-purpose of the RUC proved to be a limiting factor in the use of any implements for trenching. The absence of a heavy-duty frame for towing precluded the use of all available power the vehicle possessed. Also, fittings and frame systems employed on the existing RUC chassis did not provide the flexibility needed for trenching operations using implements. Additional data regarding use and evaluation of the trenching implements can be found in reference 25.

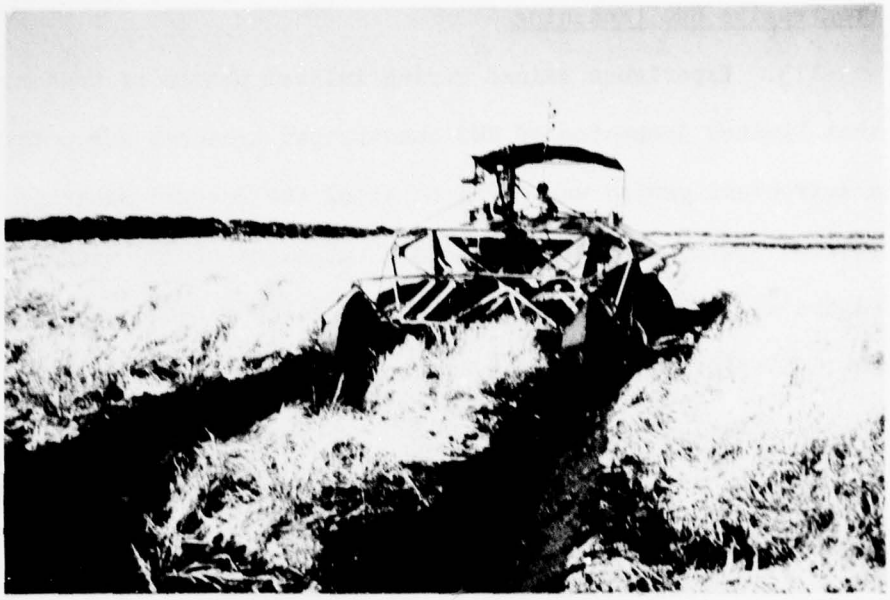


Figure 35. RUC trench formed with wheel implements

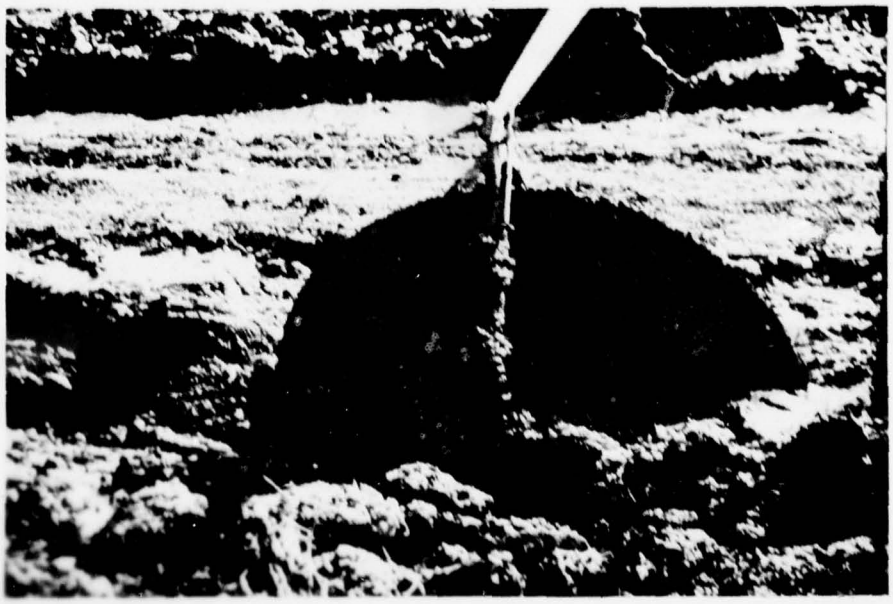


Figure 36. Dredged material re-slurry with wheel implements

Progressive RUC trenching

113. Experience gained during initial phases of trenching indicated that limited deepening of RUC constructed trenches was possible provided a sufficient period was given to allow the dredged material to dry between operations. This led to a tailoring of RUC trenching operations toward a progressive approach, during March through June 1976. Since the use of ballasted wheels did not significantly aid in trench deepening, subsequent operations were performed with rotors only. A scheme was devised for RUC movement within the study area that utilized a looping pattern resulting in only two passes of the vehicle through each trench.

114. A period of one month was allowed between RUC trenching operations. Desiccation and drying of the exposed dredged material within the RUC trenches took place during this period as shown in Figure 37. When the trenching operation was performed, the first pass over the dried material tended to throw out blocks of the dried material in a manner similar to that experienced when virgin crust material is broken. In other areas the desiccation crack patterns were smoothed, exposing wetter underlying material as shown in Figure 38. Deepening of several inches was apparent on examining the trench bottom before and after the pass. The second pass cleaned out and smoothed the ditch bottoms in all cases. As the loop pattern was formed the trench intersections were cleared by hand using a hoe. This operation was essential to ensure efficiency for removal of surface water.

115. The progressive trenching allowed the material to dry exten-

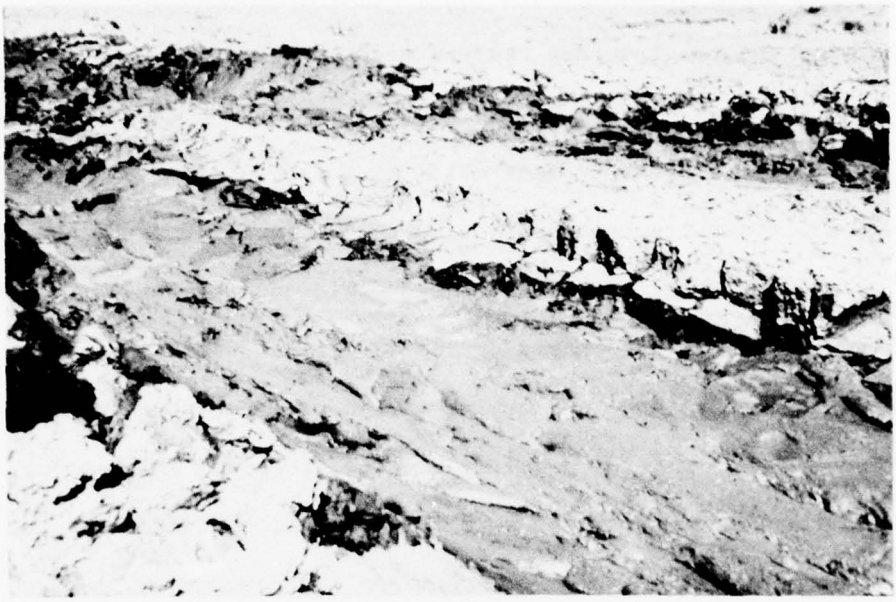


Figure 37. Dessication in RUC trenches

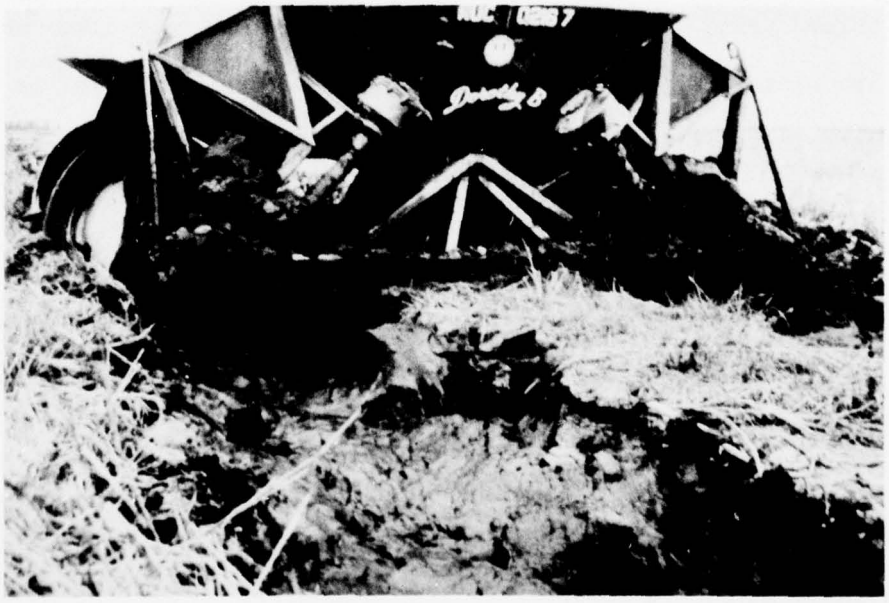


Figure 38. Progressive RUC trench

sively and the trenches reached a depth of approximately 18 inches. The area trenched by the RUC was reduced to trenches A and B only in May 1976, to allow deeper excavation with conventional equipment in portions of all other trenches north of station 16+00. Conventional excavation of all trenches further increased efficiency of the surface drainage system and promoted rapid drying within the remaining RUC-constructed trenches. Drainage and drying within trenches A and B continued during May and June until a significant crust began to inhibit RUC operation. RUC trenching operations were therefore discontinued in June 1976.

Conventional Trenching

116. Conventional trenching techniques have been successfully used by CE Districts to promote localized drainage of dredged material around the periphery of disposal areas. These trenching operations are performed using draglines operating from the retaining dikes or on mats immediately adjacent to the dikes. The drained material is then placed onto the existing dikes to raise the dike heights.

117. Similar trenching concepts were also evaluated at the UPB disposal area using conventional excavating equipment. Flotation draglines used for excavation work in marsh areas were evaluated in addition to conventional equipment operating on mats.

Flotation dragline trenching equipment characteristics

118. Flotation draglines or marsh cranes have been used for excavation in marsh areas and in water. These machines consist of a chassis supported by twin pontoons for flotation. A continuous chain-driven tracking system enables the machine to swim in open water or track on

soft material. The flotation dragline used in this study is shown in Figure 39.

119. At first glance, these machines seem ideally suited to operations within a dredged material disposal area. However, differences in the operational environment present limitations. Though natural marsh areas are as soft as dredged material disposal areas, the strength of natural marsh material tends to increase with depth and a well-developed root mat is usually present. After sinking some distance into the marsh, the pontoon and chain drive system can achieve sufficient traction to enable movement. The opposite is true within dredged material disposal areas, since wetter dredged material lies beneath the surface crust and conditions do not improve with depth.

120. Station 10+00 to 16+00. A flotation dragline was procured by contract through the MD in late October 1975 for trenching operations within the UPB disposal area. The machine consisted of a Bantam Model 350 dragline mounted on twin pontoons with 30-inch wide aluminum tracking system and is shown in Figure 39. The dragline was fitted with a 40-foot boom and 3/8-cubic yard bucket. The flotation dragline tracked satisfactorily over a majority of the study area. However, as the machine tracked into areas of crust thickness less than 4 inches, the pontoons broke through the crust and the vehicle was stranded. The consistency of dredged material near the liquid limit beneath the crust was too viscous for effective swimming action and too liquid for effective tracking.

121. The flotation dragline was subsequently restricted to areas

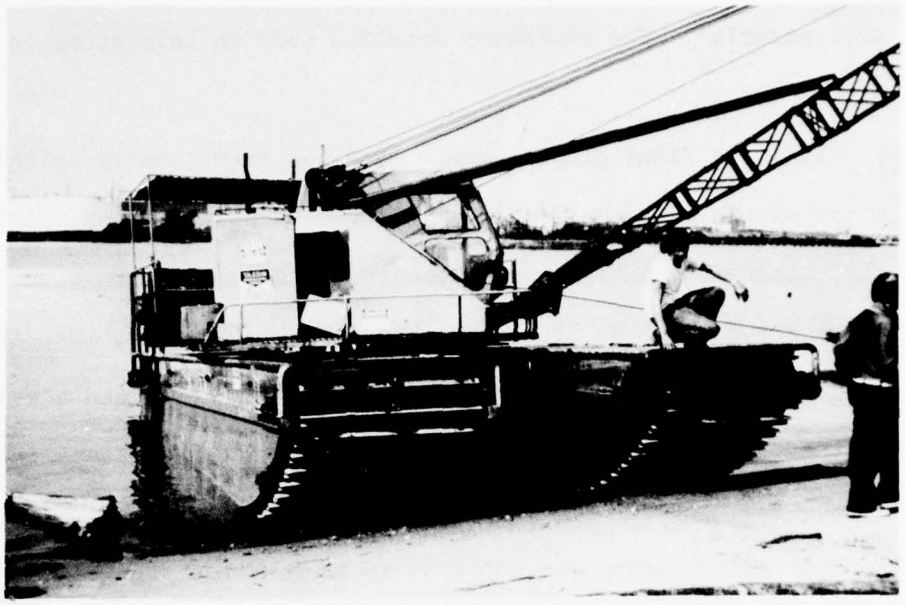


Figure 39. Flotation dragline

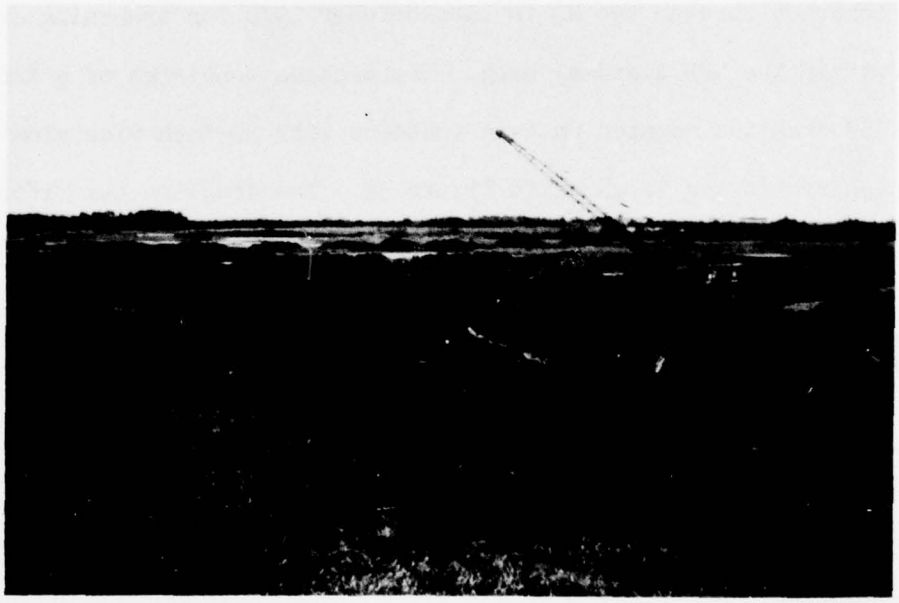


Figure 40. Flotation dragline trenching

generally south of station 16+00, which had surface crust 6 inches or thicker. Crust thickness of 6 inches or more provided enough bridging action for effective tracking.

122. The trenching system was constructed from approximately station 10+00 north to station 16+00 with the flotation dragline during October and November 1976. The dragline constructed the network by straddling the trench centerline, trailing the boom, and casting the excavated material to either side of the trench in broken windrows. Approximately 6700 linear feet of trench was constructed in 200 operating hours. This operation is shown in progress in Figure 40.

123. The excavated trenches were able to hold open to depths of 3 to 6 feet with approximately 1V on 1H side slopes. Sloughing did occur in localized areas but did not significantly affect the efficiency of the trenches. Lateral trenches A through F held depths of approximately 3 feet near station 16+00 and were graded to depths of 5 to 6 feet near station 12+00. The feeder trench H held depths averaging 6 feet and was graded toward the south sump and weir. Appearance of the dragline trenches is shown in Figures 41 and 42.

124. High spots were created by dredged material flow and sloughing in some trenches, ponding water. The trench inverts were practically level at approximate elevation +4.0 to +5.0 MLW. Increasing trench depth was due primarily to increasing surface elevation north to south.

125. During excavation, the trenches, filled with water, which quickly drained from lenses of silt and wood pieces throughout the dredged material. After the network was completed and water was allowed

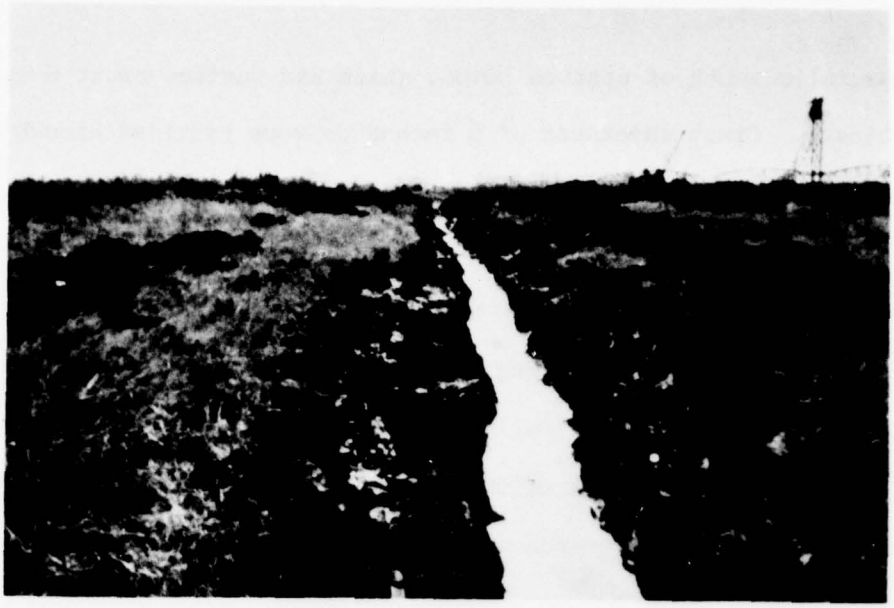


Figure 41. Appearance of flotation dragline trench C

Figure 42. Flotation dragline trench deepening of trench H

to drain to the sumps the trenches began to dry and desiccate. Similar behavior was observed in the excavated material that exhibited significant shrinkage upon drying as shown in Figure 6.

126. Station 16+00 to 24+00. The northern portion of the progressive trenching study area had been initially trenched and deepened with the RUC during October to May 1976 as described in paragraph 120. During this period crust thickness had increased to 6 inches or more over much of this portion of the study area due to drainage and evaporation.

127. A second flotation dragline was procured by contract through the MD to deepen this portion of the trench network. This machine was similar in appearance to the first flotation dragline used at the UPB site but had 60-inch wide pontoons and aluminum tracks, which provided additional flotation and tracking ability. The dragline was fitted with a 3/4-cubic yard bucket with a 40-foot boom. Little difficulty was encountered in tracking within the study area with the 60-inch wide tracking system. When the machine occasionally broke through thinly crusted areas, barrels were chained to the tracks and the machine walked onto the crust and continued work.

128. A majority of the existing trenching system between approximately station 16+00 to 24+00 was deepened with the flotation dragline during late May to July 1976. Trenches A and B were not deepened to allow continued elevation of progressive RUC trenching. Two passes of the machine were required along the network to deepen the trenches. On the first pass, the dragline trailed the boom, sitting on one side of the existing RUC trenches, and spread excavated material into a layer

approximately one foot thick. The second pass was completed in a similar manner with the machine operating from the opposite side of the trench. By placing the material in thin layers, drying and shrinkage cracks were formed down to the original dredged material ground surface allowing surface drainage into the trenches. Approximately 5400 linear feet of trench was deepened in this manner in 320 operating hours. A new trench was also constructed parallel to the west retaining dike labeled J on Figure 28. This trench consisting of approximately 1400 linear feet was constructed in one pass using 40 operating hours.

129. Some difficulty was experienced in keeping the deepened trenches open in the northern portion. Lateral trenches C through F initially held open an average of 3 feet on the first pass, but flow of dredged material back into the trench caused depths to be reduced to approximately 1½ feet. The second pass held the lateral trenches open to an average depth of 2½ feet. Views of a lateral trench after the second pass is shown in Figure 43. The feeder trench I proved difficult to keep open, and after two passes, the depth in trench I was an average of only 1½ feet. The appearance of this trench is shown in Figure 44.

130. During this deepening operation, the dredged material beneath the surface crust exhibited a mass flow behavior resulting in shallow sloughs or slides as shown in Figure 45. These slides tended to occur over a period of several hours after the trench was deepened.

131. Grading was more effective toward the southern portion of the study area and the deepened trenches were connected to the existing network near station 16+00.

Figure 43. Lateral trench E after deepening

Figure 44. Feeder trench I after deepening

Figure 45. Slough failure in trench F

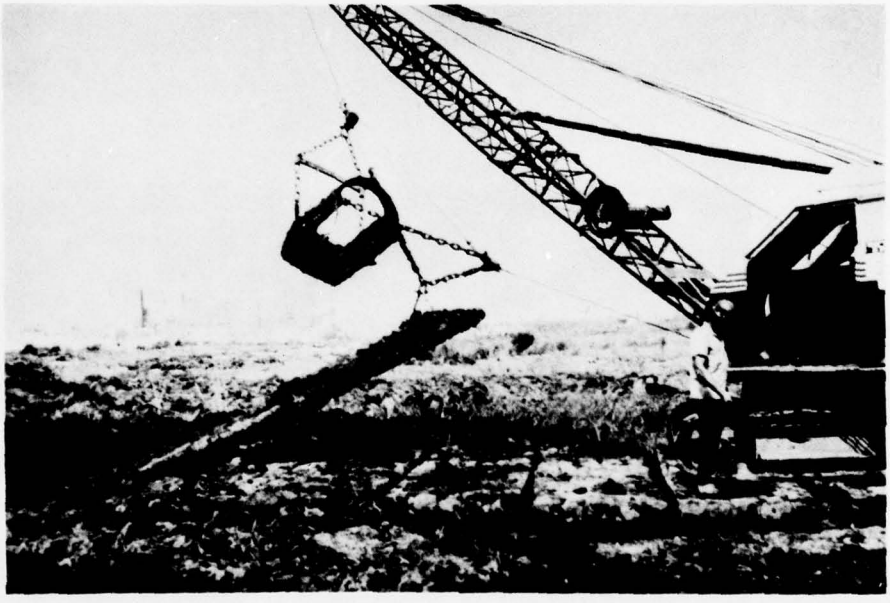


Figure 46. Matting with conventional dragline

132. The trench constructed parallel to the west dike held open to depths of 8 to 10 feet exposing the sandy material in the dike foundation in several areas. This trench served to connect the north and south sumps and provide gravity flow from feeder ditch I to the culvert adjacent to the south sump and weir.

Conventional equipment on mats

133. Trenching efforts were attempted using conventional equipment operating from mats in early October 1975. A track-mounted John Deere 690 backhoe was contracted for this work with specifications calling for matting ground pressures not in excess of 1 psi. Double mats 4 ft by 20 ft and four abreast were utilized. This equipment successfully constructed the north and south sumps while operating from mats placed near the dike. An attempt was then made to mat on the thinly crusted area adjacent to the north weir in order to trench and drain the localized high area described in Paragraph 105, which had been ponding surface water. The matting would support the equipment adequately while stationary, but the movements necessary to walk the mats forward caused the entire mat group and dragline to break through the crust and sink several feet into the dredged material. Capabilities of conventional equipment on mats is clearly limited to areas where sufficient crust has developed to allow matting to effectively distribute and support loads.

134. The trenching network from station 10+00 to station 16+00 had initially been constructed with flotation dragline during October and November 1975. A prolonged period of efficient surface drainage following this trenching promoted drying and formation of surface crust 8 to

12 in. thick over most of the southern portion of the network. A conventional dragline operating on mats was used to clean out and deepen portions of this network during April 1976. The machine utilized was a track-mounted Bucyrus Erie 15B with 35-foot boom and 5/8-cubic yard bucket. Single mats 3 x 20 feet were used to support the dragline.

135. Lateral trenches A through G and feeder trench H were deepened up to 3 feet from station 12+00 to 16+00. Dredged material that had been excavated by flotation draglines and dried was spread by the dragline, and the mats were placed on the layer of dried material to further distribute the load. The matting operation is shown in Figure 46. Trenches were filled with dry material to allow bridging across the trenches and later cleared after completion of deepening. Approximately 1500 linear feet of trench was deepened in 122 operating hours.

136. Trench depths of up to 12 feet, near original foundation levels, were reached adjacent to the south sump and weir. This enabled efficient grading of the entire trenching system toward the south sump and culvert. Deepening operations are shown in Figures 47 and 48. No major stability problems were encountered and only minor sloughing occurred during this deepening operation.

Summary of Progressive Trenching Methodology

137. Considering the trenching abilities of the RUC, flotation dragline, and conventional dragline equipment, a progressive approach to trenching was utilized at the UPB disposal area. Each piece of equipment has unique capabilities that contributed to the construction of an

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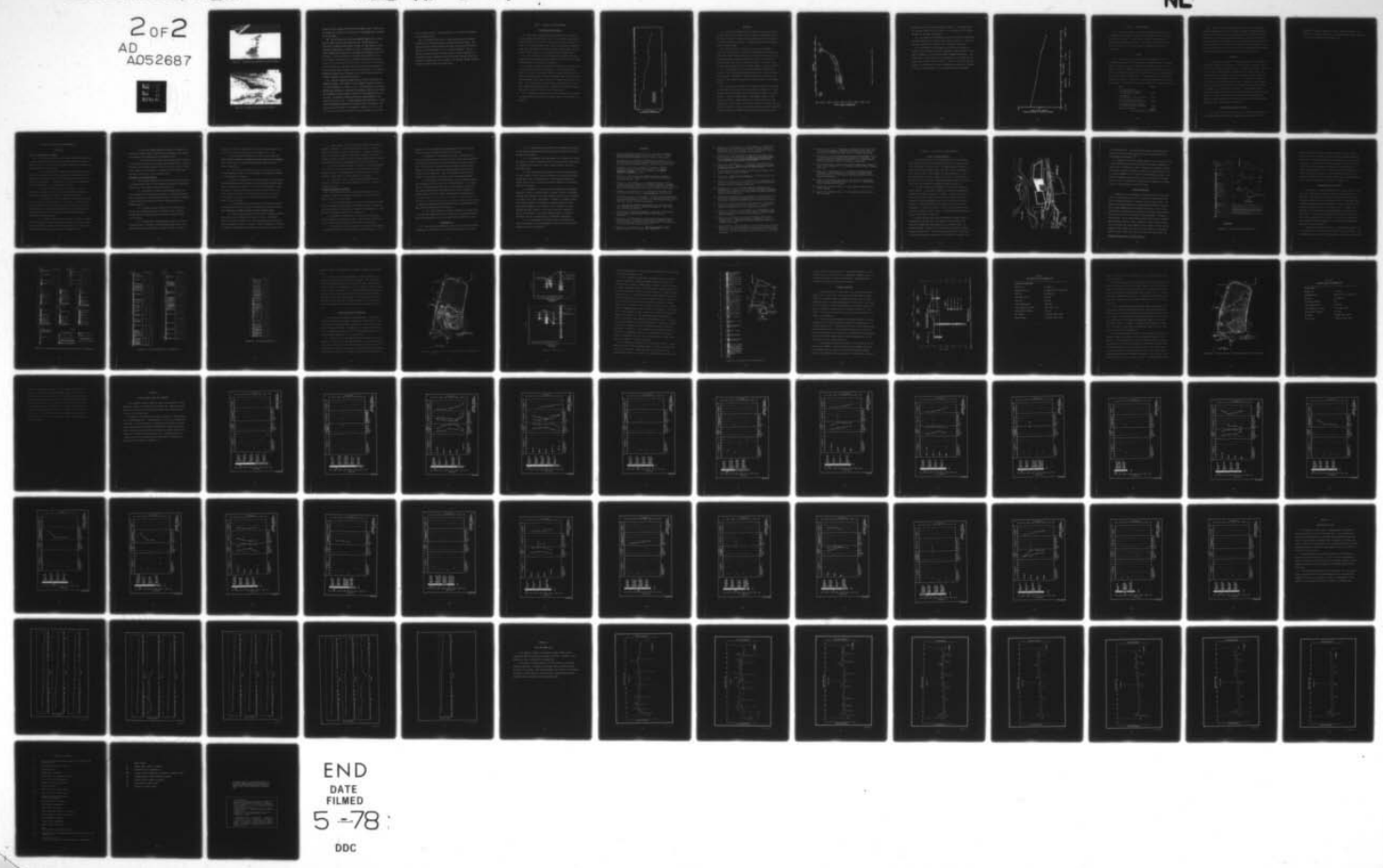

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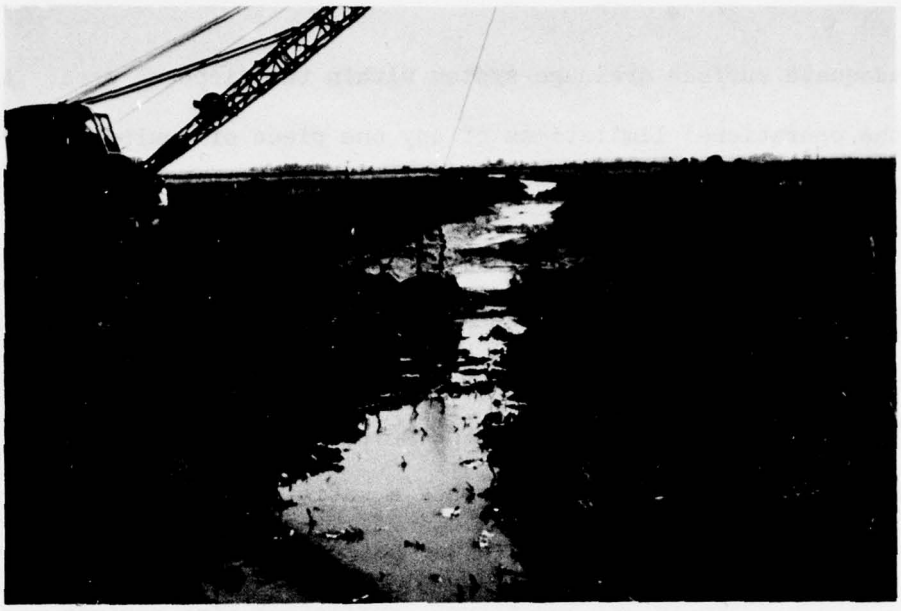

Figure 47. Deepening with dragline at lateral trench B

Figure 48. Deepening with dragline at trench H

adequate surface drainage system within the disposal area. Additionally, the operational limitations of any one piece of equipment were adequately met by the others.

138. The RUC proved to be the only equipment capable of initiating work in thinly crusted areas within the site. The RUC was highly successful in draining surface water from the low lying areas and allowing surface evaporation to thicken the crust. A progressive deepening of RUC trenches was achieved once a satisfactory trenching procedure was developed. A traffic pattern was established that limited the passes of the vehicle in any one trench, sufficient time periods were established that allowed drying and desiccation in the trench bottoms between successive operations, and hand grading procedures were established to allow effective surface drainage at trench intersections. RUC trenching operations promoted crust thicknesses from 6 to 18 inches allowing the flotation dragline to operate successfully.

139. Flotation dragline equipment proved effective in grading and deepening trenches. The chassis on this equipment allows its operation on a crust thickness of 6 inches or more. As with the RUC, a progressive approach was successful in deepening the trenches in thinly crusted areas. The equipment was best operated on one side of the trench with the boom trailing. The excavated dredged material was spread adjacent to the trench and allowed to dry. A similar approach was then used for a second pass with equipment operating on the opposite side of the trench. This approach allowed trenches to be excavated to depths of 1-1/2 to 2-1/2 feet in the northern portion of the UPB site, and depths of 3 to 6 feet

in the southern portion. Crust thickness of 8 to 12 inches was achieved in the southern portion.

140. The thicker surface crust in the southern portion eventually allowed use of conventional dragline equipment operating on mats. The mats were placed on dried material previously excavated by the flotation dragline, and trench depths of 6 to 12 feet were achieved. The progressive trenching approach utilizing the RUC, flotation dragline, and conventional dragline equipment allowed the surface drainage system to be successfully deepened and its efficiency to be improved, thereby promoting effective drainage within the disposal area.

PART VI: RESULTS OF FIELD TRENCHING

Groundwater Table Drawdown

141. Open riser observation wells were installed in 24 borehole locations within the UPB disposal area in July and August 1975, as described in PART III. Locations of the wells are shown in Figure 12. A total of 13 of the observation wells within the progressive trenching study area survived field trenching operations without damage and were used to monitor changes in the dredged material groundwater table.

142. The wells were monitored periodically throughout the study. Dredged material groundwater table elevations versus time for individual observation wells are presented in Appendix C.

143. Trends of drawdown are practically identical for all well locations showing a drawdown of approximately 1.5 feet occurring over a period of 15 months. Piezometer locations between the trenches did not allow accurate evaluation of localized drawdown conditions, and no well-defined drawdown curve between trenches was evident from the data available. This indicates that gravity flow had little influence on loss of water through the trenching system. Drawdowns are therefore primarily the result of water loss through surface evaporation.

144. The average drawdown versus time relationship for all observation wells within the progressive trenching study area is presented in Figure 49.

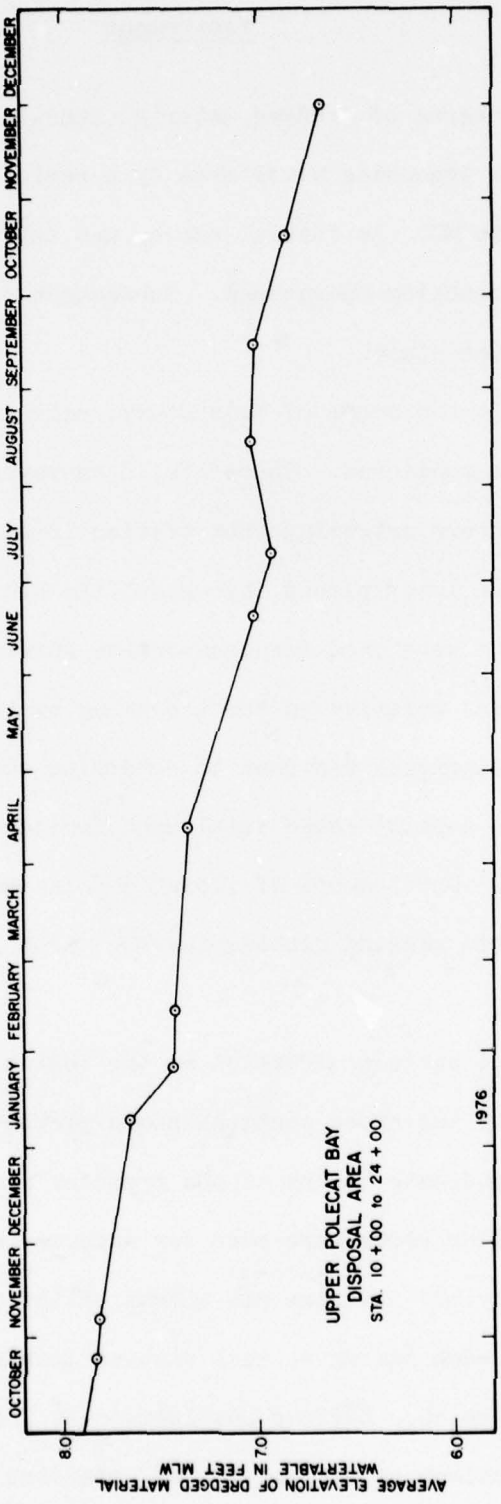

Figure 49. Average drawdown versus time

Settlement

145. The degree of dredged material densification was monitored for the progressive trenching study area by a series of topographic surveys performed by the MD. An initial survey was taken in July 1975 previous to any field trenching operations. Subsequent surveys were made periodically during the study.

146. Within the scope of this study, only a limited number of points could be monitored. Therefore, 8 survey ranges were established on 200-foot centers extending from station 10+00 to station 24+00. Location stakes were later placed throughout the sections to assure that identical points were used for consecutive surveys. Locations of the surveyed stations relative to the trenching system are shown in Figure 28.

147. This approach was used to determine surface settlements as opposed to more sophisticated settlement devices due to the large size of the study area. Settlements of isolated points within a 60-acre area would have little meaning considering the variable nature of the dredged material.

148. Ground surface elevation at the beginning and end of the study are indicated by the cross sections shown plotted in Appendix D. These sections also indicate depths of the trenches and placement of excavated material. Similar plots were made for intermediate surveys but were omitted for clarity. Average elevations of the dredged material were determined for each survey at each station location. These data are shown plotted in Figure 50. Surface settlements as indicated by these data show practically constant settlement for all stations except station 10+00

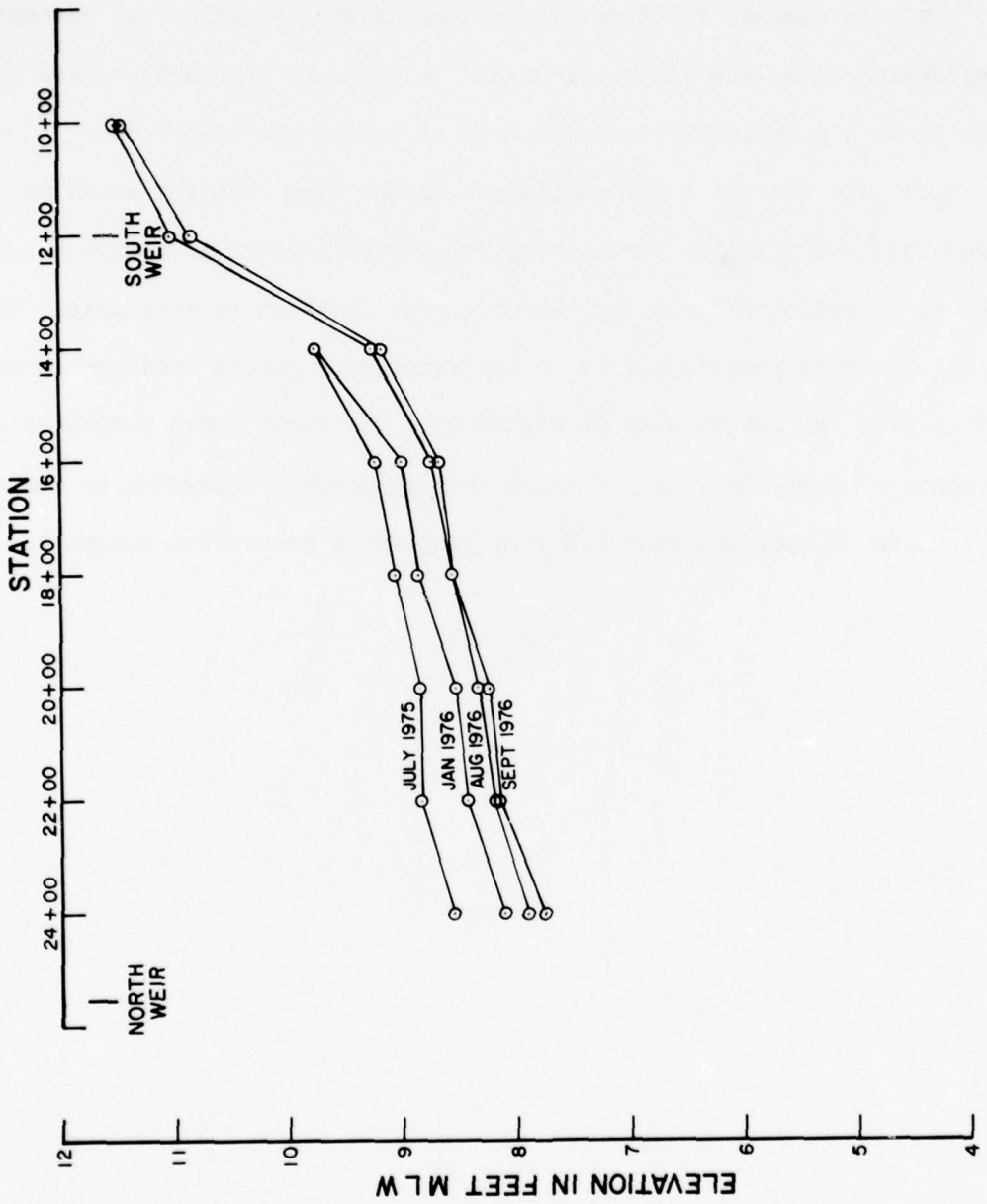

Figure 50. Surface settlements by station

and station 12+00 for which settlements are smaller. The surface crust was initially thicker in this vicinity due to the nature of the disposal operation as described in Appendix A.

149. An average field settlement versus time relation was determined considering data from all stations and is shown in Figure 51. This relation shows a practically constant rate of settlement with time.

150. The average field settlement versus time relation shown in Figure 51, and drawdown versus time relationship shown in Figure 49, were used to determine a field settlement versus drawdown relationship. This relationship is shown compared to the settlement versus drawdown as predicted from laboratory data in Figure 27. The field curve indicates settlements of approximately 0.6 times the magnitude of drawdown as compared to a value of approximately 0.4 from laboratory predictive analysis.

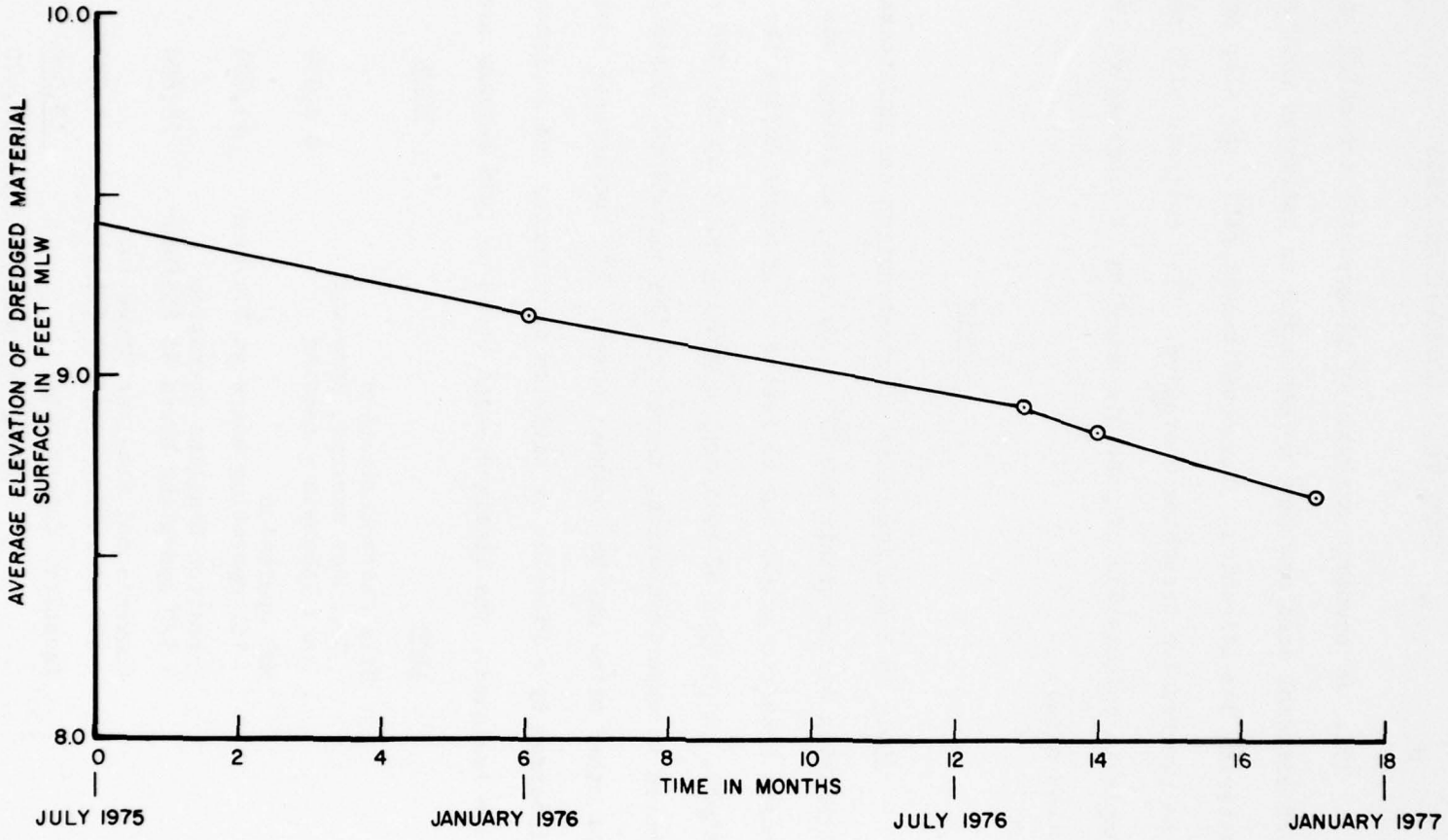

Figure 51. Average settlement versus time

PART VII: ECONOMIC ANALYSIS

151. An economic analysis of progressive trenching operations at the UPB disposal area was made to determine an estimated unit cost for dredged material densification. The benefit-cost ratio was also determined for the progressive trenching operation. This analysis will serve as an example in calculation of possible benefits of progressive trenching at other sites.

Costs

152. In computing costs of construction and maintenance of the trenching system within the UPB study area, an attempt was made to segregate costs incurred solely due to research interests during the course of the study. A portion of equipment operating costs at the UPB site can be attributed to experimentation, therefore the operational costs for implementation at other sites may be somewhat lower. All operational costs that would be incurred by a District or Division in planning and implementing the project are included. The itemized costs based on 1976 dollars are summarized below:

Item	Cost
Site Characterization Includes surveys, sampling, and laboratory testing	$ 2,000
RUC Operation 181 operating hours at $74/hour	13,600
Flotation Dragline Operation 520 operating hours at $55/hour	28,600
Conventional Dragline Operation 122 operating hours at $35/hour	4,270
Technical Supervision	10,000
Total Operational Cost	$58,470

153. Costs of site characterization are based on those necessary for obtaining adequate data to choose equipment and predict potential benefits. RUC operational costs of $850 per day include use of a trained two-man crew, operation of 8 hours per day, normal maintenance costs, and crew per diem. The availability of RUC equipment for use in disposal area reconnaisance and trenching operations is currently being expanded by planned overhaul of six additional RUC vehicles. These RUCs may be later made available to Divisions or Districts resulting in a reduced operational cost for the RUC.

Benefits

154. Computation of benefits derived through progressive trenching can be related directly to densification of dredged material resulting in increased capacity within a disposal site. Accumulation of benefits continues as long as the dredged material groundwater table is being lowered. An average settlement throughout the 60-acre progressive trenching study area of 0.75 feet through November 1976 relates to an increase in capacity of 72,600 cubic yards for the UPB disposal area. New worth or replacement cost per cubic yard of disposal capacity was estimated at $2.00 by MD personnel in January 1977 for the Polecat Bay vicinity. A net monetary benefit of $145,200 was therefore gained by the progressive trenching operations at the UPB site. Benefits in reality may be even greater since replacement of existing disposal areas near the Upper Mobile River Project would be nearly impossible due to environmental constraints.[25]

Unit Cost and Benefit Cost Ratio

155. A unit cost of $0.81 per cubic yard of increased capacity due to dredged material densification was computed using the total cost of the

progressive trenching operation and total volumetric reduction. The benefit cost ratio was computed as 2.48 using the total cost of the operation and total benefits as of November 1976.

PART VIII: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Benefits of progressive trenching

156. The following conclusions can be drawn regarding determination of potential densification benefits derived through progressive trenching, based on results of the field and laboratory investigations and predictive analysis performed for this study:

a. The successful field sampling program conducted at the UPB disposal area indicates that detailed sampling of fine-grained dredged material in confined disposal areas is possible without the use of conventional drilling equipment. Instrumentation of the site with observation wells and piezometers is also operationally feasible.

b. Conventional laboratory testing programs as outlined in this study are adequate to define the overall engineering and physical properties of dredged material within a confined disposal area.

c. Conventional tests were adequate for obtaining consolidation data for the very soft dredged material. No special test provisions were necessary other than care in specimen preparation and use of low initial load increments. Consolidation characteristics of the material were well defined by the tests and no difficulty was encountered in performing conventional settlement analyses.

d. A relatively simple test procedure was developed to estimate potential shrinkage of dredged material due to drying. The linear shrinkage test procedure as described in this study can easily be duplicated by other laboratories and used for analysis of shrinkage effects.

e. Based upon dredged material properties and present site conditions, dredged material consolidation and shrinkage can be induced by a drawdown of the dredged material groundwater table.

f. Piezometer data indicated that the natural water table was not influenced by changes in the dredged material water table. Therefore, reductions in the dredged material water table would not result in additional loading and consolidation of foundation soils at the UPB site. This may not be true for all land disposal sites.

Construction of trenching systems

157. The following conclusions can be drawn regarding construction of trenching systems within confined disposal areas based on experience gained during field operations at the UPB study site:

a. Construction of surface trenching systems within confined disposal areas is operationally feasible. Trenching operations must be progressive in nature and remain flexible to adjust to changing conditions within the disposal area due to drainage and drying of dredged material.

b. As dredged material drying and crust formation progresses, the trenching system must be deepened to allow efficient drainage within the desiccation crack patterns and promote further crust formation.

c. Trenching with the RUC amphibious vehicle is the best available method to initiate a surface drainage system within a disposal area where crust thickness is less than 6 inches. The RUC is

effective in removal of ponded surface water and trenching systems constructed with the RUC can promote crust thickness up to a foot.

d. RUC-constructed trenches tend to hold constant depth and trench grading is therefore governed by existing disposal area topography. This condition leads to isolated low spots where effective removal of water is impossible.

e. The maximum trench depth that can be attained using the RUC is approximately 18 inches. Use of implements had no apparent advantage in trench deepening or grading.

f. The most effective method of RUC utilization is a progressive trenching approach, with sufficient time allowed between trenching operations for drying and reformation of crust in the RUC trenches. A minimum number of RUC passes through both lateral and feeder trenches prevents excessive re-slurry of wet dredged material and loss of trench effectiveness. Hand cleaning of trench intersections is required to ensure efficient drainage.

g. As conditions within the disposal area are improved through increased drying and crust formation, conventional excavation equipment can be employed to deepen and grade the trench drainage system.

h. Flotation type draglines are effective in trenching operations with existing crust thicknesses in excess of 6 inches. Lightweight draglines operating from mats can be effectively employed with existing crust thicknesses in excess of 12 inches. Dragline equipment is effective in deepening trenches and grading trench bottoms to allow efficient flow.

i. Trench depths of several feet may be attained using dragline equipment. Thickness of surface crust and water content of dredged material beneath the crust are limiting factors. Stability of dragline-constructed trenches presented no significant problems in maintaining drainage efficiency although flow and sloughing limited depths of trenches in areas where subcrust dredged material was near the liquid limit.

j. The most effective method of employment of dragline equipment is to side cast the excavated material to the same side of the trench, trailing the boom. The dredged material should be placed in broken windrows to allow paths for surface drainage to the trench.

k. Monitoring of site conditions by knowledgeable personnel is necessary to determine both type and optimum time for use of various trenching equipment.

Effects of progressive trenching

158. The following conclusions are made regarding the effects of progressive trenching on drying and densification of dredged material based on results of the UPB study:

a. Trench drainage systems are effective in lowering the dredged material groundwater table within confined disposal areas. Observation well data indicated an average rate of drawdown of approximately 0.1 feet per month was achieved within the UPB study area.

b. Magnitude of drawdown was not affected by trench spacing based on available observation well data. No well-defined phreatic profile indicating higher drawdown near the trenches was observed.

c. Densification of dredged material as indicated by measurements of surface settlement was achieved throughout the UPB study area. The

magnitude of surface settlement was approximately 0.05 feet per month and was practically constant throughout the study area.

d. Examination of the drawdown and surface settlement versus time data indicates that densification benefits gained through progressive trenching are primarily due to increased efficiency of surface evaporation. Construction of an efficient surface drainage system prevents recharge of the dredged material groundwater table and allows removal of water through evaporation. Since the gradients involved are low, gravity flow contributes little water loss in fine-grained material.

e. Densification of dredged material due to progressive trenching operations at the UPB site is due to a combination of: (1) consolidation of dredged material induced by increased effective stress below the lowered dredged material groundwater table, and (2) shrinkage of dredged material above the lowered dredged material groundwater table. Predictive analyses that account for consolidation using conventional Terzaghi consolidation theory and that account for shrinkage using results of laboratory shrinkage tests and observed changes in water content compare favorably with observed field behavior.

f. Full scale progressive trenching operations for densification of fine-grained dredged material have proven to be economically feasible, with both comparatively low unit cost and favorable benefit/cost ratio.

Recommendations

159. The following recommendations concerning the use of progressive trenching for densification of fine-grained dredged material are made.

a. It is recommended that additional data regarding densification of fine-grained dredged material through progressive trenching be gained through field experience.

b. It is recommended that implementation of a progressive trenching approach to dewater dredged material in selected disposal areas should be considered by CE Districts in which confined disposal capacity is now running short.

c. Field investigation and laboratory testing programs similar to those outlined in this study are recommended for disposal areas under consideration prior to implementation of field trenching operations. Results should be used in performing predictive analyses of anticipated densification benefits.

d. Evaluations of required trenching equipment and anticipated magnitude of required trenching based on disposal area size, topography, existing crust thickness, and dredged material properties are recommended for disposal areas under consideration. Estimates of equipment requirements should be based on a progressive trenching approach in which specialized equipment such as the RUC is used to promote sufficient drainage and crust formation to allow more conventional equipment to improve the efficiency of the surface drainage system. Estimate of trenching cost can be computed based on anticipated requirements.

e. It is recommended that final decision for implementation should be based upon an economic analysis in which both the anticipated benefits and costs are considered.

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APPENDIX A: SITE HISTORY AND CHARACTERISTICS

Source of Dredged Material

1. The dredged material in the UPB disposal area is from maintenance dredging activities in the Upper Mobile River and Chickasaw Creek, a main tributary of the Mobile River. Navigation channel dimensions in this area have been enlarged several times since initial improvement of Mobile Harbor in 1826. These channels are now maintained as a part of the Mobile Harbor Project to a dimension of 40 feet by 500 feet and 25 feet by 250 feet for the Mobile River and Chickasaw Creek, respectively. The Mobile River segment of the project is shown in Figure A1.

2. The upper segments of the project are maintained by hydraulic pipeline dredge. In past years, disposal of material from maintenance dredging in the upper river was not confined. Blakeley Island shown in Figure A1 has a long history of unconfined disposal and the area has undergone considerable physical change due to accretion and shoaling. Disposal in confined land areas is now required due to environmental constraints. A total of 918 acres of confined area have been utilized for disposal during the past 10 years. Locations of disposal areas near Polecat Bay are shown in Figure A1.

3. Average shoaling rates require maintenance dredging volumes of approximately 1,150,000 cubic yards annually from the Mobile River Channel and 200,000 cubic yards annually from Chickasaw Creek. The sediment material is primarily silt and clay as determined by sampling programs conducted by MD. Continued dredging requirements in this area are causing considerable concern due to the shortage of available land

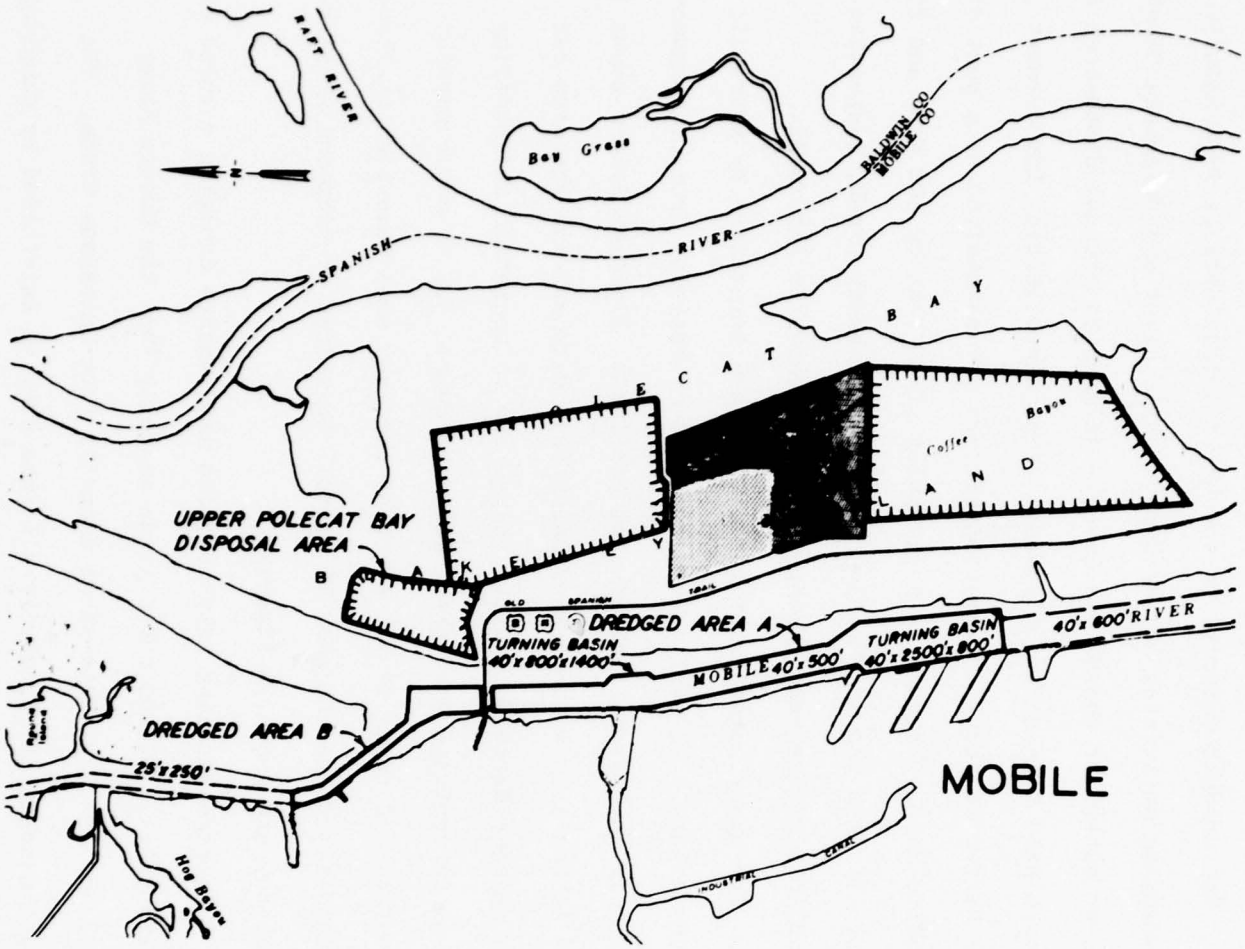


Figure A1. Location of channels, disposal areas, and dredged areas, Polecat Bay and vicinity

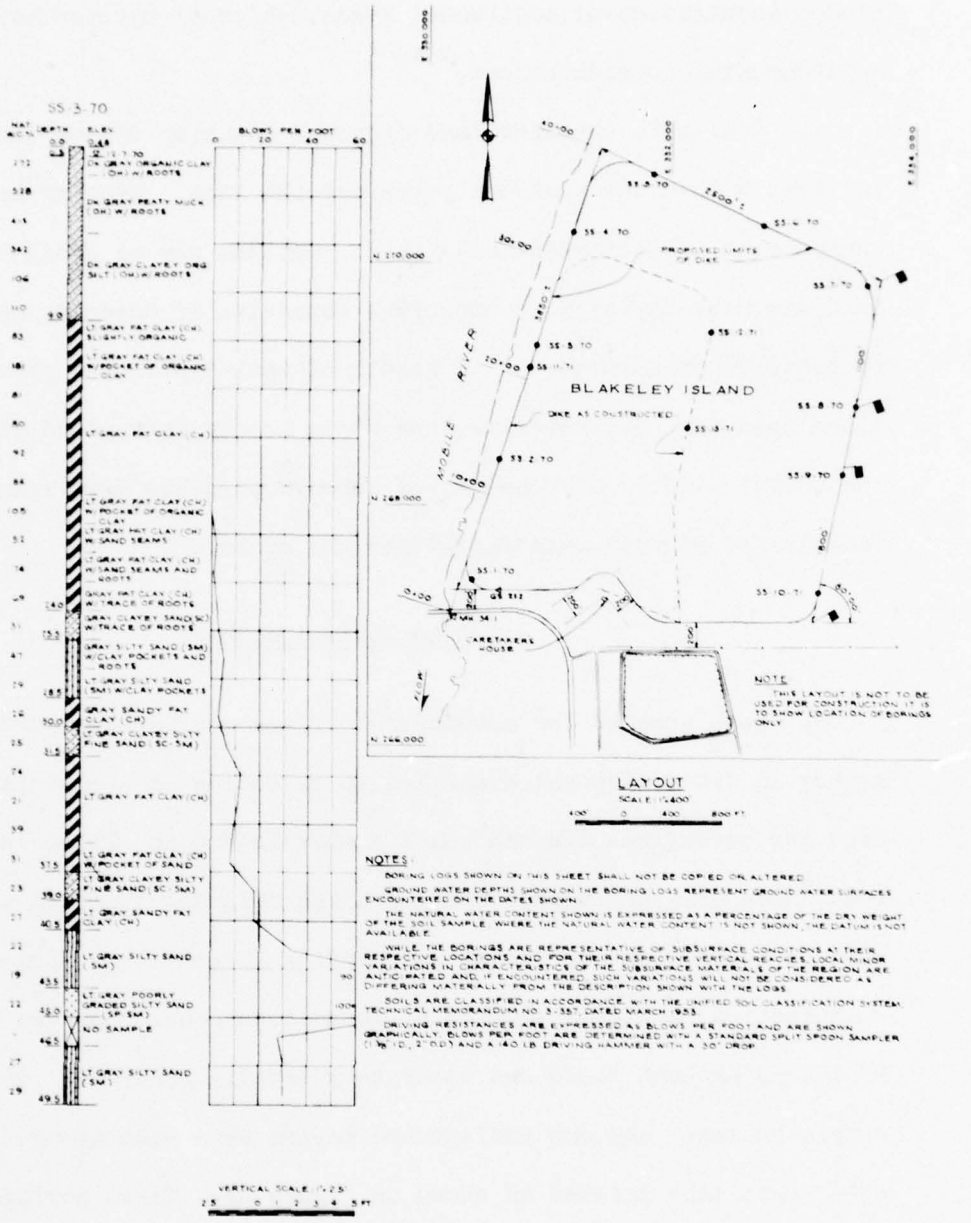
for containment areas. Long-range disposal plans formulated by MD included acquisition of additional lands but were rejected because of environmental considerations.[26*]

4. Available confined land disposal capacity is now limited to sites utilized within the past ten years and the total capacity remaining in these sites is estimated at 5 years. Optimum use of available confined land disposal capacity is therefore essential if dredging operations are to continue unhampered. As a result of the significant shortage of confined land disposal capacity, the MD is keenly interested in extending the useful life of disposal areas through possible dewatering and densification of dredged material within the sites.

Site Investigations

5. Requirements for confinement of dredged material from the upper harbor in diked disposal areas led to selection of areas historically used for unconfined disposal on Blakeley Island and Pinto Island. The total area originally approved for diked disposal included a large portion of upper Blakeley Island surrounding Polecat Bay. Prior to dike construction, an investigation of foundation conditions was conducted by MD including both field and laboratory testing programs. Ten general sample borings and one undisturbed boring were made along the proposed dike centerline located as shown on Figure A2. These borings revealed that the foundation at upper Blakeley Island consisted of marsh deposits composed of soft organic clays and silts (OH) underlain by alternating strata of plastic clays (CH), silty sands (SM), and clayey sands (SC).

* References section is located on page 109.



NOTES

BORING LOGS SHOWN ON THIS SHEET SHALL NOT BE COPIED OR ALTERED.

GROUND WATER DEPTHS SHOWN ON THE BORING LOGS REPRESENT GROUND WATER SURFACES ENCOUNTERED ON THE DATES SHOWN.

THE NATURAL WATER CONTENT SHOWN IS EXPRESSED AS A PERCENTAGE OF THE DRY WEIGHT OF THE SOIL SAMPLE. WHERE THE NATURAL WATER CONTENT IS NOT SHOWN, THE DATUM IS NOT AVAILABLE.

WHILE THE BORINGS ARE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THEIR RESPECTIVE LOCATIONS AND FOR THE IN RESPECTIVE VERTICAL REACHES, LOCAL NON-UNIFORMITIES OR VARIATIONS IN CHARACTERISTICS OF THE SUBSURFACE MATERIALS OF THE REGION ARE ANTICIPATED AND, IF ENCOUNTERED, SUCH VARIATIONS WILL NOT BE CONSIDERED AS DIFFERING MATERIALLY FROM THE DESCRIPTION SHOWN WITH THE LOGS.

SOILS ARE CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM, TECHNICAL MEMORANDUM NO. 3-357, DATED MARCH 1953.

DRIVING RESISTANCES ARE EXPRESSED AS BLOWS PER FOOT AND ARE SHOWN GRAPHICALLY. BLOWS PER FOOT ARE DETERMINED WITH A STANDARD SPLIT SPOON SAMPLER (1⅜" I.D., 2" O.D.) AND A 140 LB. DRIVING HAMMER WITH A 30" DROP.

Figure A2. Layout and log of boring SS-3-70

Silty sands and sands overlie the organic material over the southern portion of the site, probably deposited by previous dredging operations. Some of this coarse-grained material was subsequently utilized for dike construction. Laboratory tests including triaxial compression and consolidation tests were performed on samples from the upper strata of organic clays and plastic clays. Pertinent test data and logs are presented on Figures A3 through A5. Results indicated that the in situ foundation material had very low shear strengths and was highly compressible. Detailed test results are available in Reference 10.

Containment Area Construction

6. Construction of stable retaining dikes on the soft organic foundation was accomplished by end-dumping sand and displacing the soft materials. A bulldozer was used to push the dumped sand into the soft foundation and shape a base for the advancing fill. During construction foundation material was displaced creating a mud wave of displaced soft material at the head and sides of the base section. Following final placement of the base section, the dike embankment was formed by end-dumping sand. It was partially compacted by truck traffic on the fill but no other compactive effort was used. Slopes of the completed dike were seeded and overlapping sheets of 6-mil polyethylene sheeting was placed on the interior slopes.[27]

7. Approximately 250,000 cubic yards of sandy material available in the southern portion of the area was borrowed for dike construction. Conventional dragline construction techniques were used to place dike material

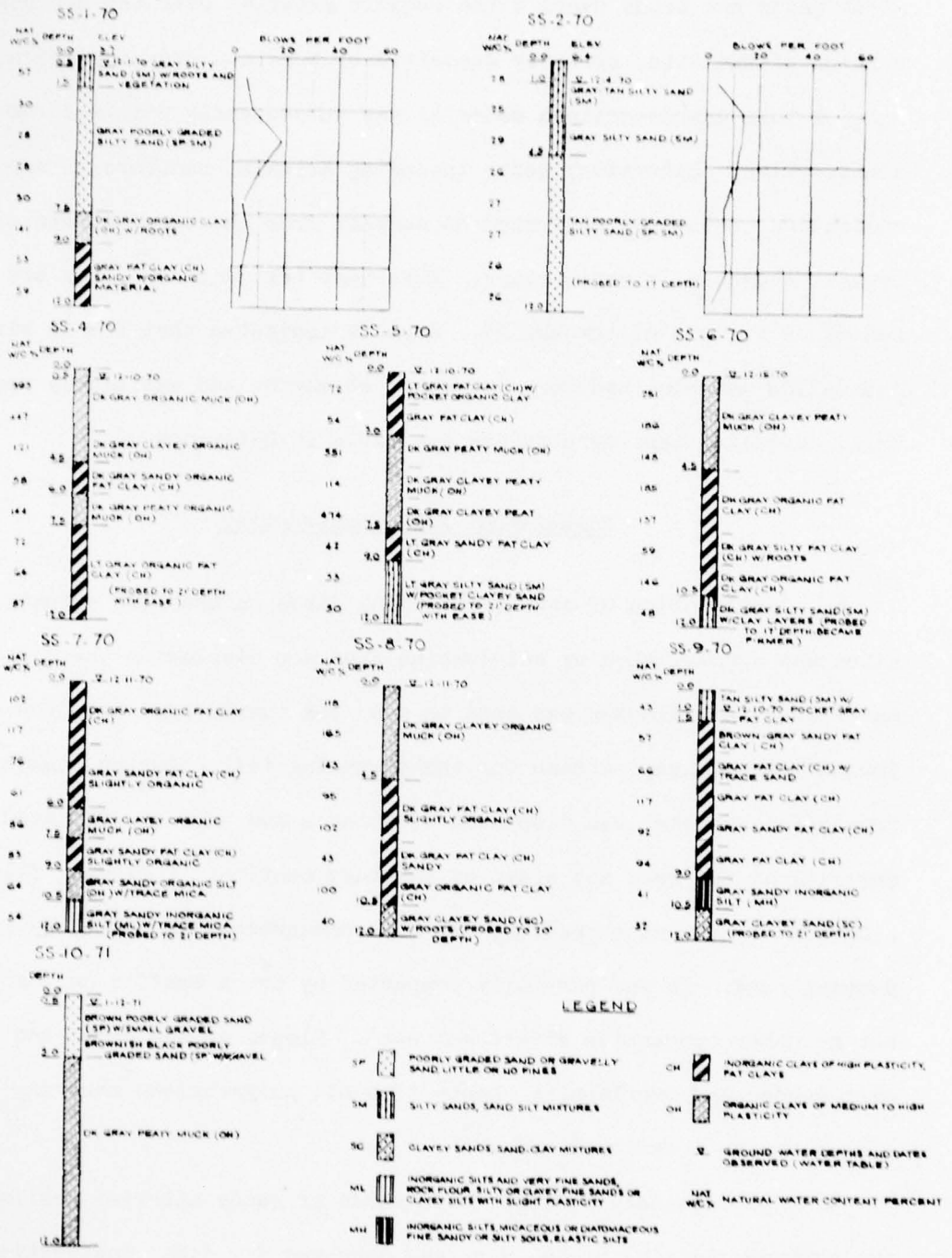


Figure A3. Logs of borings SS-1-70, SS-2-70, SS-4-70 and SS-10-70

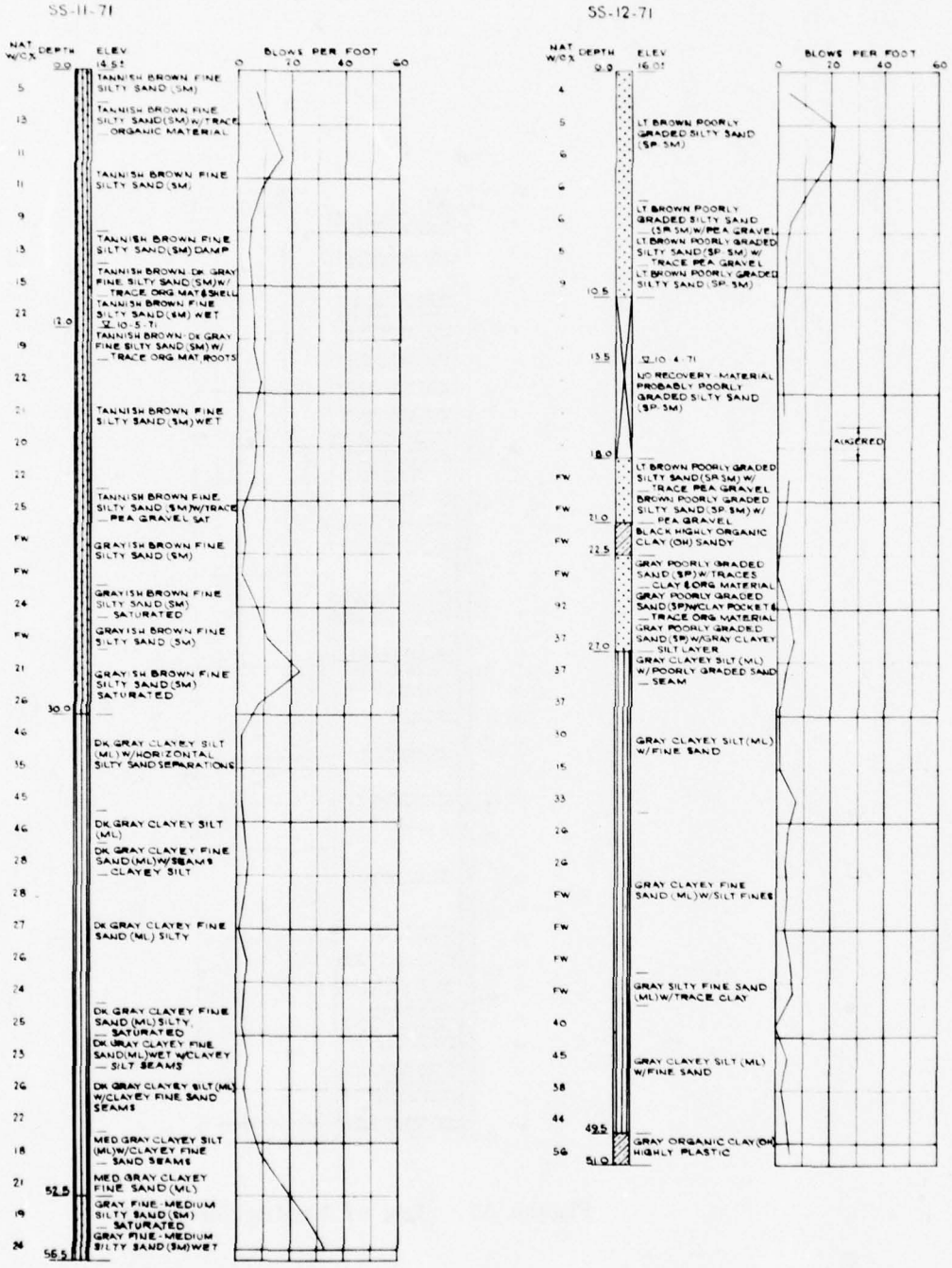


Figure A4. Log of borings SS-11-71 and SS-12-71

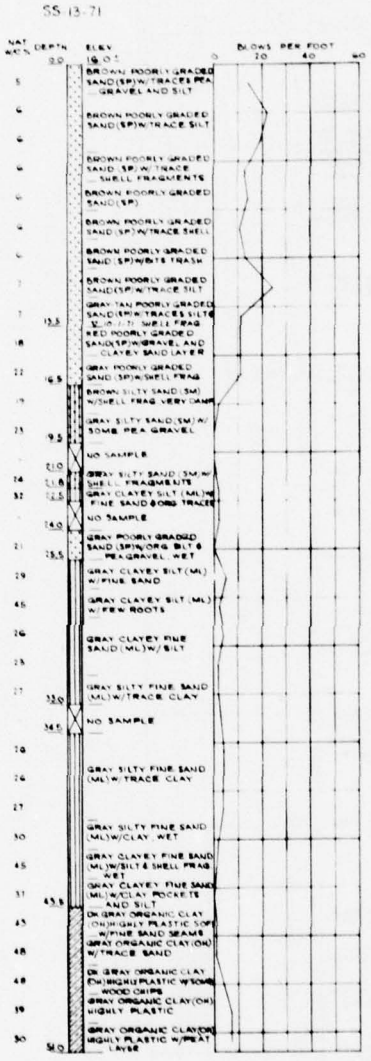


Figure A5. Log of boring SS-13-71

along this dike section where better foundation conditions were encountered.

8. Location of the dike as constructed is shown in Figure A6. A total of 9,500 linear feet of dike was constructed. Dike crown elevations varied between elevation 14.0 and 16.0 feet mean low water (MLW) with side slopes of approximately 1V on 1H. Elevations of natural ground on the site interior averaged 2.0 to 3.0 feet MLW with higher elevations remaining in the southern portion of the site where previous dredging disposal activities left sandy material. Two outlet weirs were located at points along the east dike as shown in Figure A6. The weirs were of the box type fabricated from sheet steel with a weir crest length of 20 feet.

After-construction Investigations

9. Three additional foundation borings were made at the UPB site following completion of the dikes to determine the displacement of foundation material resulting from dike construction. These borings are presented on Figures A4 and A5. An examination of these borings indicated that a significant displacement of the soft marsh materials had in fact occurred during construction of the confining dike.

10. A separate field investigation was later conducted by the MD to determine the nature of the sand dike foundation. This investigation included eight borings at two dike locations and field vane shear tests.[28] Configuration of the dike foundations as determined by this investigation are presented in Figure A7. The sand base formed in a bulb-shaped mass

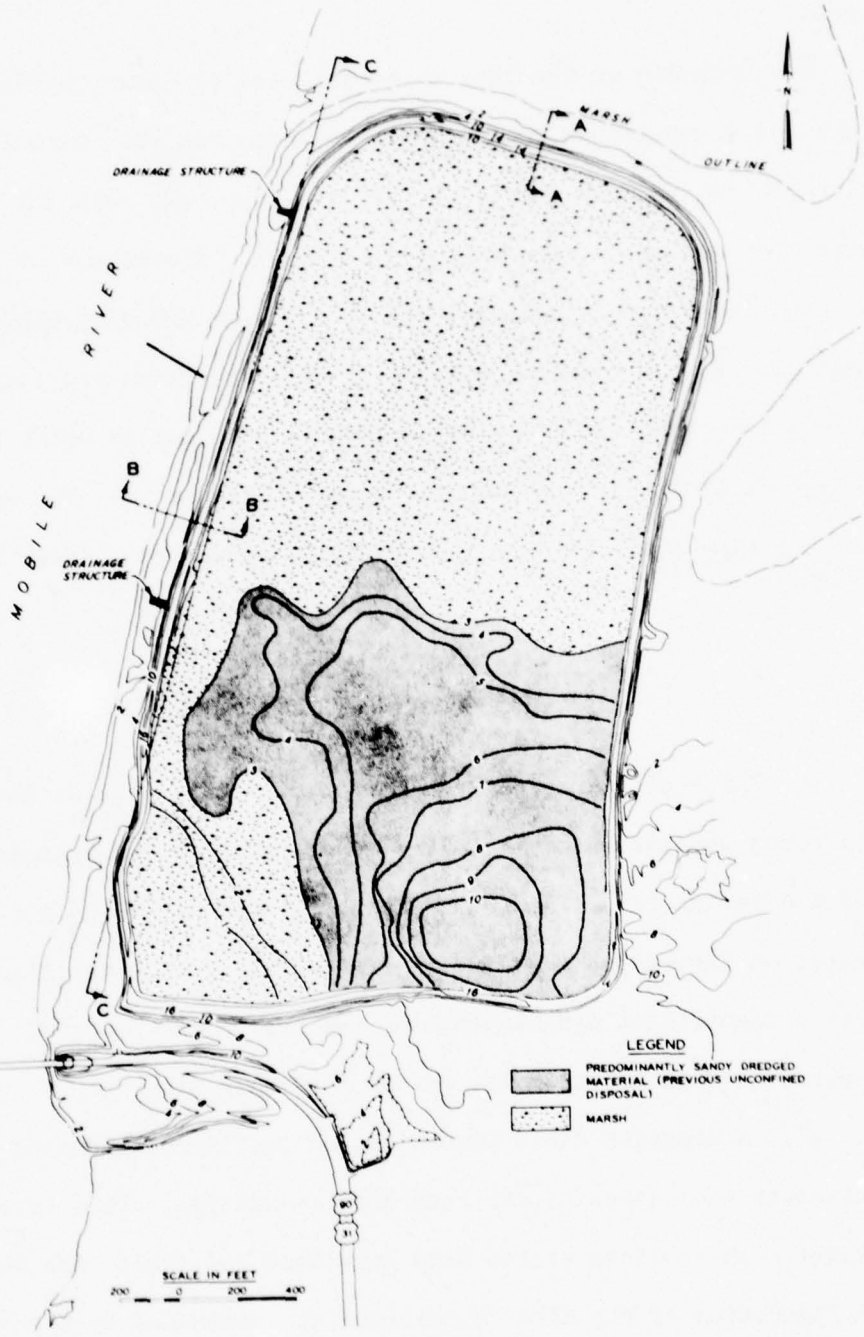


Figure A6. UPB disposal area after dike construction, September 1971 survey

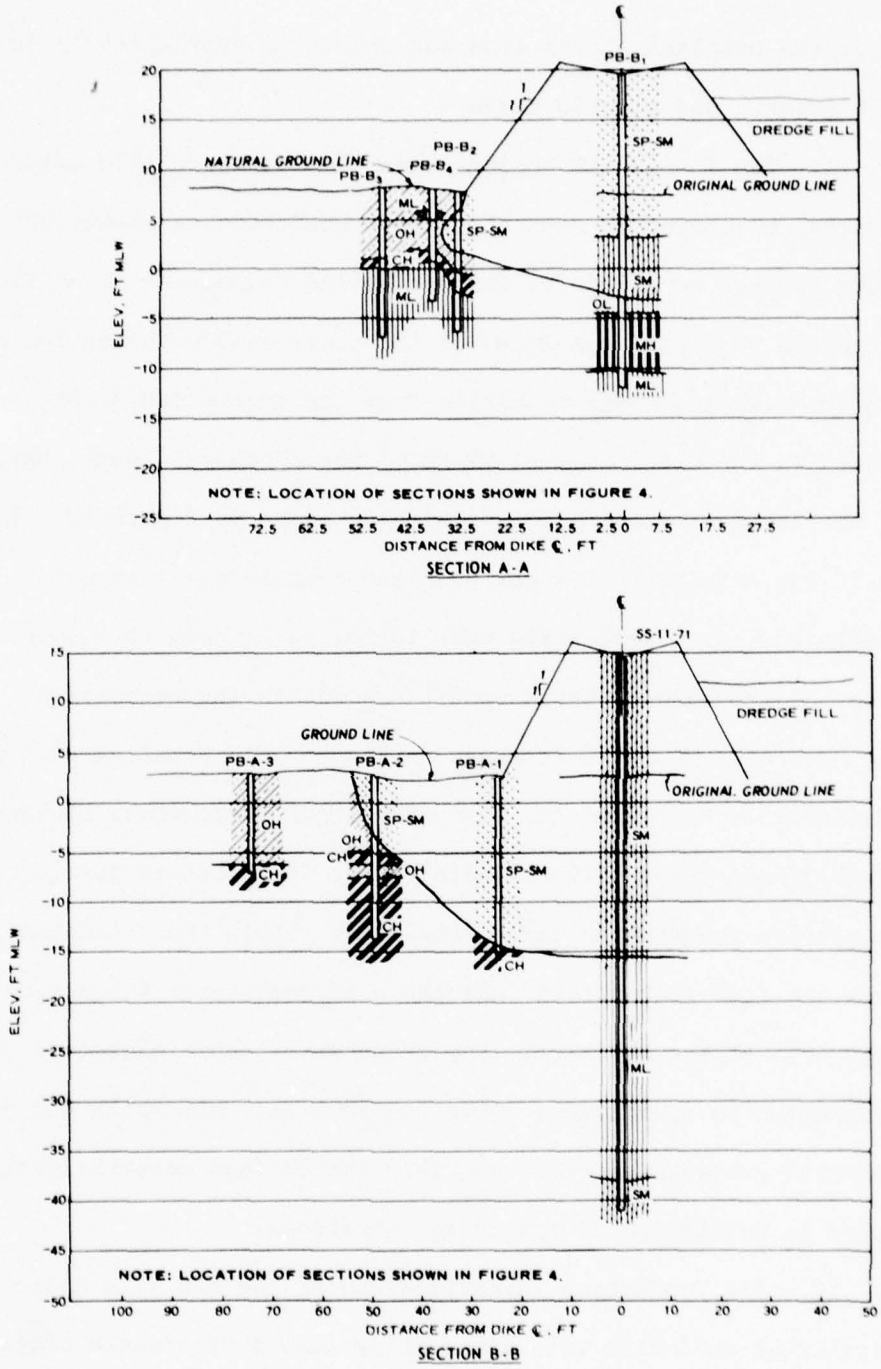


Figure A7. Dike sections

below the original ground line and displaced approximately 16 feet of the soft organic and plastic clays.

11. Two foundation borings were also taken in 1976 after dredged material placement in connection with DMRP studies at the UPB site. These borings were made to further define foundation stratification and to obtain undisturbed samples of the compressible foundation material in the consolidated state resulting from the overburden of dredged material placed in the site. Boring MP-SS-76 was a general sample boring located in the southern portion of the site as shown in Figure A8. Boring MP-UD-76 was an undisturbed boring taken immediately adjacent to general sample boring. Piezometers were installed in both bore holes to determine the groundwater table conditions within the foundation. The graphic log of boring MP-SS-76 is shown on Figure A8. Detailed test results are available in Reference 10. Two additional piezometers designated MP-SS-77 and MP-UD-77 were installed in the northern portion of the site to confirm groundwater table conditions within the foundation. Readings from the four piezometers indicate a perched water table condition at both ends of the UPB site. The groundwater table elevation within the foundation is approximate elevation +2.0 feet MLW while the dredged material groundwater table was near the dredged material ground surface prior to initiation of trenching operations.

12. All foundation investigations of the UPB site indicate a highly stratified condition with alternating layers of organic clays and silts (OH), plastic clays (CH), clayey sands (SC), and silty sands (SM). A coarse-grained foundation is present in the southern portion of the site

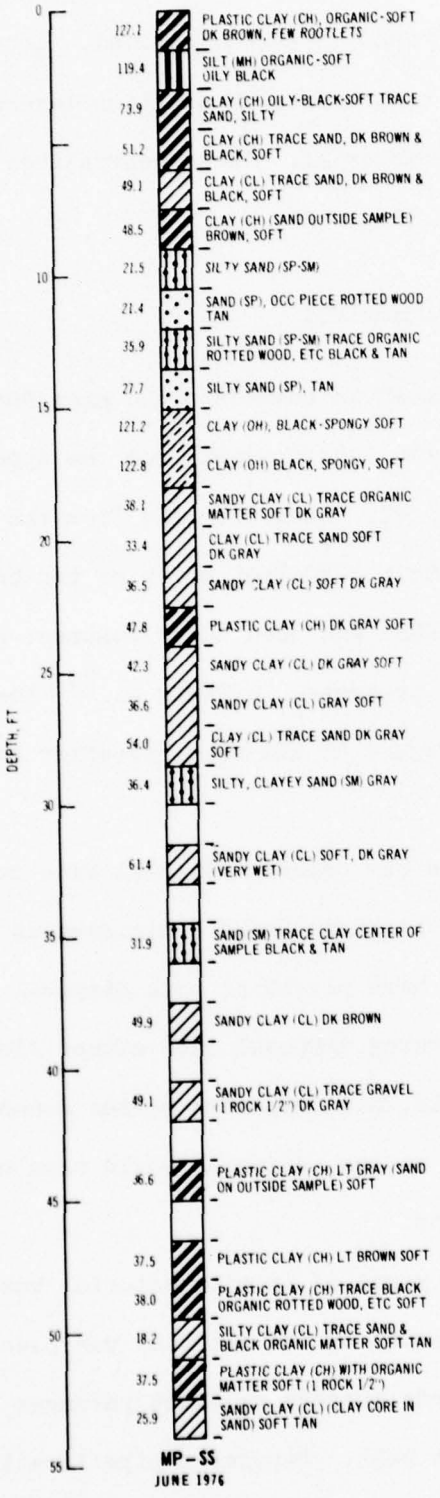


Figure A8. Layout and log of boring MP-SS-76

caused by prior unconfined disposal of sandy dredged material. In the northern portion of the site the more compressible foundation layers lie immediately below the confined dredged material. These generalized foundation conditions are indicated in Figure A9.

Disposal Operations

13. Dredged material was first placed in the UPB diked area during December 1971 to March 1972. The material was dredged from the upper Mobile River navigation channel immediately below the site from the U. S. Highway 90 bridge to a point approximately 2750 feet south of the bridge. The 27-inch pipeline dredge DAVE BLACKBURN was used under contract with the MD. A summary of dredging data is presented in Table A1.[29] The limits of this work are indicated on Figure A1 and will hereafter be referred to as "Dredging A."

14. The UPB site was designated as the primary disposal site during Dredging A with a diked area opposite Chickasaw Creek designated as the secondary disposal site. Outlet pipes were placed at both disposal areas and were connected with "Y" valves allowing disposal into either site. As material was placed in the prime site, and suspended solids concentrations in the effluent reached limiting values, disposal would then be temporarily routed to the secondary site.

15. Approximately 1,600,000 cubic yards of in situ material was removed from the channel. The great majority of the material was placed in the primary UPB site; however, records concerning exact yardages placed in the respective sites were not kept. Discharge pipe location at

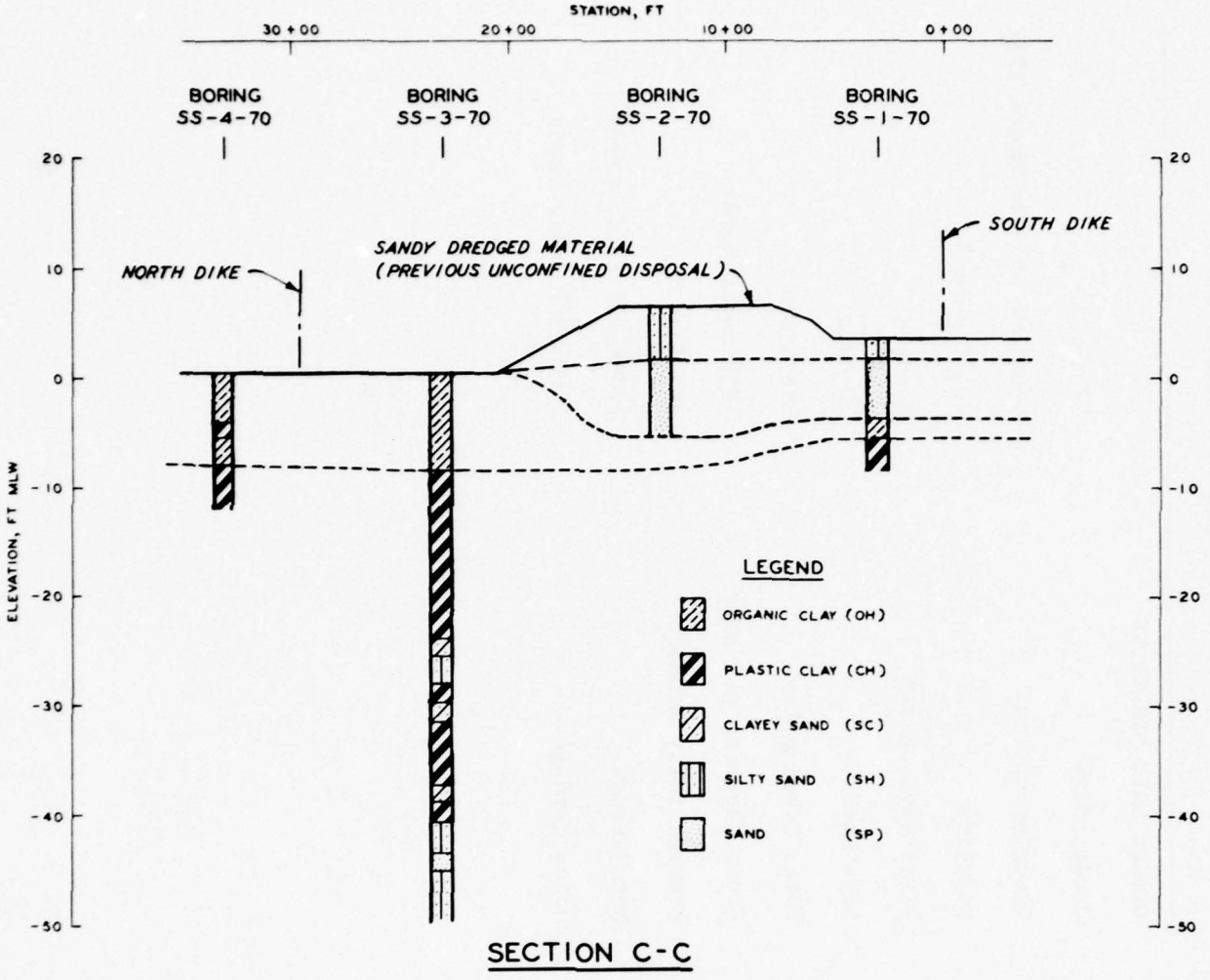


Figure A9. Generalized foundation conditions prior to placement of dredged material

Table A1

Pertinent Data for Dredging "A"

Dredge DAVE BLACKBURN	
Dredge Size	27 inches
Dredging Period	December 1971 to March 1972
Location	see Figure 3
Total Days on Job	83 days
Days Lost	20 days
Total Pumping Time	894 hours
Gross Capacity per Hour	1819 cubic yards
Average Daily Advance	385 feet
Net Yardage	1,399,175 cubic yards
Gross Yardage	1,625,387 cubic yards

the UPB site was near the southeast corner of the disposal area as indicated in Figure A10.

16. Dredged material placed during Dredging A consisted primarily of fine-grained clays and silts with a small fraction of sands. During the disposal operation, the coarser materials were deposited near the outlet pipe, creating an area of high ground in the southeast corner of the disposal area as indicated in Figure A10. Fine-grained material was carried toward the north weir and was eventually deposited over most of the disposal area.

17. The UPB site remained inactive until January through March 1973 when dredging operations were again performed in the upper Mobile River. Material was placed in the UPB site from an area immediately north of the U. S. Highway 90 bridge extending approximately 5430 feet into the Chickasaw Creek Channel. The 18-inch pipeline dredge STUART was used under contract with the MD. A summary of dredging data is presented in Table A2.[30] The limits of this work are indicated on Figure A1 and will hereafter be referred to as "Dredging B."

18. The discharge pipe for Dredging B was initially located in the southeast corner of the disposal area as indicated in Figure 8 in the main text. Sandy material was encountered immediately above the Highway 90 bridge during the dredging operation, and this material further added to the high mounded area in the southeast corner of the disposal area. The discharge pipe was later moved adjacent to the south weir during the dredging operation in the Chickasaw Creek channel. This weir was closed during that portion of the dredging operation. The dredged material from

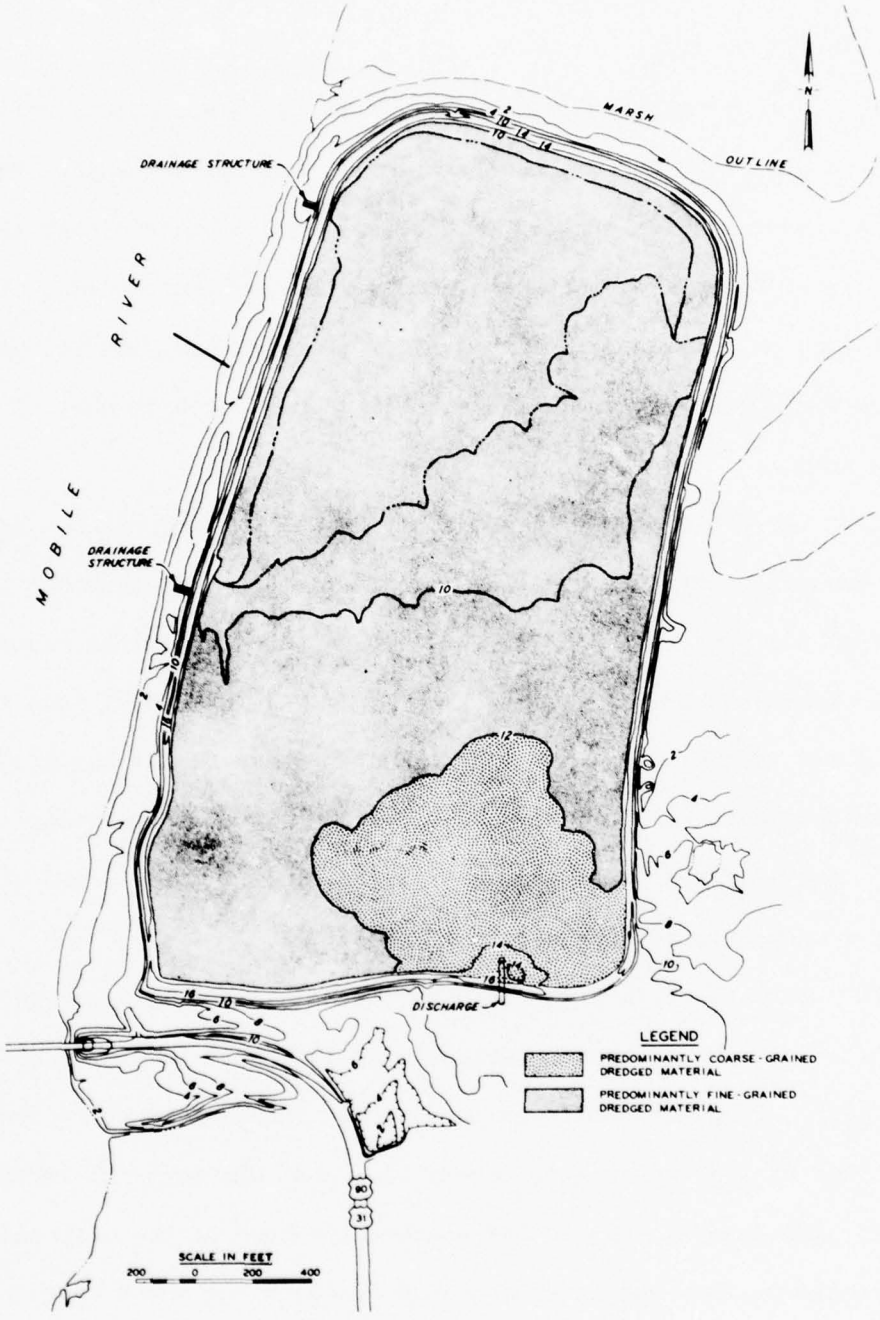


Figure A10. UPB disposal area, following dredging A, July 1972 survey

Table A2

Pertinent Data for Dredging "B"

Dredge STUART	
Dredge size	18 inches
Dredging Period	October 1972 to June 1973
Location	see Figure 3
Total Days Worked	68
Total Pumping Time	887 hours
Gross Capacity per Hour	1577 cubic yards
Average Daily Advance	227 feet
Net Yards	959,694 cubic yards
Gross Yards	1,401,171 cubic yards

Chickasaw Creek primarily consisted of fine-grained clays with small fractions of sand but contained significant amounts of wood chips and bark that were present in the channel as residue from wood-processing industries located along the creek. The coarser-grained materials and wood chips were deposited in a fanlike fashion around the outlet pipe as indicated in Figure 8 in the main text. Fine-grained material was carried toward the north weir and into a low energy area created by poo circulation in the southwest corner of the disposal area. A total of 254,587 cubic yards of in situ material was removed during Dredging B from both channels.

APPENDIX B:

DREDGED MATERIAL TEST DATA SUMMARIES

1. This Appendix contains graphical boring logs and results of tests performed on samples from borings BI-1 through BI-26. These borings were taken within the Upper Polecat Bay (UPB) disposal area located as shown in Figure 12 in the main text.

2. Samples were obtained by hand pushing a 3-inch I.D. vacuum sampler into the dredged material. A maximum depth of 12.5 feet was attained with this method. Laboratory testing was performed by the WES Soils and Pavements Laboratory and included USCS Classifications, grain-size analyses, water content and Atterberg Limits determinations, specific gravity tests, laboratory vane shear, and consolidation tests. Shrinkage tests were conducted by the WES Environmental Effects Laboratory. Individual test data results are available in Reference 10.

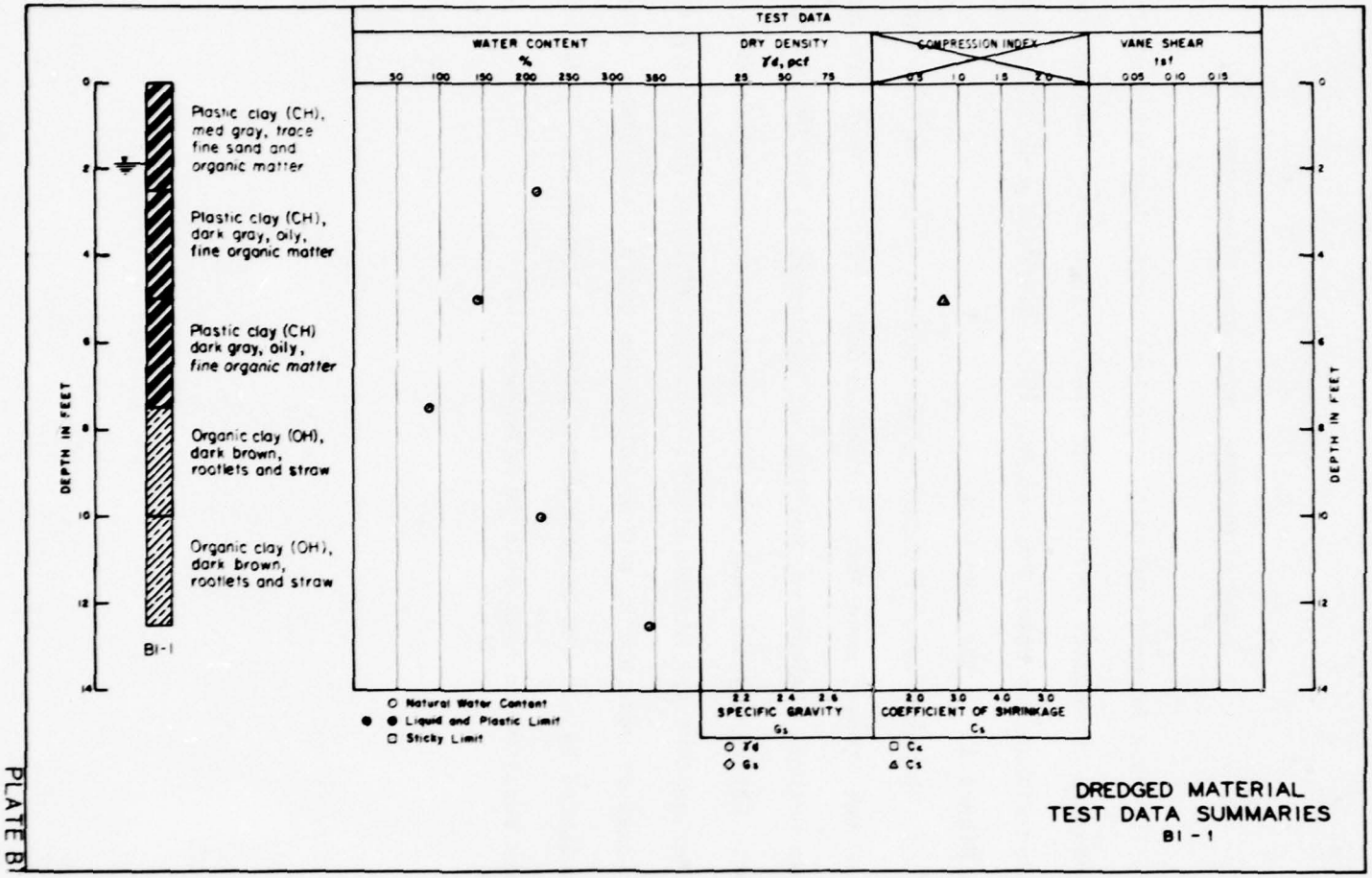
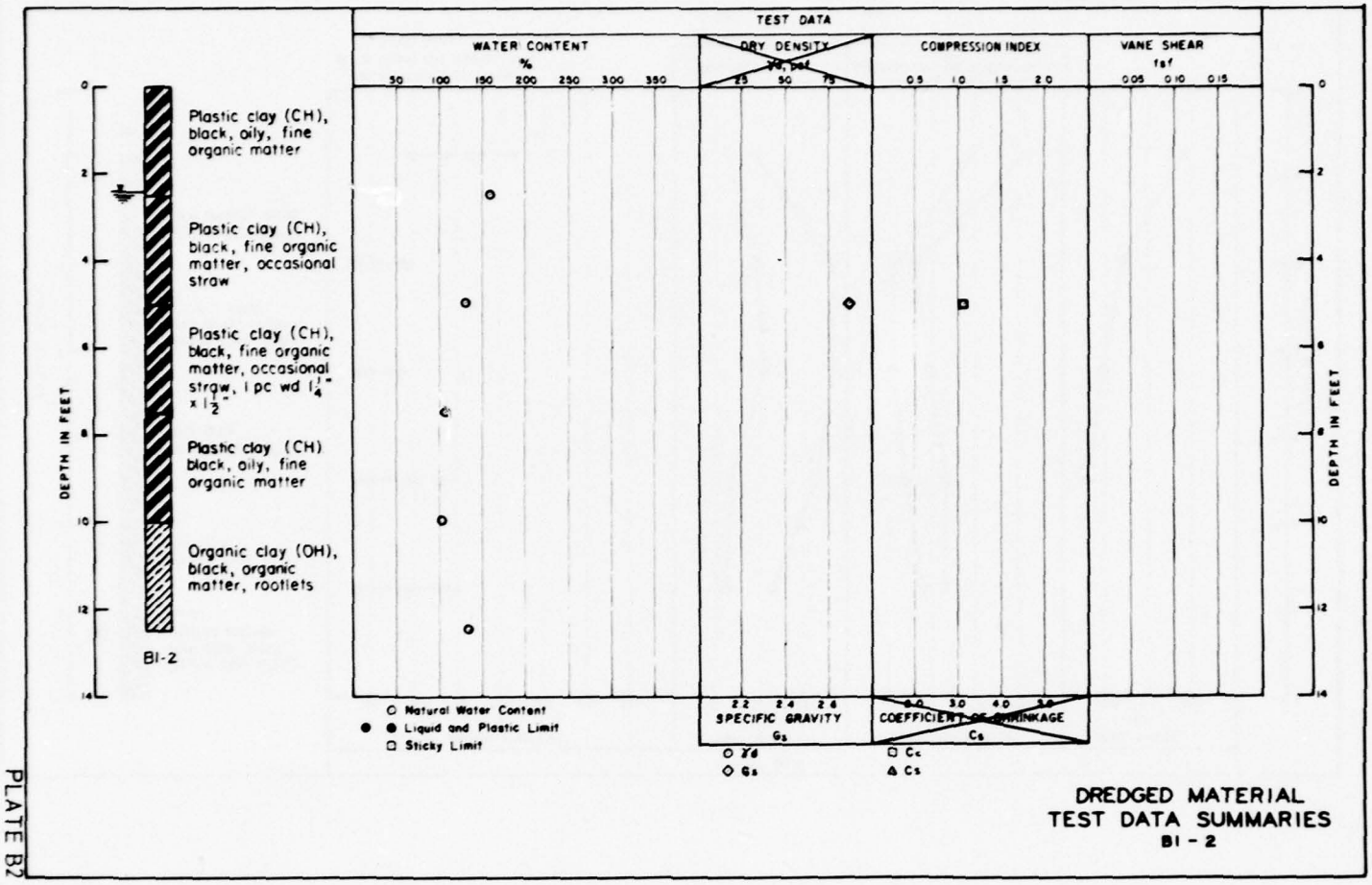

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), med gray, trace fine sand and organic matter
Plastic clay (CH), dark gray, oily, fine organic matter
Plastic clay (CH) dark gray, oily, fine organic matter
Organic clay (OH), dark brown, rootlets and straw
Organic clay (OH), dark brown, rootlets and straw
B1-1
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 1

PLATE B1



DREDGED MATERIAL
TEST DATA SUMMARIES
BI - 2

PLATE B2

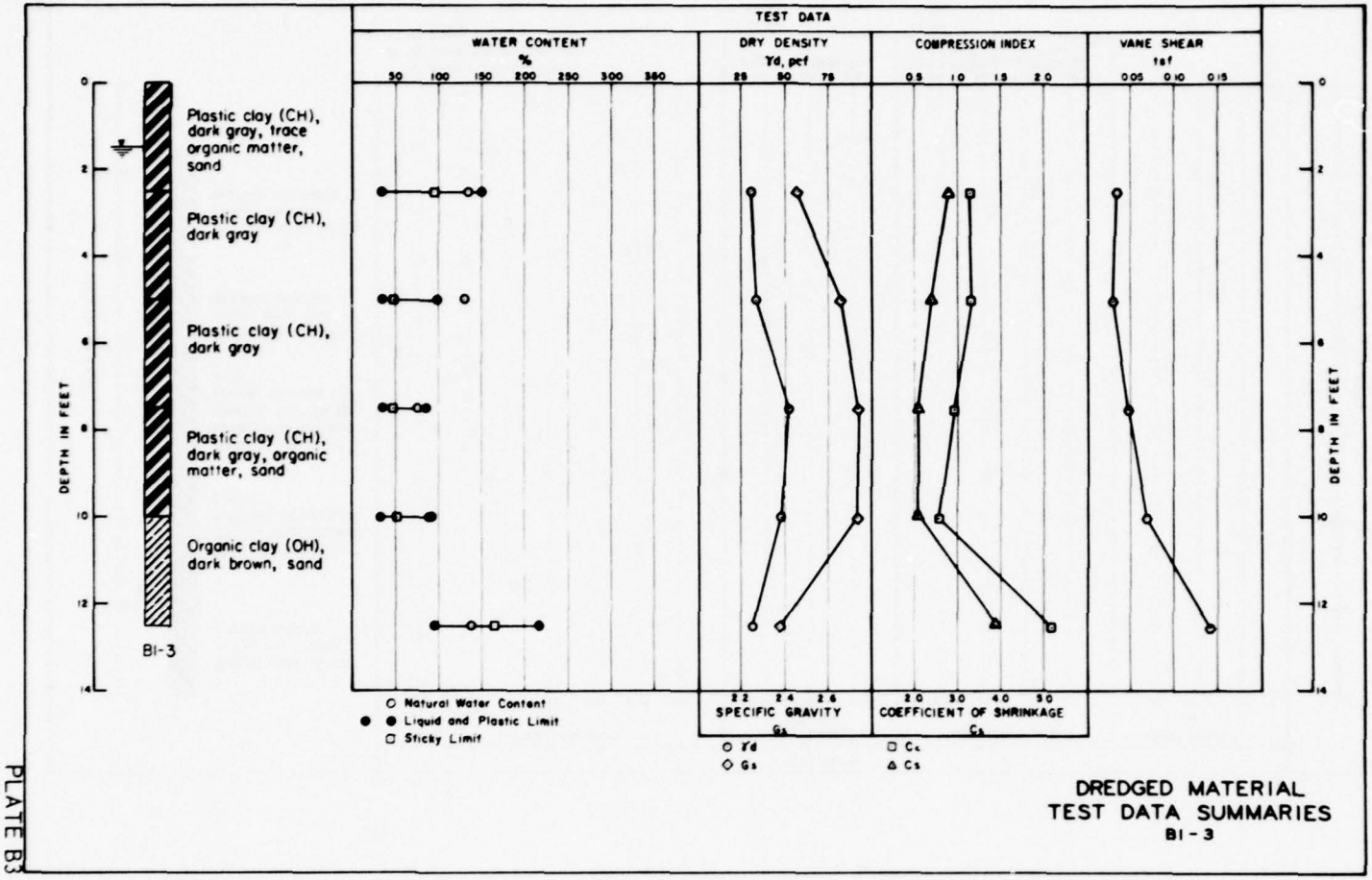
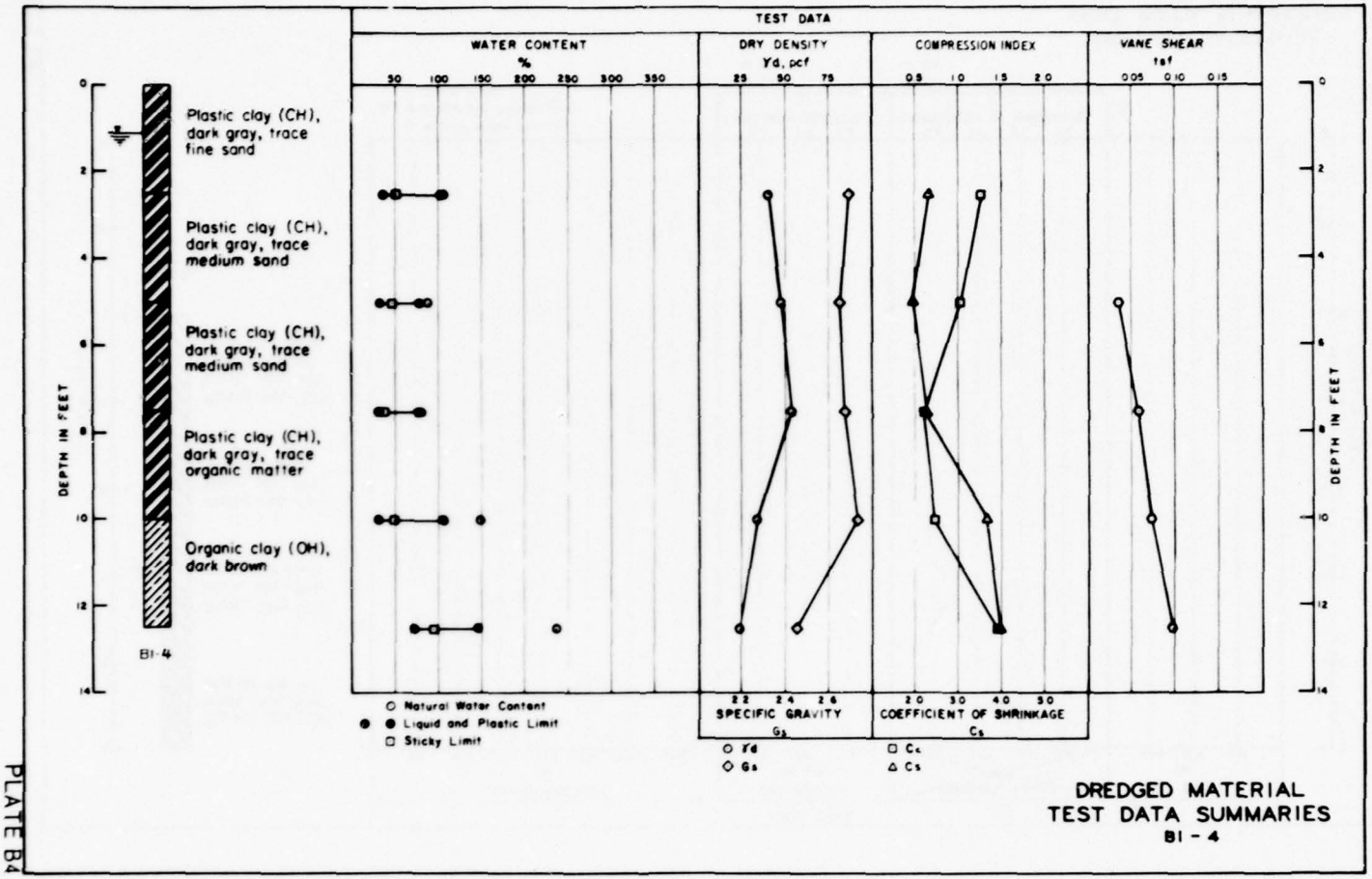

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), dark gray, trace organic matter, sand
Plastic clay (CH), dark gray
Plastic clay (CH), dark gray
Plastic clay (CH), dark gray, organic matter, sand
Organic clay (OH), dark brown, sand
B1-3
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 3

PLATE B3



DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 4

PLATE B4

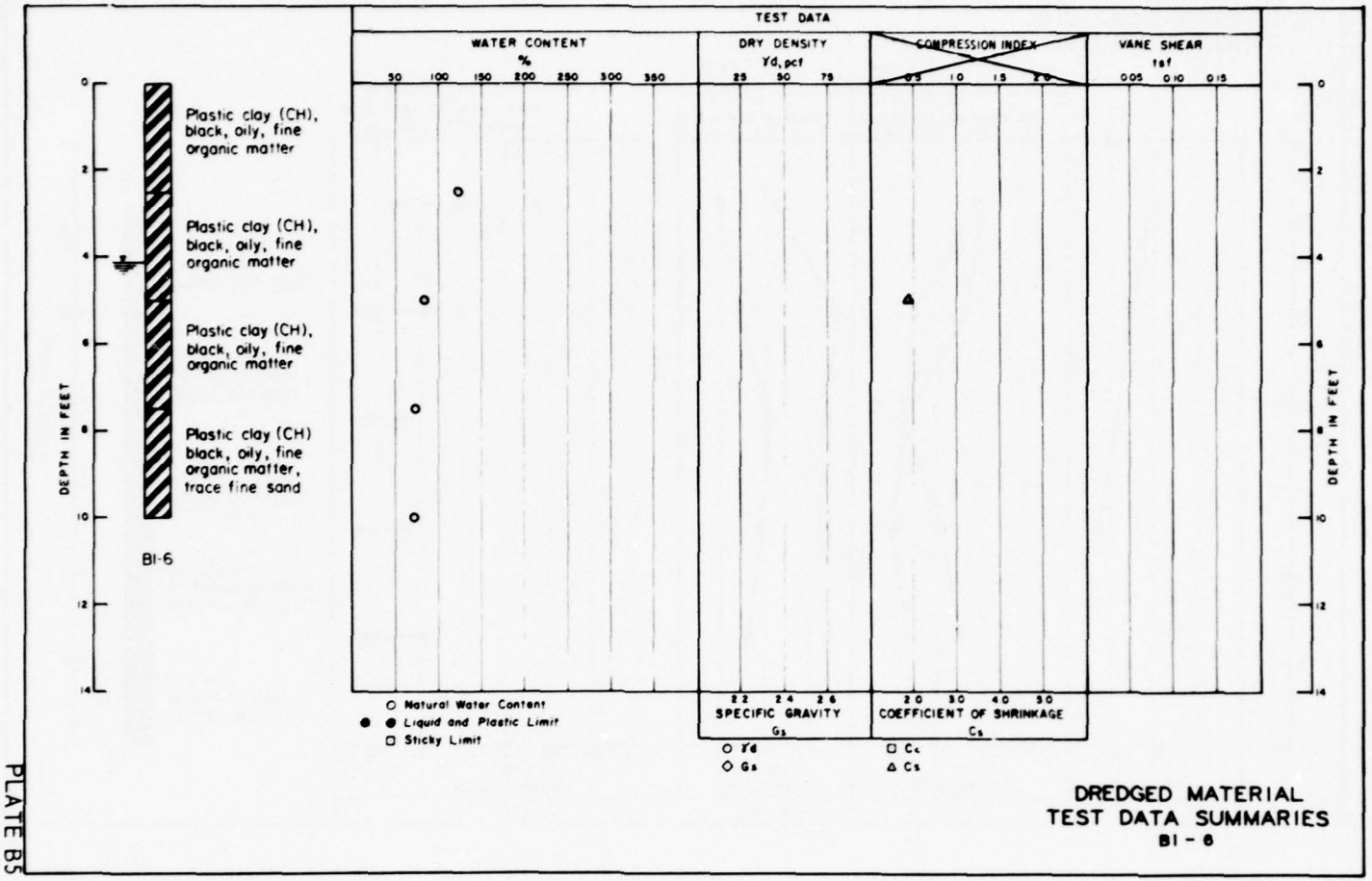

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
Yd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH) black, oily, fine organic matter, trace fine sand
B1-6
○ Natural Water Content
● ◉ Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 6

PLATE B5

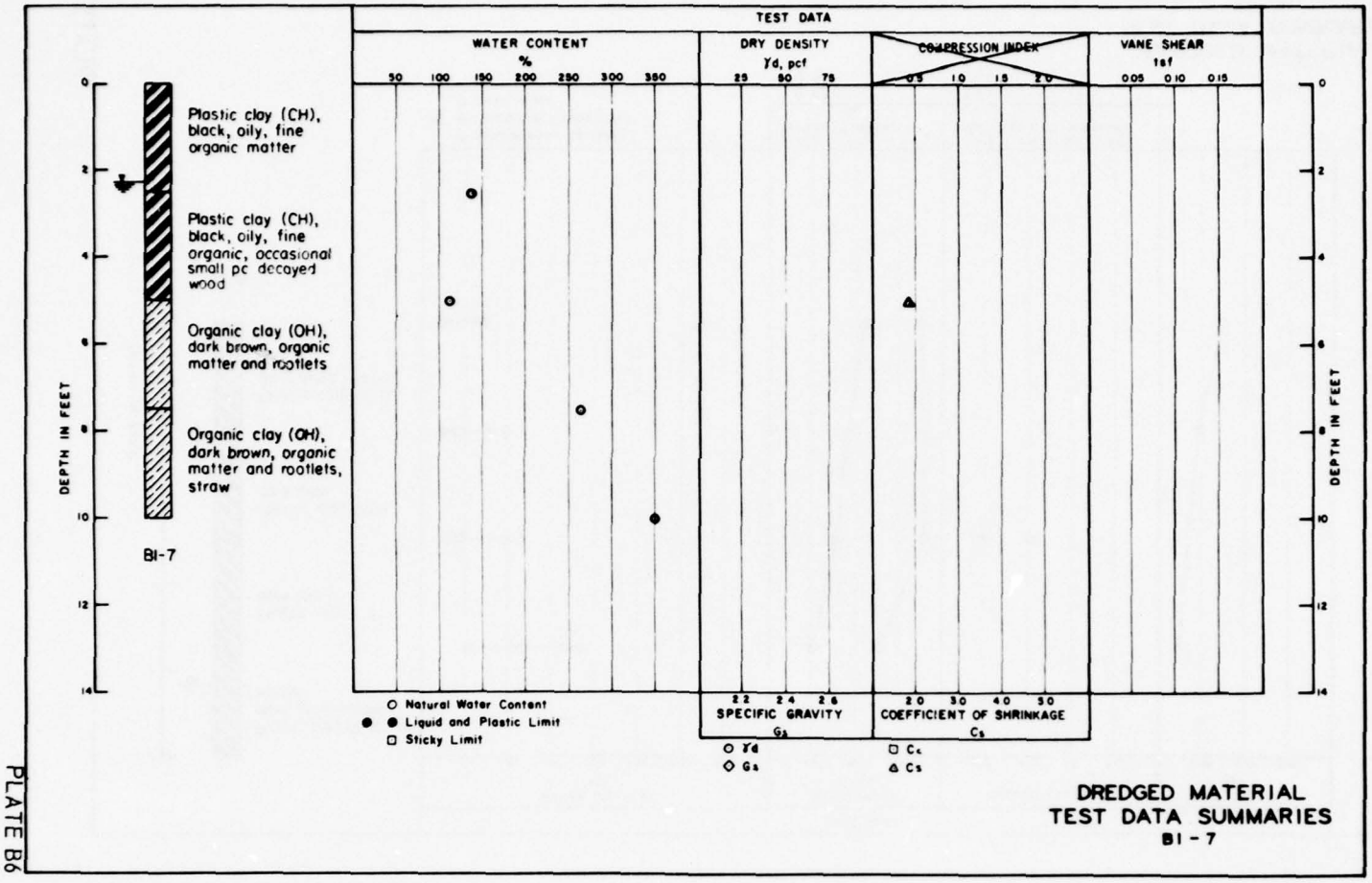
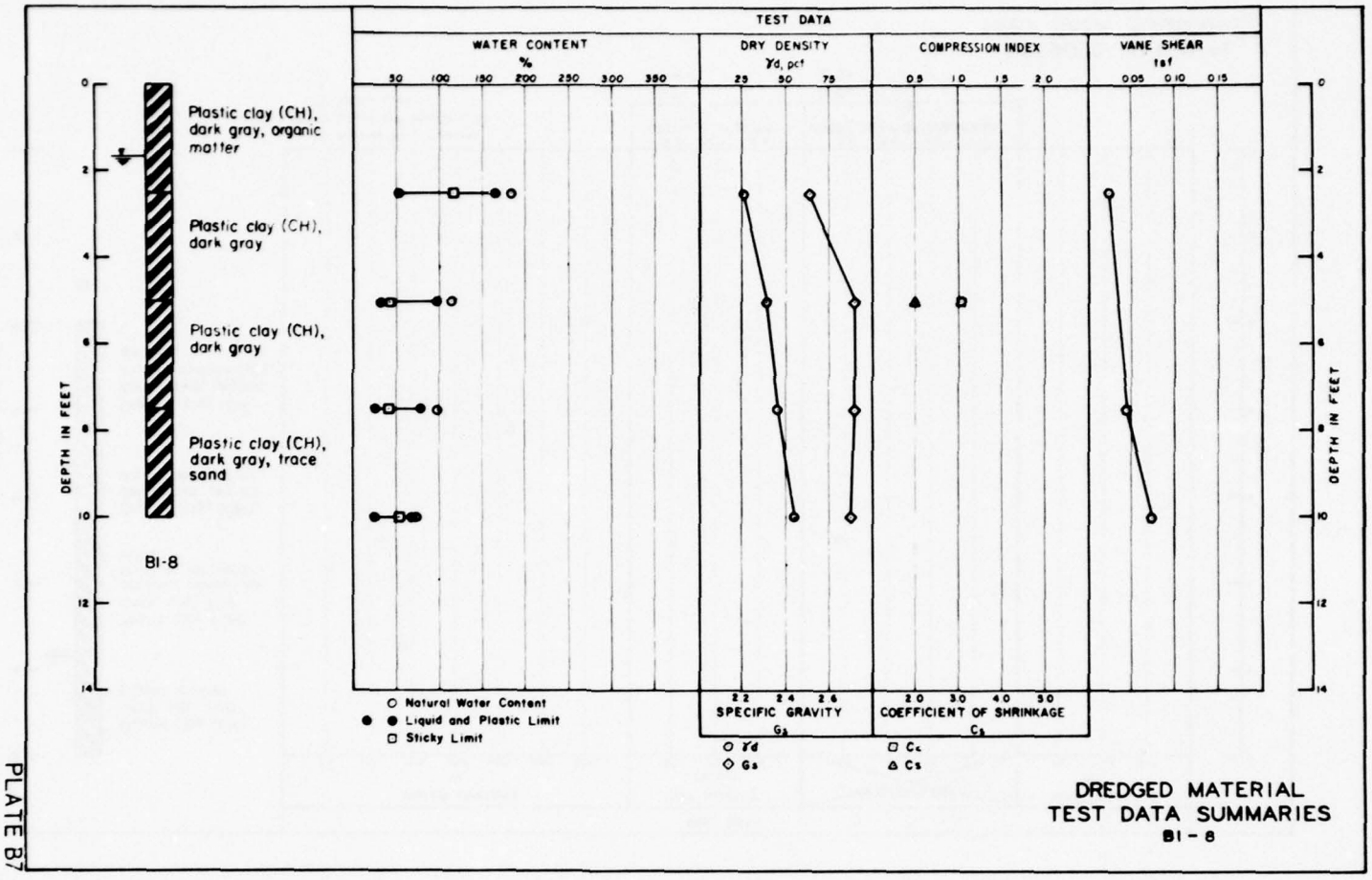

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic, occasional small pc decayed wood
Organic clay (OH), dark brown, organic matter and rootlets
Organic clay (OH), dark brown, organic matter and rootlets, straw
B1-7
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 7

PLATE B6



DREDGED MATERIAL
TEST DATA SUMMARIES
BI - 8

PLATE B7

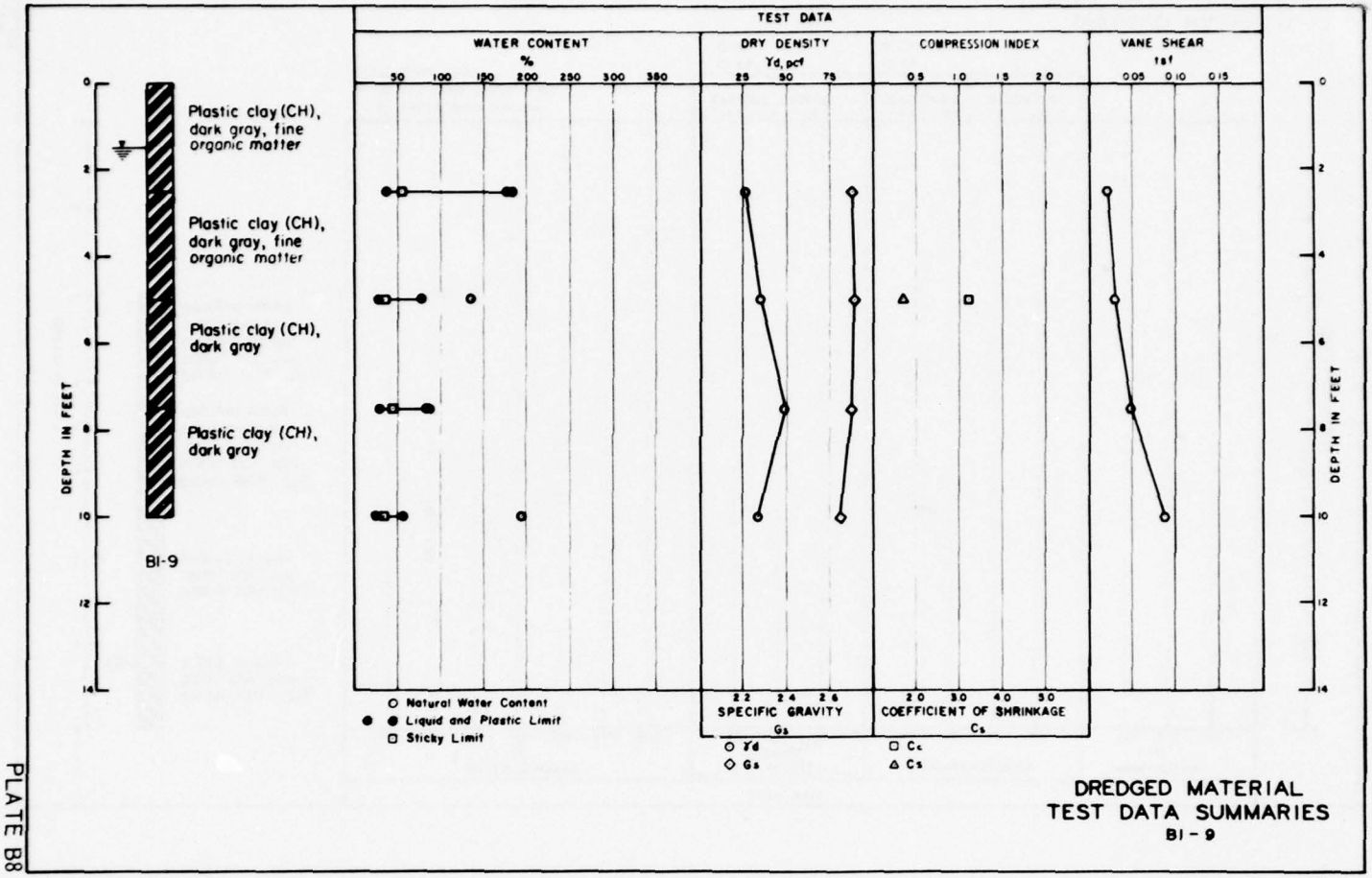

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), dark gray, fine organic matter
Plastic clay (CH), dark gray, fine organic matter
Plastic clay (CH), dark gray
Plastic clay (CH), dark gray
BI-9
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI - 9

PLATE B8

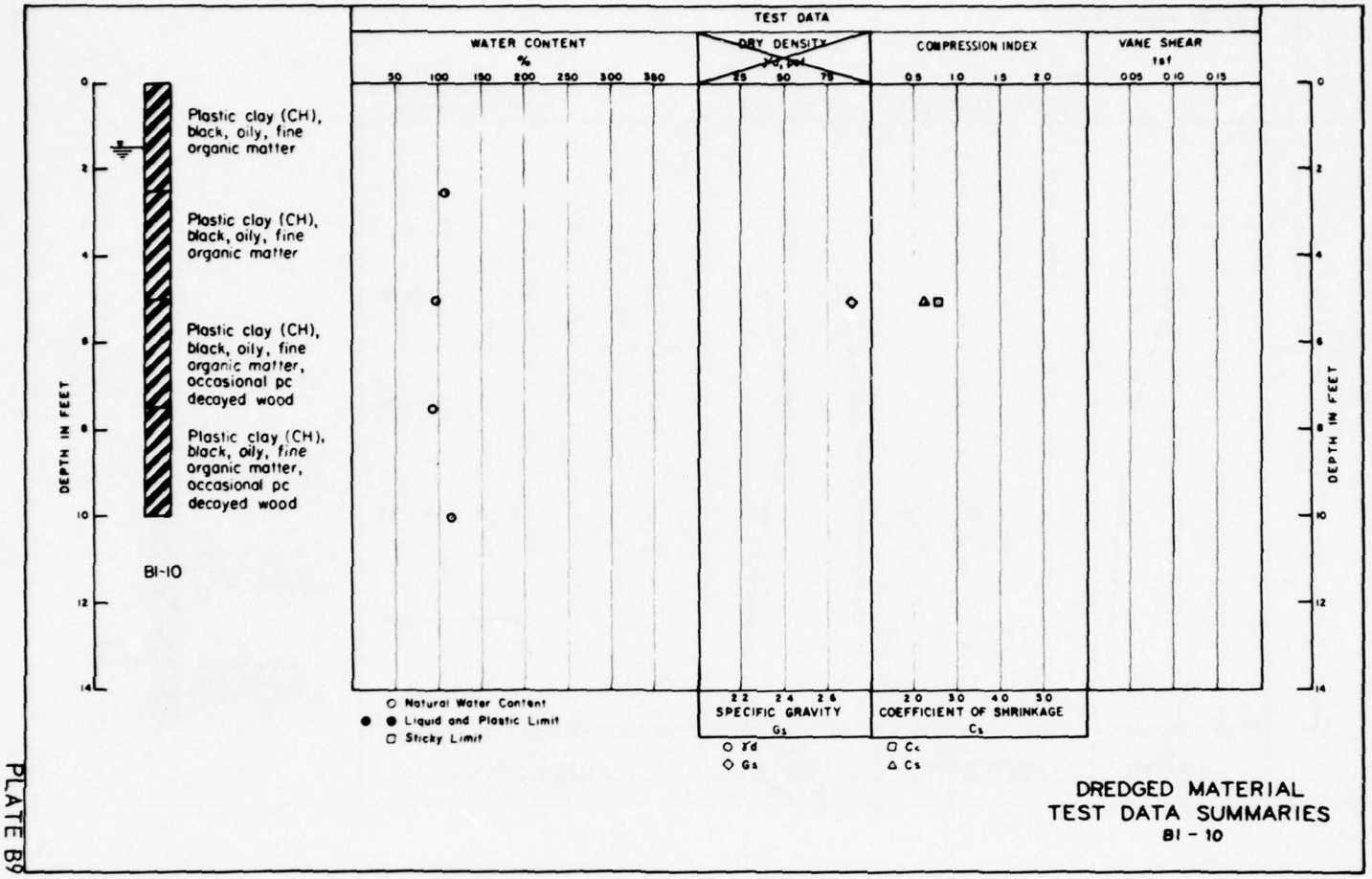

TEST DATA
WATER CONTENT
%
30 100 150 200 250 300 350
DRY DENSITY
γd, pcf
75 90 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter, occasional pc decayed wood
Plastic clay (CH), black, oily, fine organic matter, occasional pc decayed wood
BI-10
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI - 10

PLATE B9

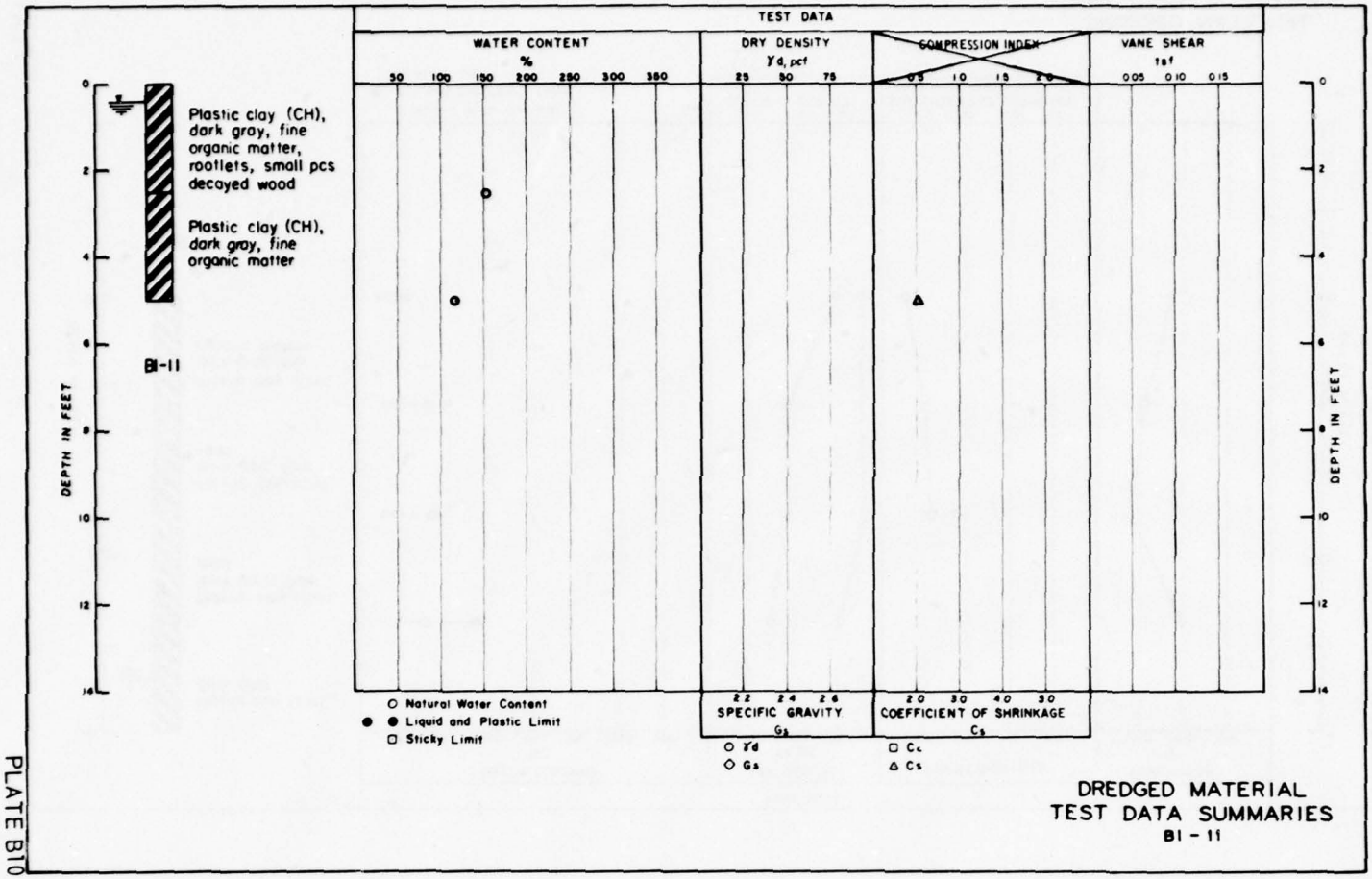
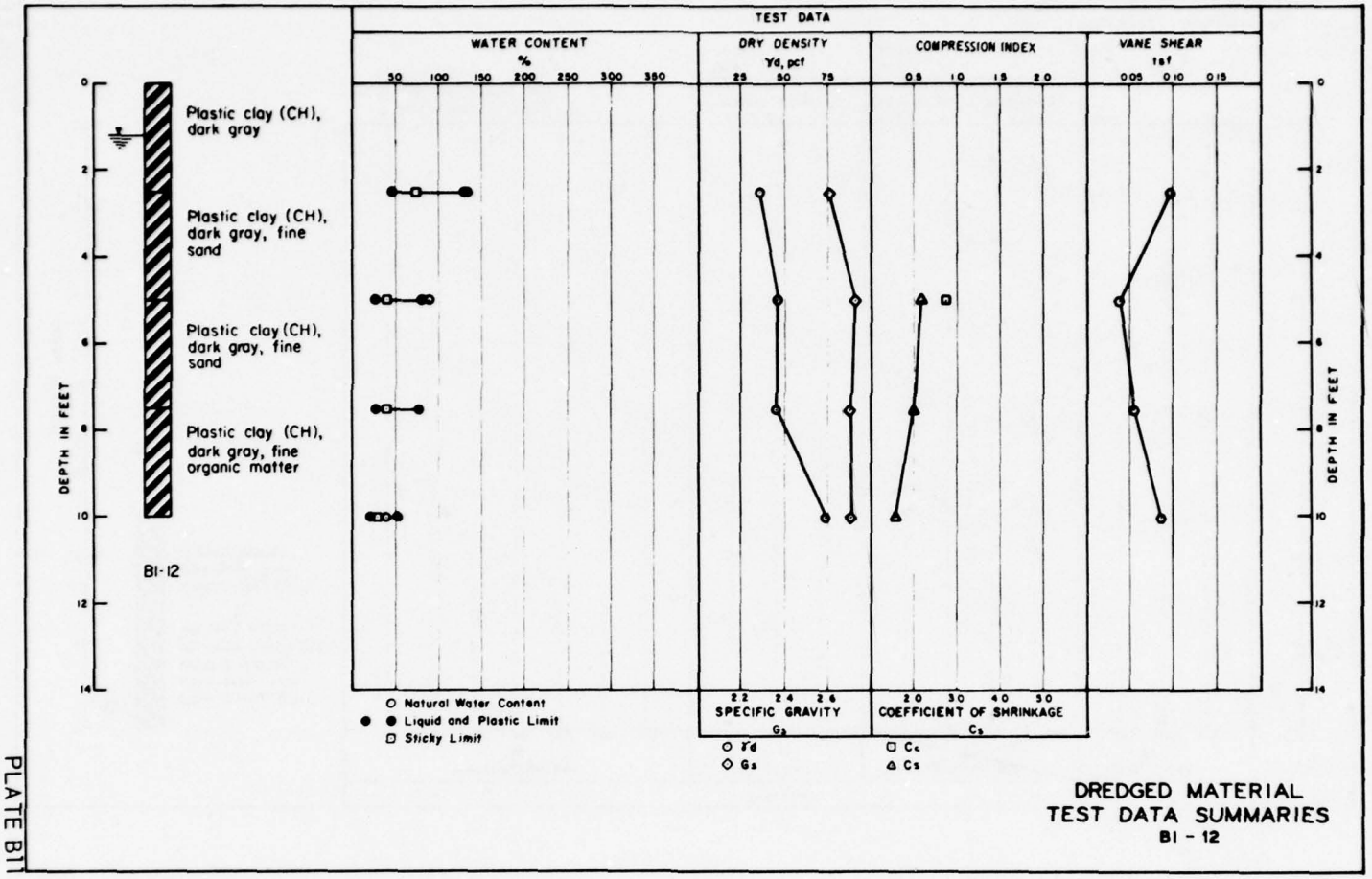
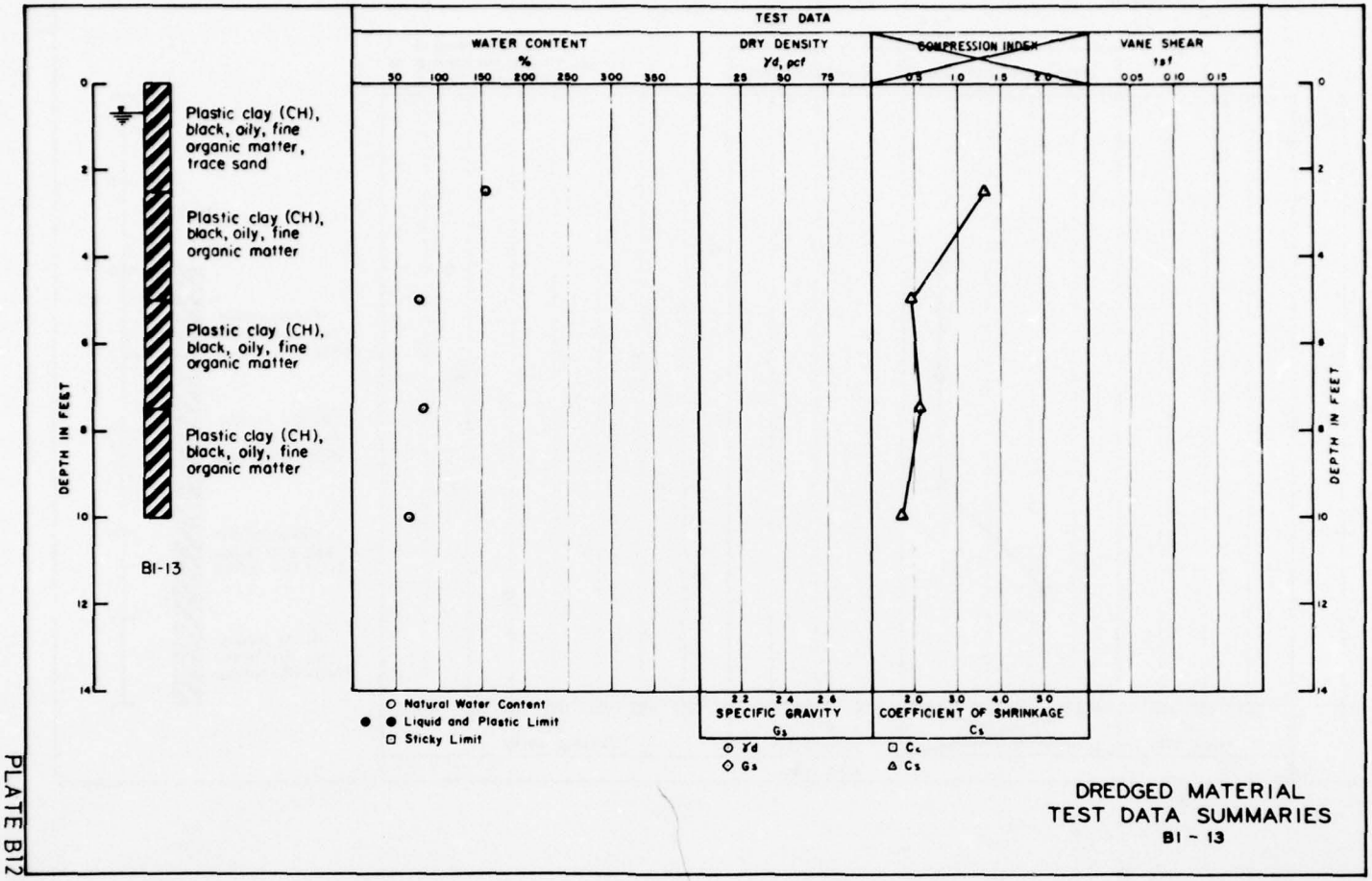

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), dark gray, fine organic matter, rootlets, small pcs decayed wood
Plastic clay (CH), dark gray, fine organic matter
B1-11
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
SPECIFIC GRAVITY
Gs
2.2 2.4 2.6
○ γd
◇ Gs
COEFFICIENT OF SHRINKAGE
Cs
2.0 3.0 4.0 5.0
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 11

PLATE B10



DREDGED MATERIAL
TEST DATA SUMMARIES
BI - 12

PLATE BI



DREDGED MATERIAL
TEST DATA SUMMARIES
BI - 13

PLATE B12

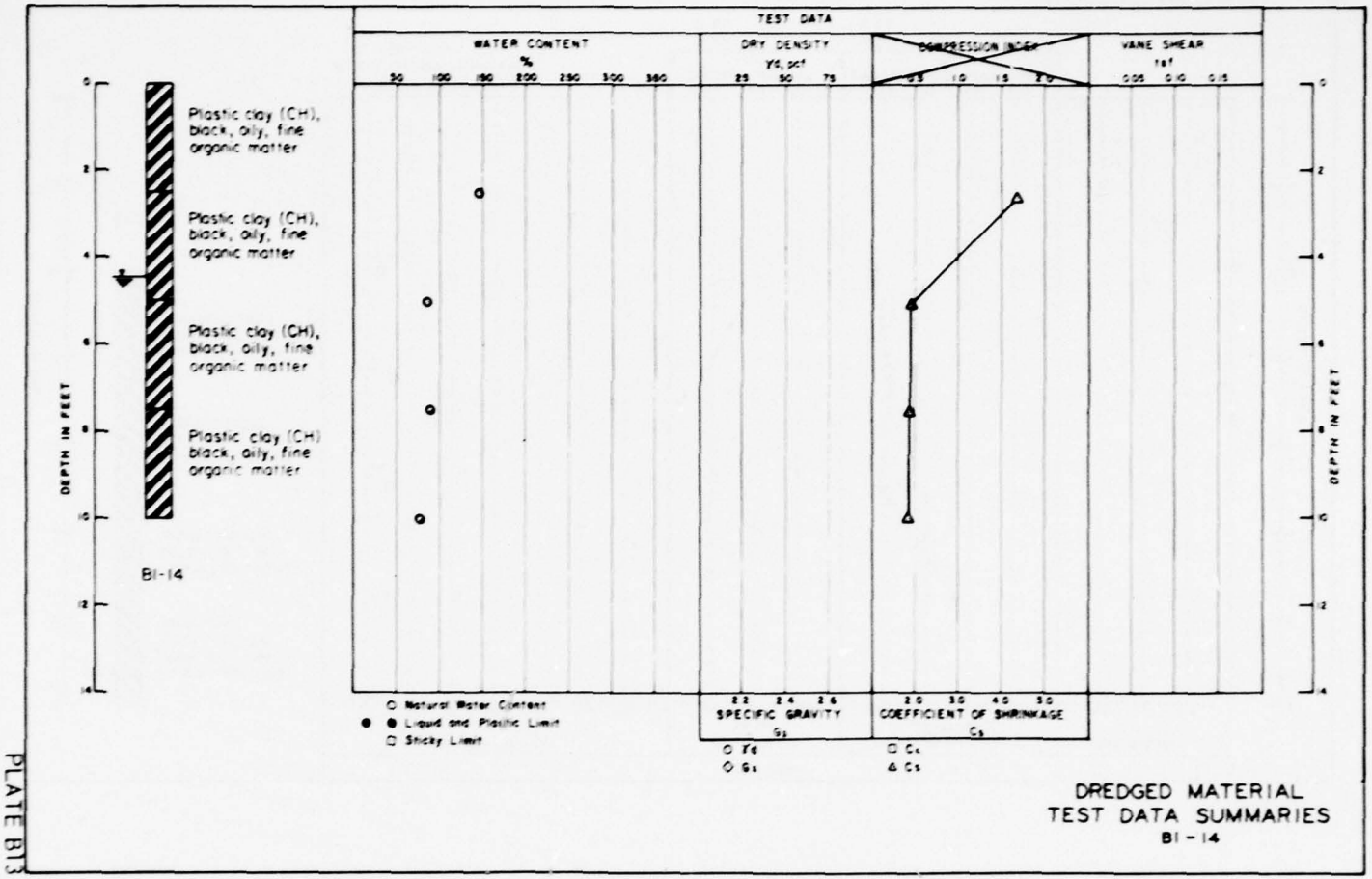

TEST DATA
WATER CONTENT
%
DRY DENSITY
γd, pcf
COMPRESSION INDEX
VANE SHEAR
tsf
DEPTH IN FEET
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH) black, oily, fine organic matter
B1-14
Natural Water Content
Liquid and Plastic Limit
Sticky Limit
SPECIFIC GRAVITY
Gs
COEFFICIENT OF SHRINKAGE
Cs
γd
Gs
Cs
Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 14

PLATE B13

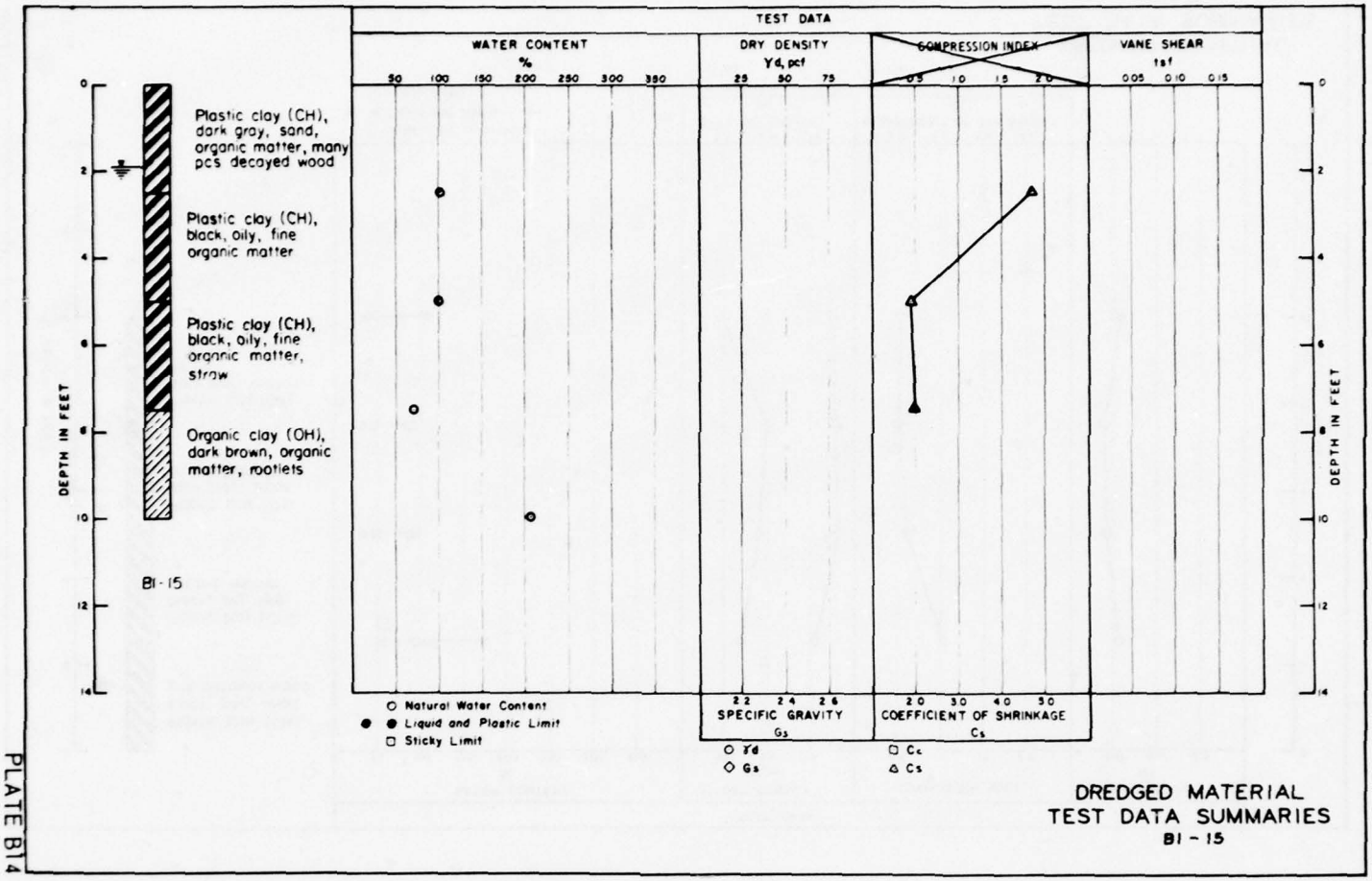

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
Yd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), dark gray, sand, organic matter, many pcs decayed wood
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter, straw
Organic clay (OH), dark brown, organic matter, rootlets
B1-15
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DEPTH IN FEET
DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 15

PLATE B14

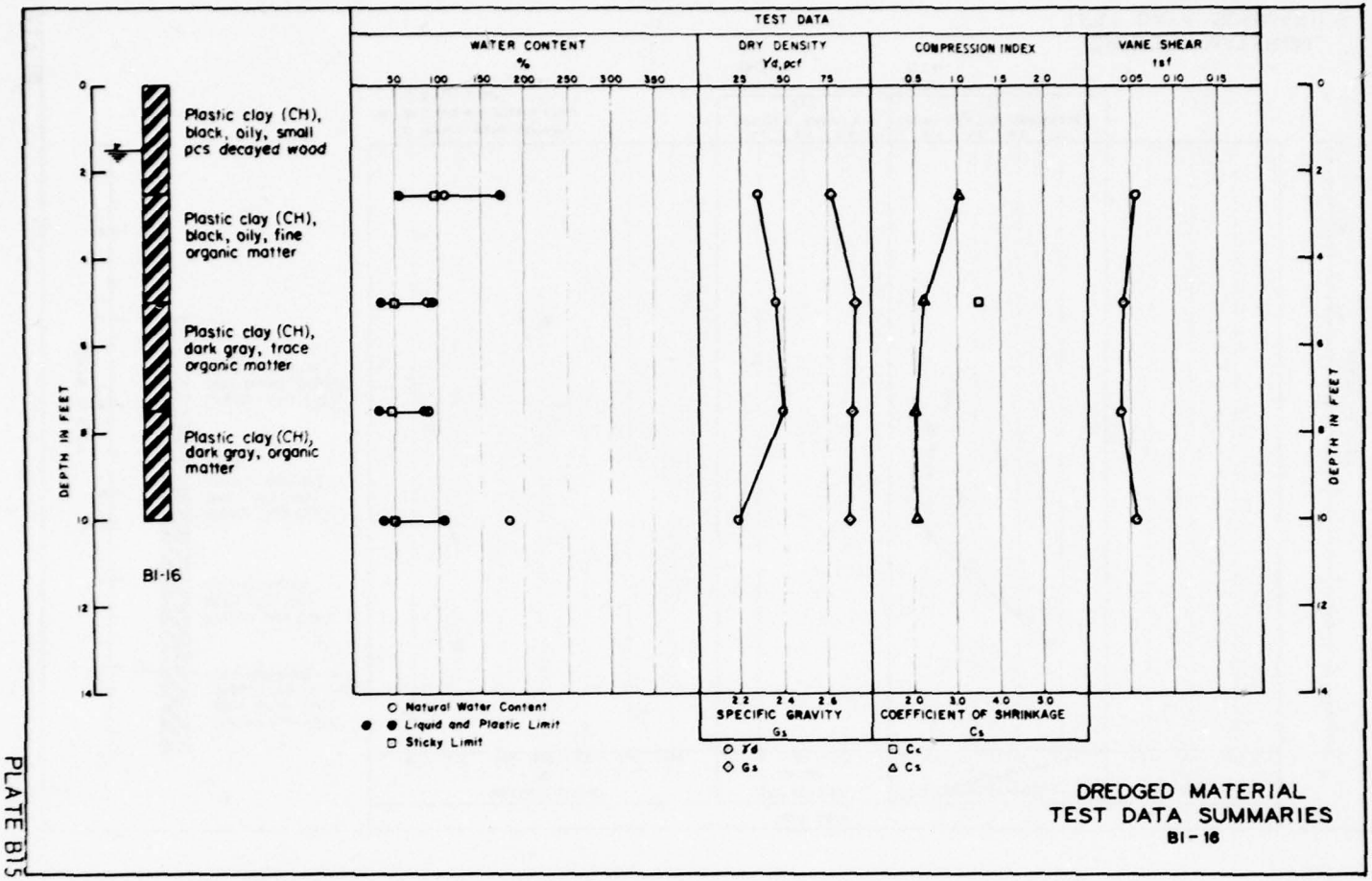

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
Yd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), black, oily, small pcs decayed wood
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), dark gray, trace organic matter
Plastic clay (CH), dark gray, organic matter
BI-16
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI-16

PLATE B15

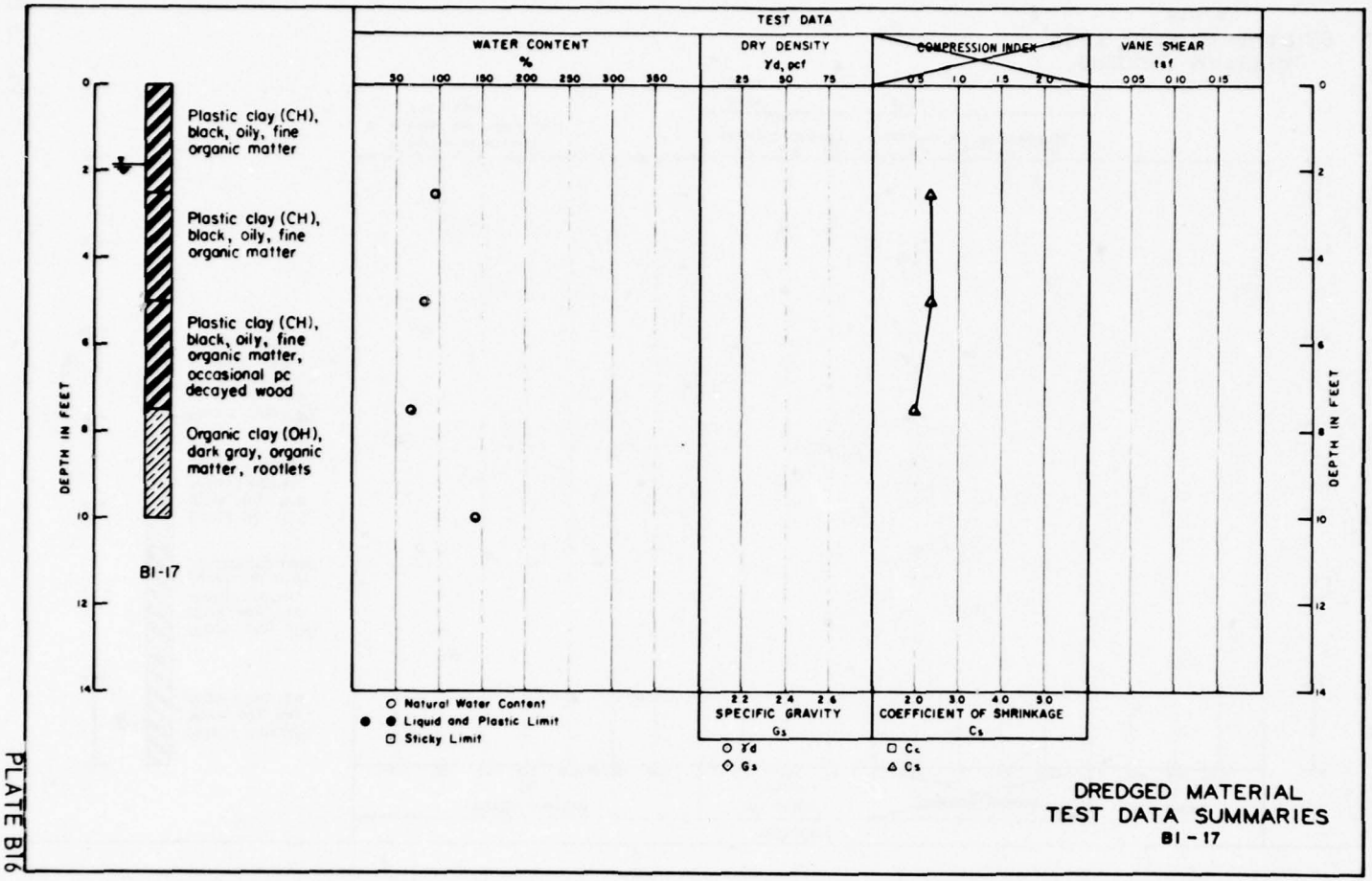

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter, occasional pc decayed wood
Organic clay (OH), dark gray, organic matter, rootlets
B1-17
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DEPTH IN FEET
DREDGED MATERIAL
TEST DATA SUMMARIES
B1 - 17

PLATE B16

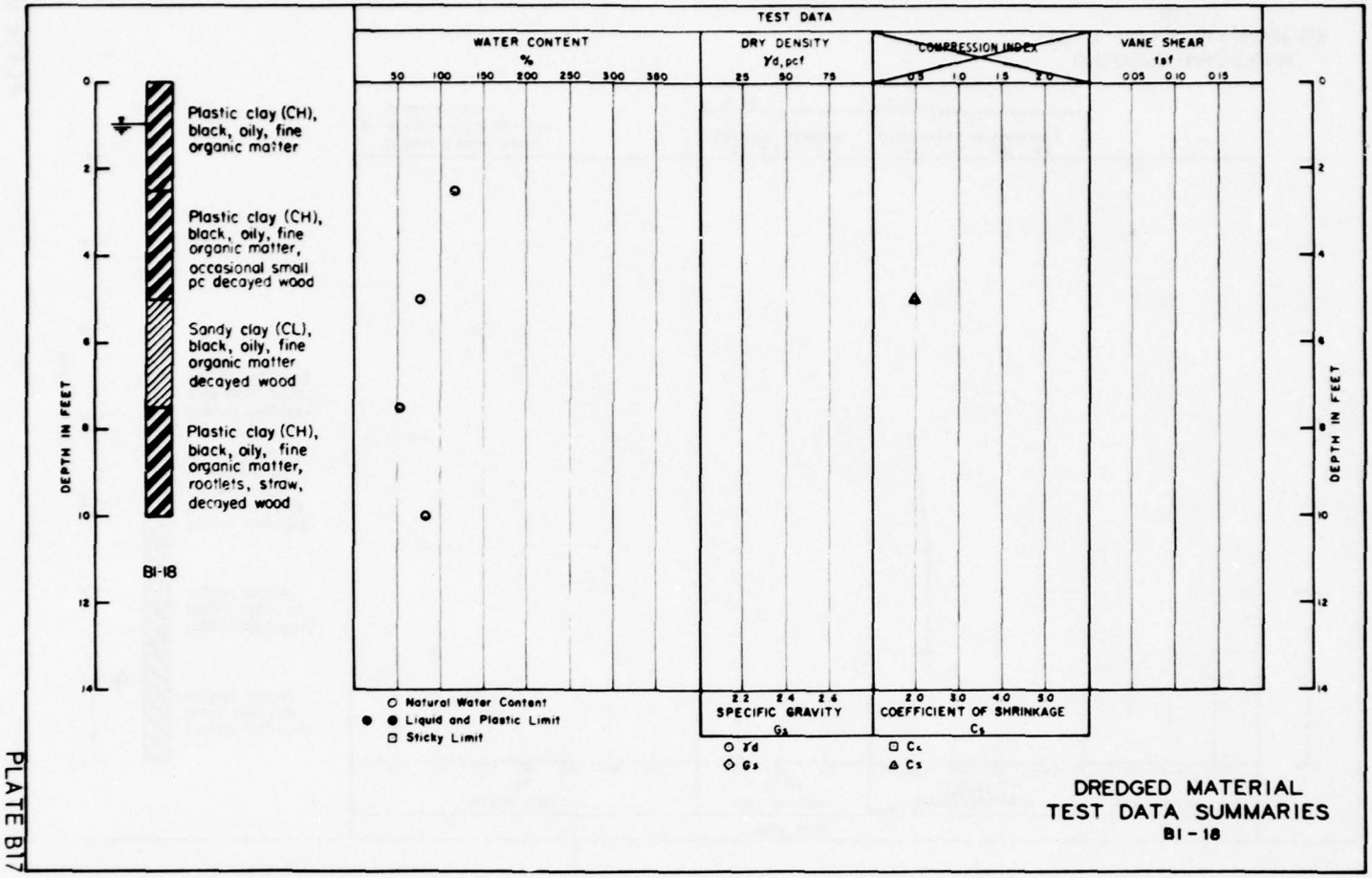

TEST DATA
WATER CONTENT
%
30 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter, occasional small pc decayed wood
Sandy clay (CL), black, oily, fine organic matter decayed wood
Plastic clay (CH), black, oily, fine organic matter, rootlets, straw, decayed wood
BI-18
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
SPECIFIC GRAVITY
Gs
2.2 2.4 2.6
○ γd
◇ Gs
COEFFICIENT OF SHRINKAGE
Cs
2.0 3.0 4.0 5.0
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI - 18

PLATE B17

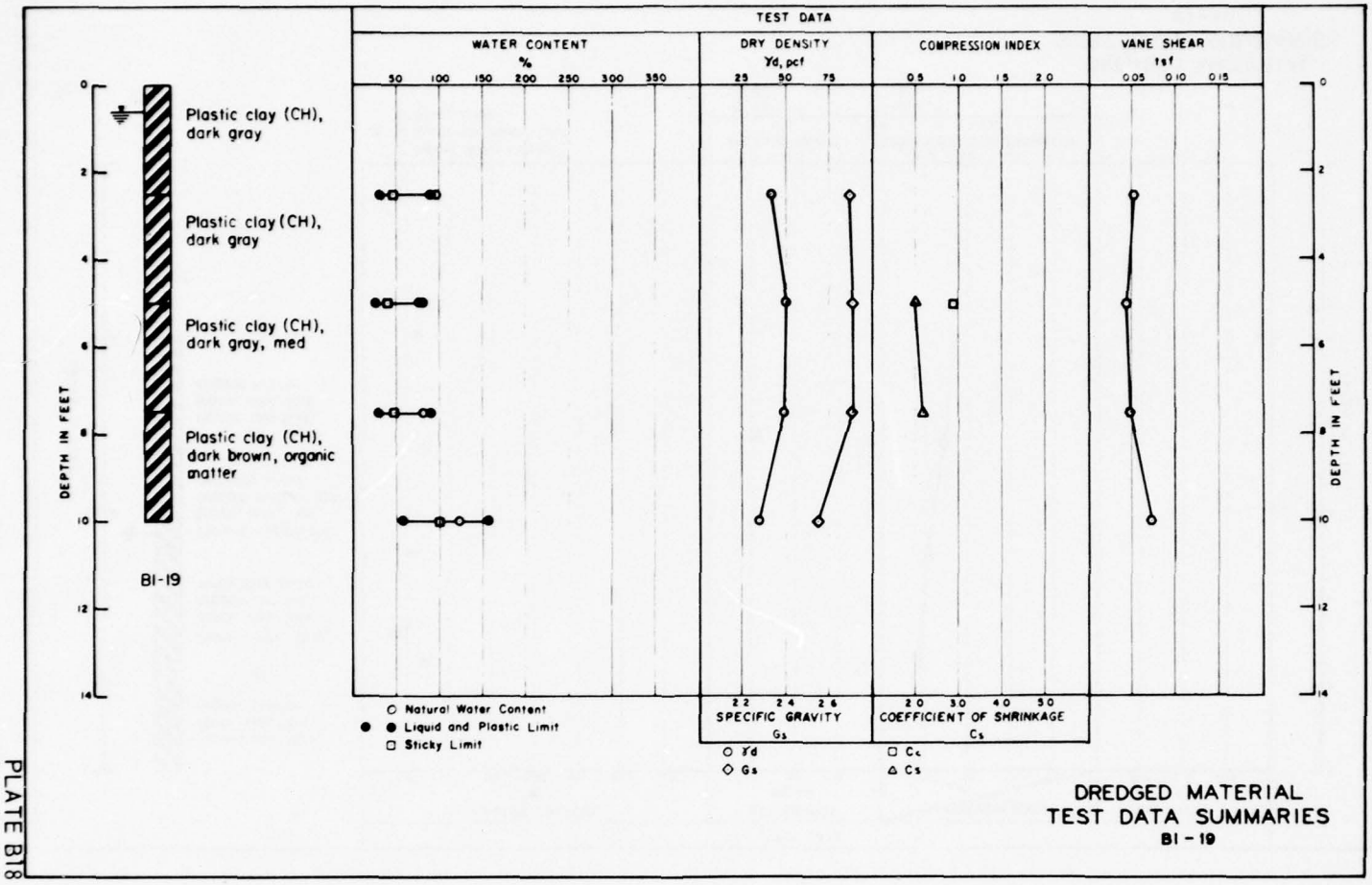

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), dark gray
Plastic clay (CH), dark gray
Plastic clay (CH), dark gray, med
Plastic clay (CH), dark brown, organic matter
BI-19
○ Natural Water Content
● Liquid and Plastic Limit
□ Sticky Limit
SPECIFIC GRAVITY
Gs
2.2 2.4 2.6
○ γd
◇ Gs
COEFFICIENT OF SHRINKAGE
Cs
2.0 3.0 4.0 5.0
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI - 19

PLATE B18

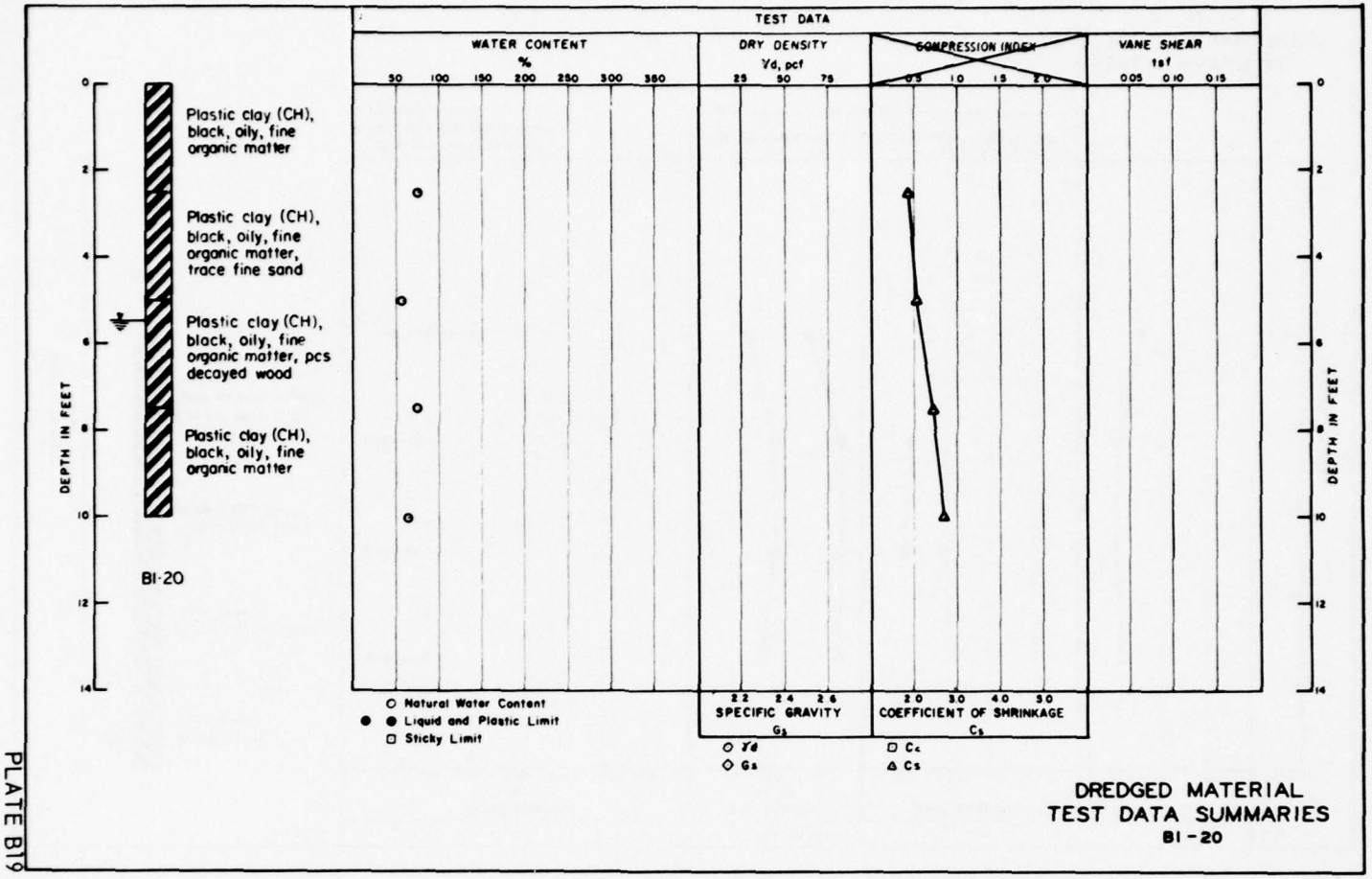

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter, trace fine sand
Plastic clay (CH), black, oily, fine organic matter, pcs decayed wood
Plastic clay (CH), black, oily, fine organic matter
BI-20
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
SPECIFIC GRAVITY
Gs
2.2 2.4 2.6
○ γd
◇ Gs
COEFFICIENT OF SHRINKAGE
Cs
2.0 3.0 4.0 5.0
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI-20

PLATE BI9

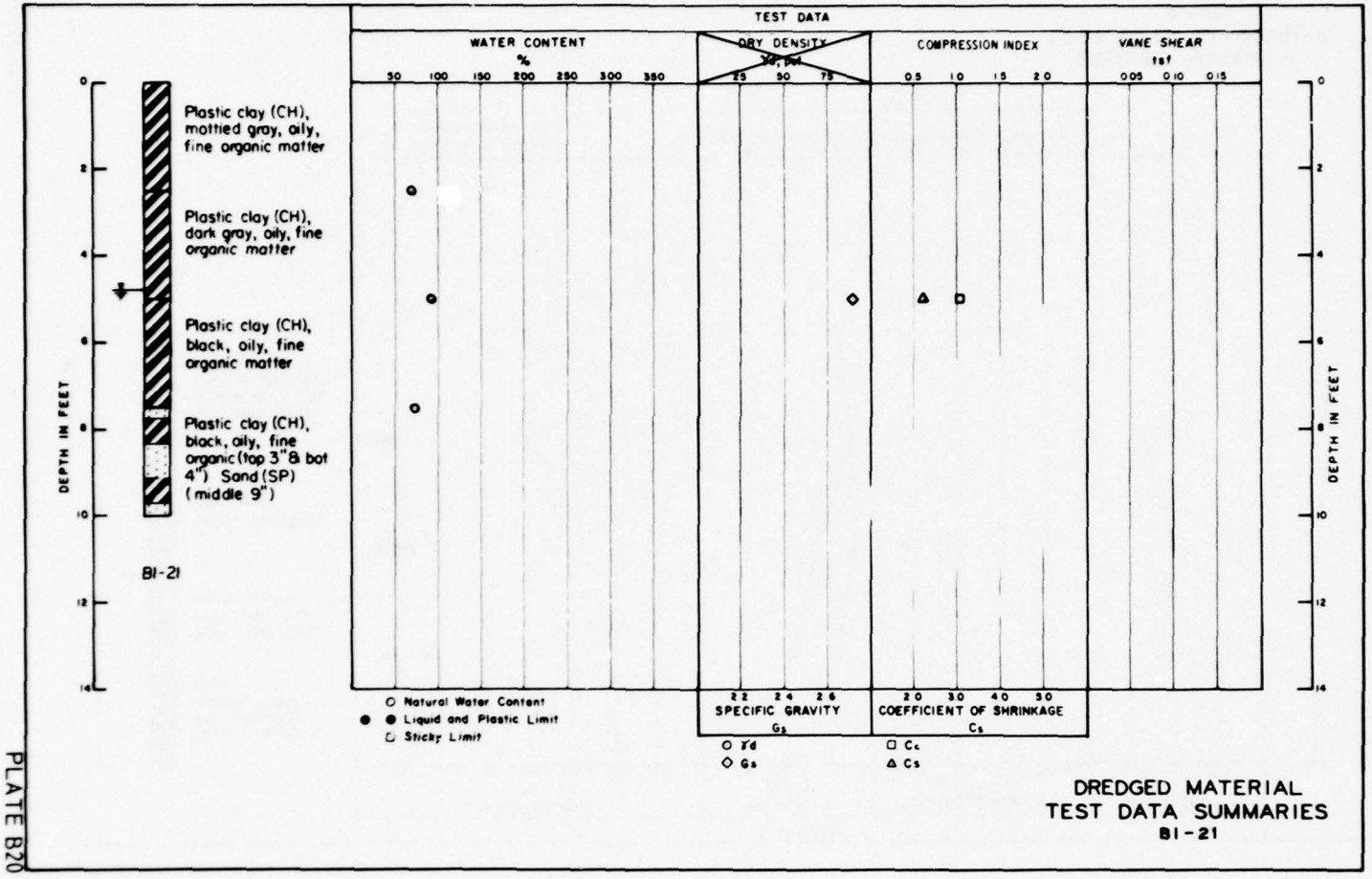

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
75 90 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), mottled gray, oily, fine organic matter
Plastic clay (CH), dark gray, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic (top 3" & bot 4") Sand (SP) (middle 9")
B1-21
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
B1-21

PLATE B20

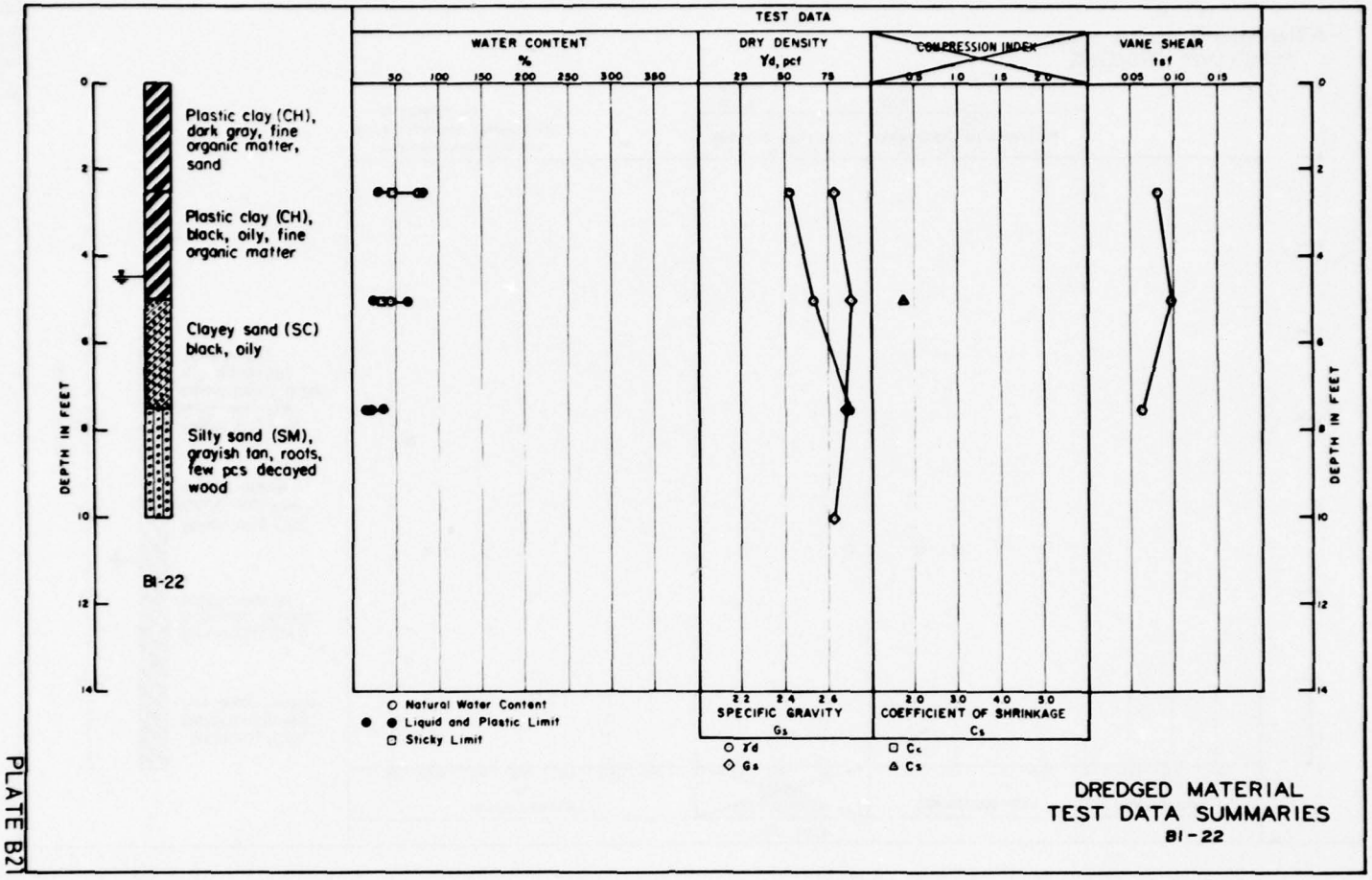
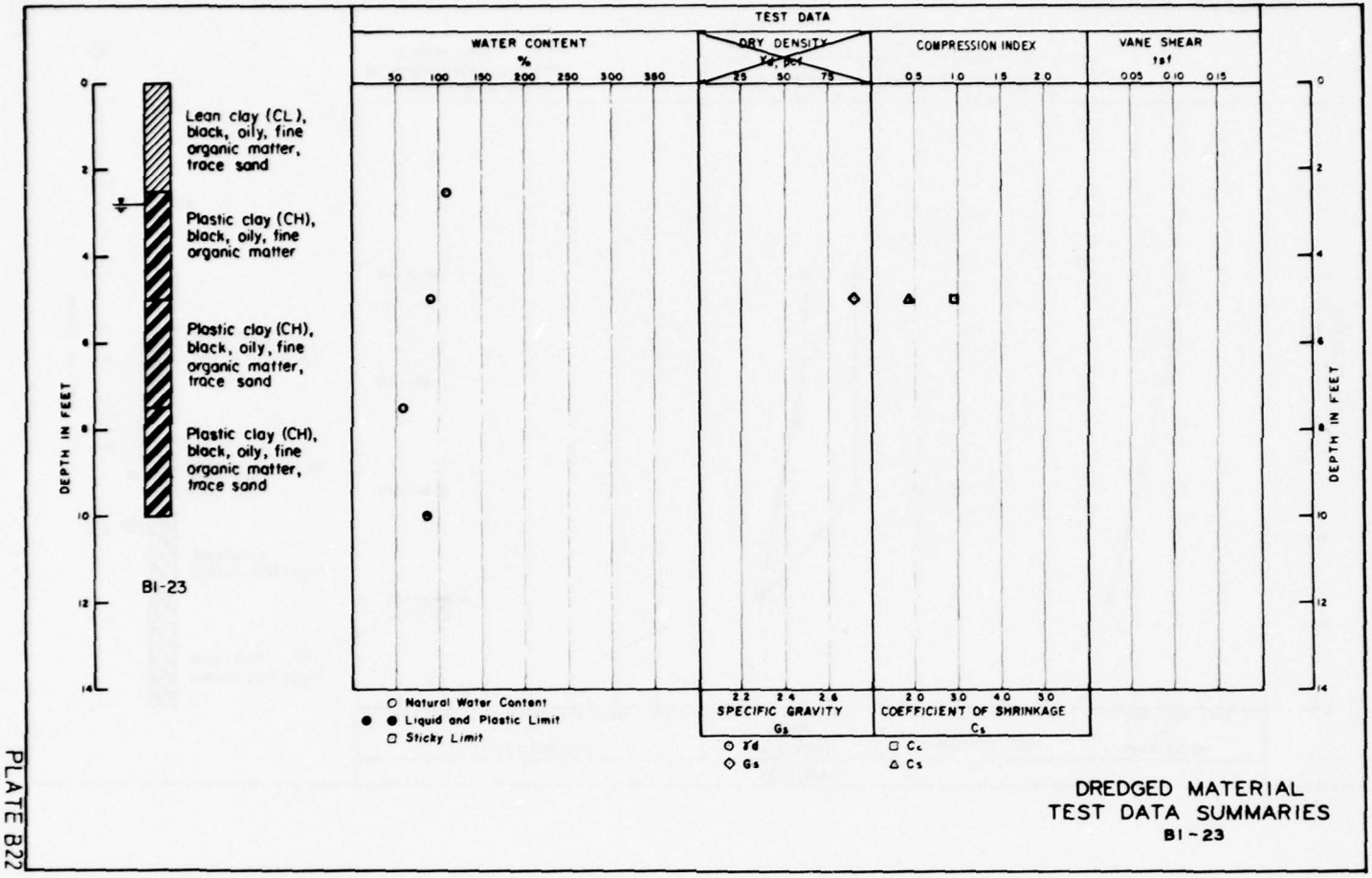

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
Yd, pcf
75 80 85
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), dark gray, fine organic matter, sand
Plastic clay (CH), black, oily, fine organic matter
Clayey sand (SC) black, oily
Silty sand (SM), grayish tan, roots, few pcs decayed wood
BI-22
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
SPECIFIC GRAVITY
Gs
2.2 2.4 2.6
○ γd
◇ Gs
COEFFICIENT OF SHRINKAGE
Cs
2.0 3.0 4.0 5.0
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI-22

PLATE B21



DREDGED MATERIAL
TEST DATA SUMMARIES
BI-23

PLATE B22

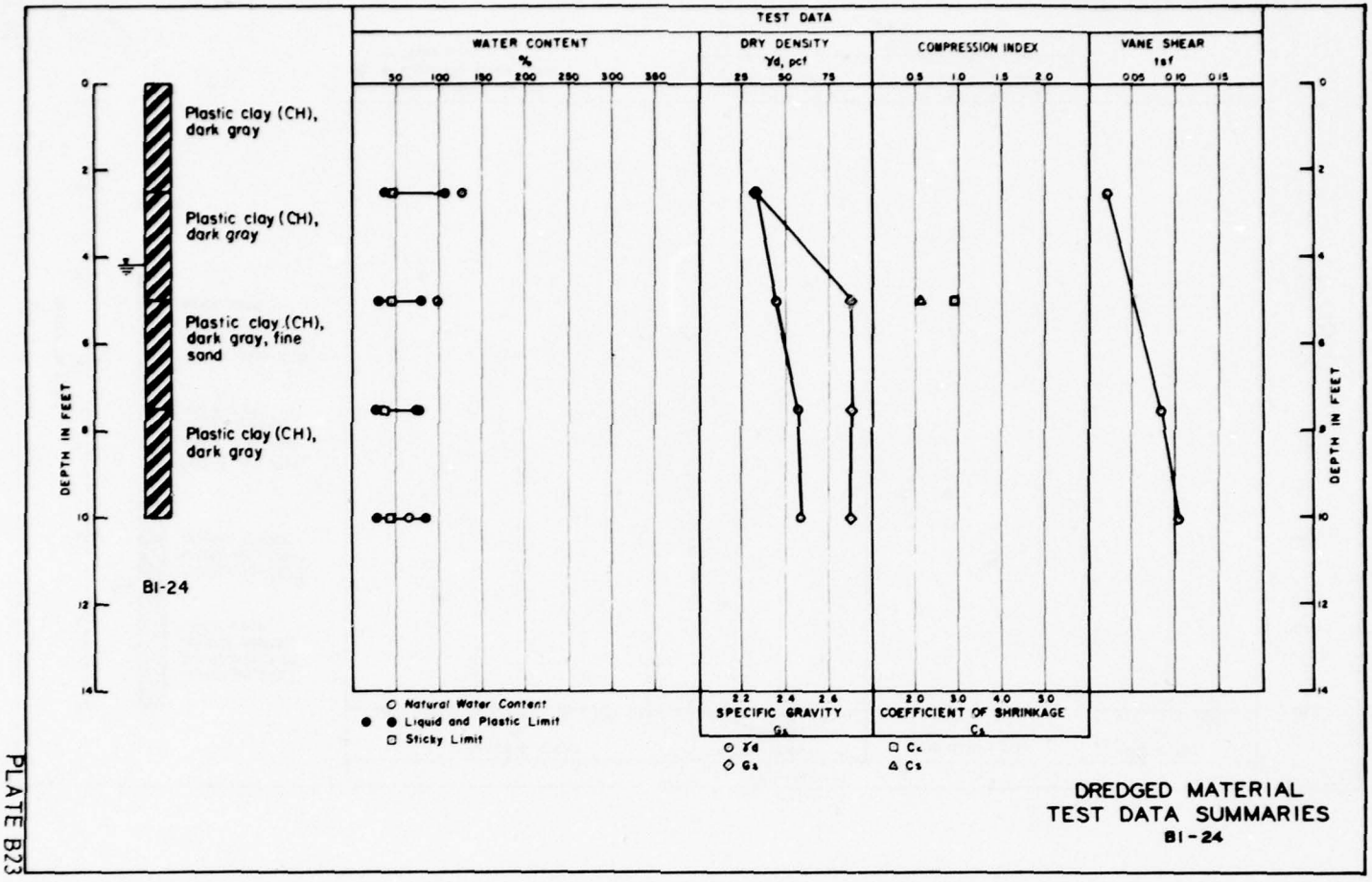

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
Yd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), dark gray
Plastic clay (CH), dark gray
Plastic clay (CH), dark gray, fine sand
Plastic clay (CH), dark gray
B1-24
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
SPECIFIC GRAVITY
Gs
2.2 2.4 2.6
○ γd
◇ Gs
COEFFICIENT OF SHRINKAGE
Cs
2.0 3.0 4.0 5.0
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
B1-24

PLATE B23

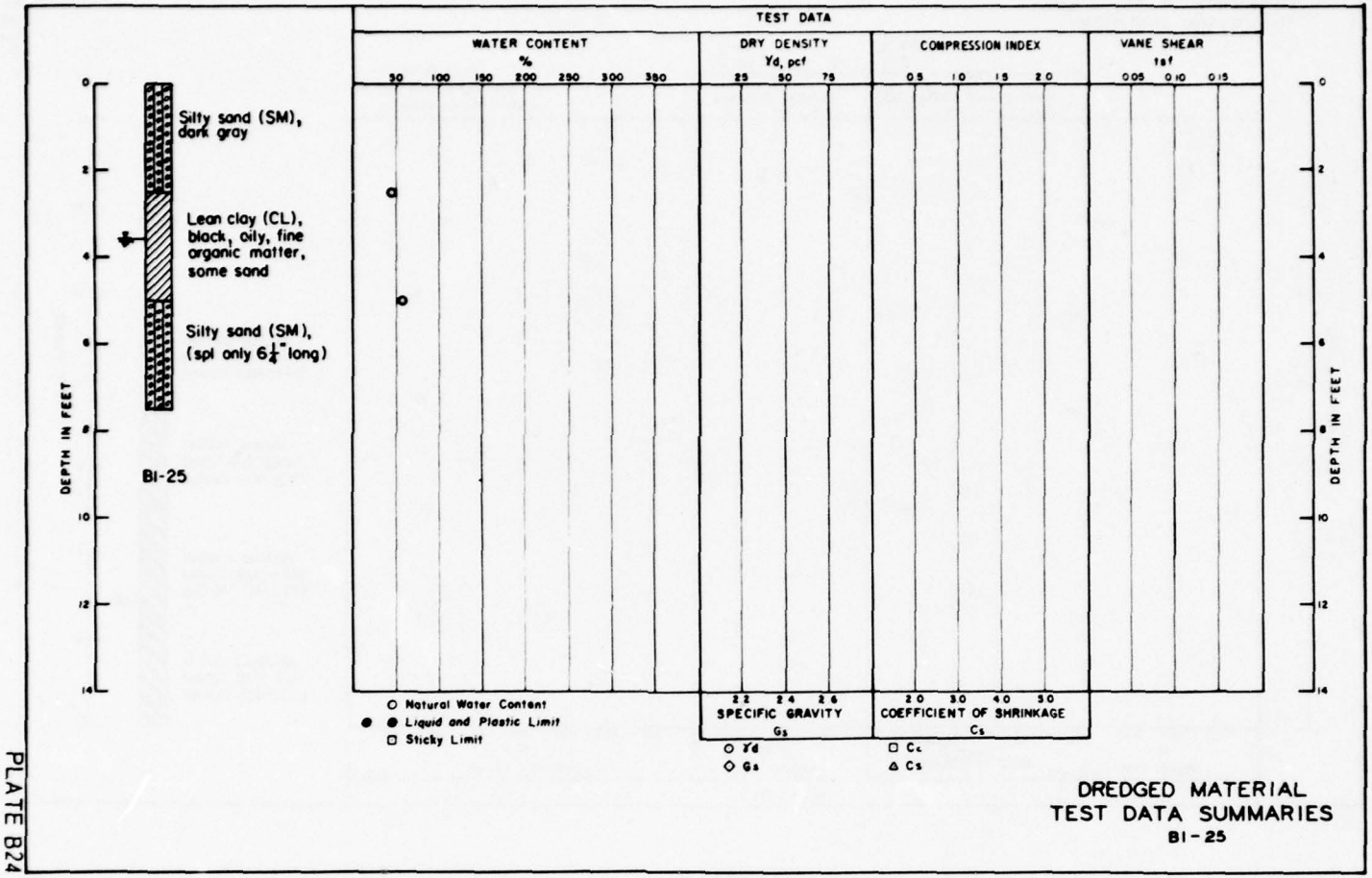

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
Yd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Silty sand (SM), dark gray
Lean clay (CL), black, oily, fine organic matter, some sand
Silty sand (SM), (spl only 6¼" long)
BI-25
○ Natural Water Content
● Liquid and Plastic Limit
□ Sticky Limit
SPECIFIC GRAVITY
Gs
2.2 2.4 2.6
○ γd
◇ Gs
COEFFICIENT OF SHRINKAGE
Cs
2.0 3.0 4.0 5.0
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI-25

PLATE B24

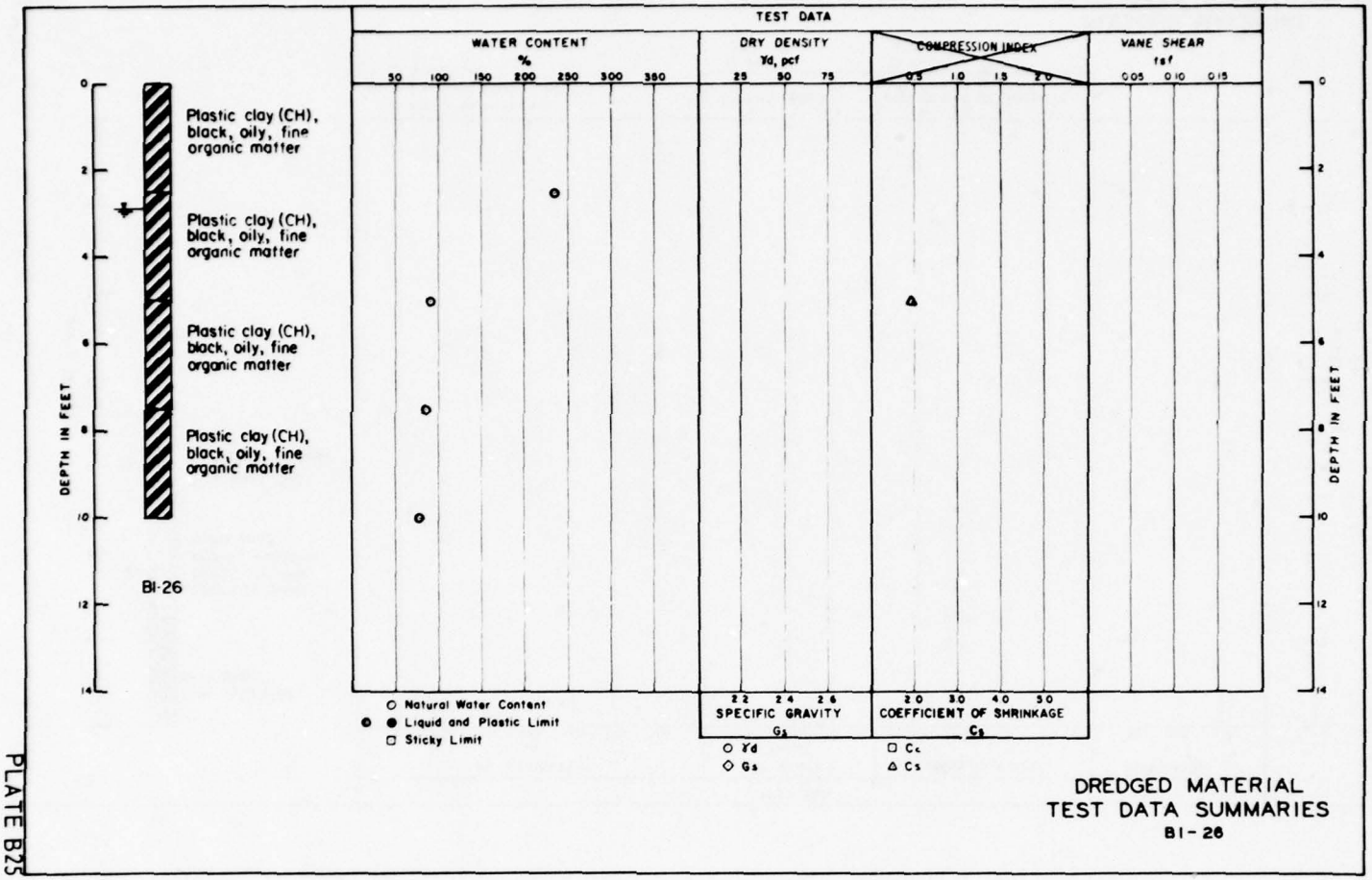

TEST DATA
WATER CONTENT
%
50 100 150 200 250 300 350
DRY DENSITY
γd, pcf
25 50 75
COMPRESSION INDEX
0.5 1.0 1.5 2.0
VANE SHEAR
tsf
0.05 0.10 0.15
DEPTH IN FEET
0 2 4 6 8 10 12 14
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
Plastic clay (CH), black, oily, fine organic matter
BI-26
○ Natural Water Content
● ● Liquid and Plastic Limit
□ Sticky Limit
2.2 2.4 2.6
SPECIFIC GRAVITY
Gs
○ γd
◇ Gs
2.0 3.0 4.0 5.0
COEFFICIENT OF SHRINKAGE
Cs
□ Cc
△ Cs
DREDGED MATERIAL
TEST DATA SUMMARIES
BI-26

PLATE B25

APPENDIX C:

OBSERVATION WELL DATA

1. This appendix contains plots of dredged material groundwater table elevation versus time for individual wells. The elevations were determined from observation well readings taken periodically during the course of the progressive trenching study. (Locations of the wells are shown in Figure 12 of the main text.) The average dredged material groundwater table elevation versus time relationship for all wells is shown in Figure 49 of the main text.

2. Observation wells were originally installed in 24 boreholes located within the UPB disposal area. A total of 13 wells within the progressive trenching study area survived field trenching operations without damage and were used to monitor changes in the dredged material groundwater table.

3. The wells were fabricated from 5-foot sections of No. 80 slotted plastic pipe connected to 8 foot plastic pipe risers. The points were wrapped in filter cloth and seated to a depth of approximately 10 feet. Details of the installation are shown in Figure 14 of the main text.

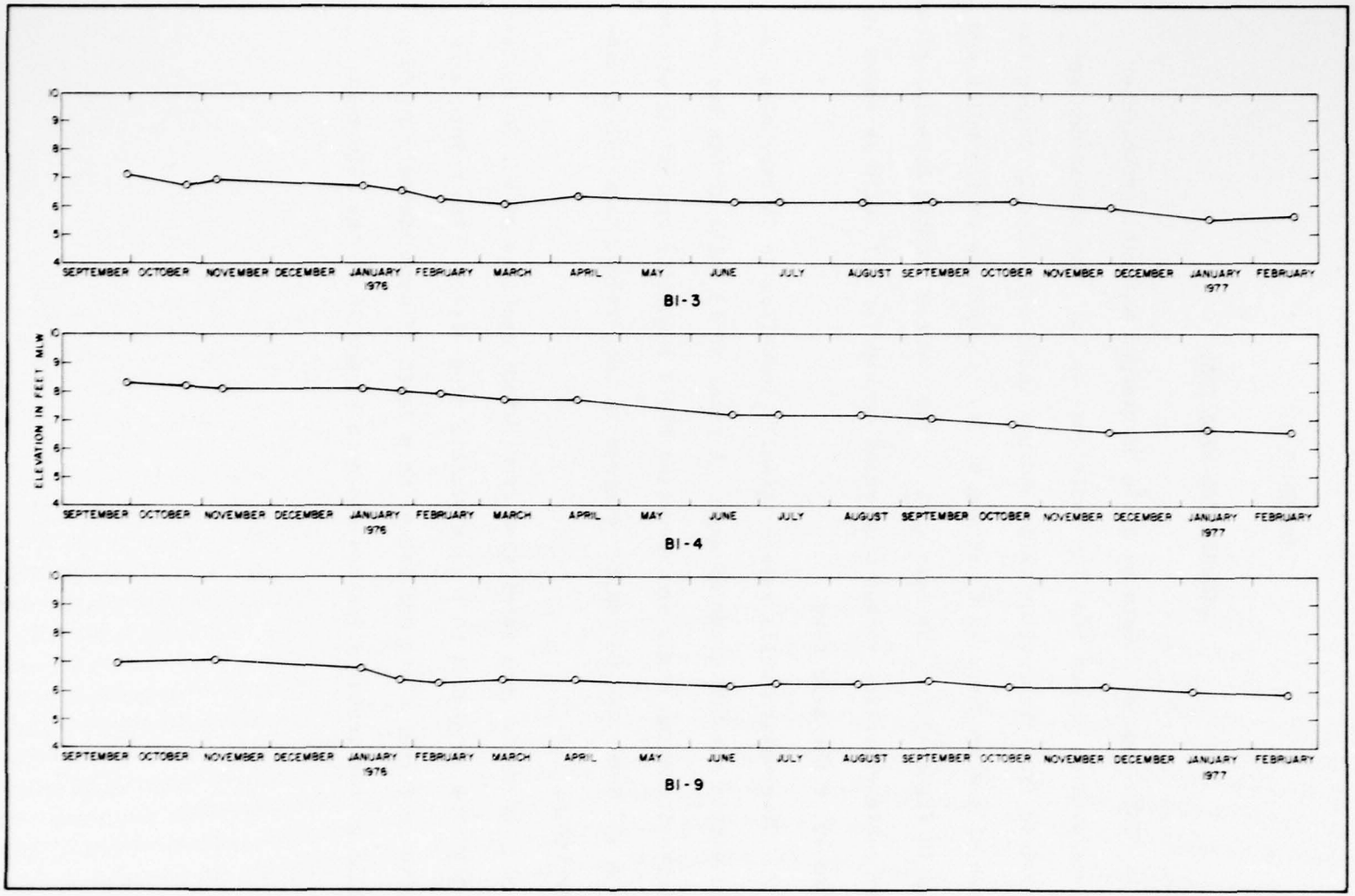
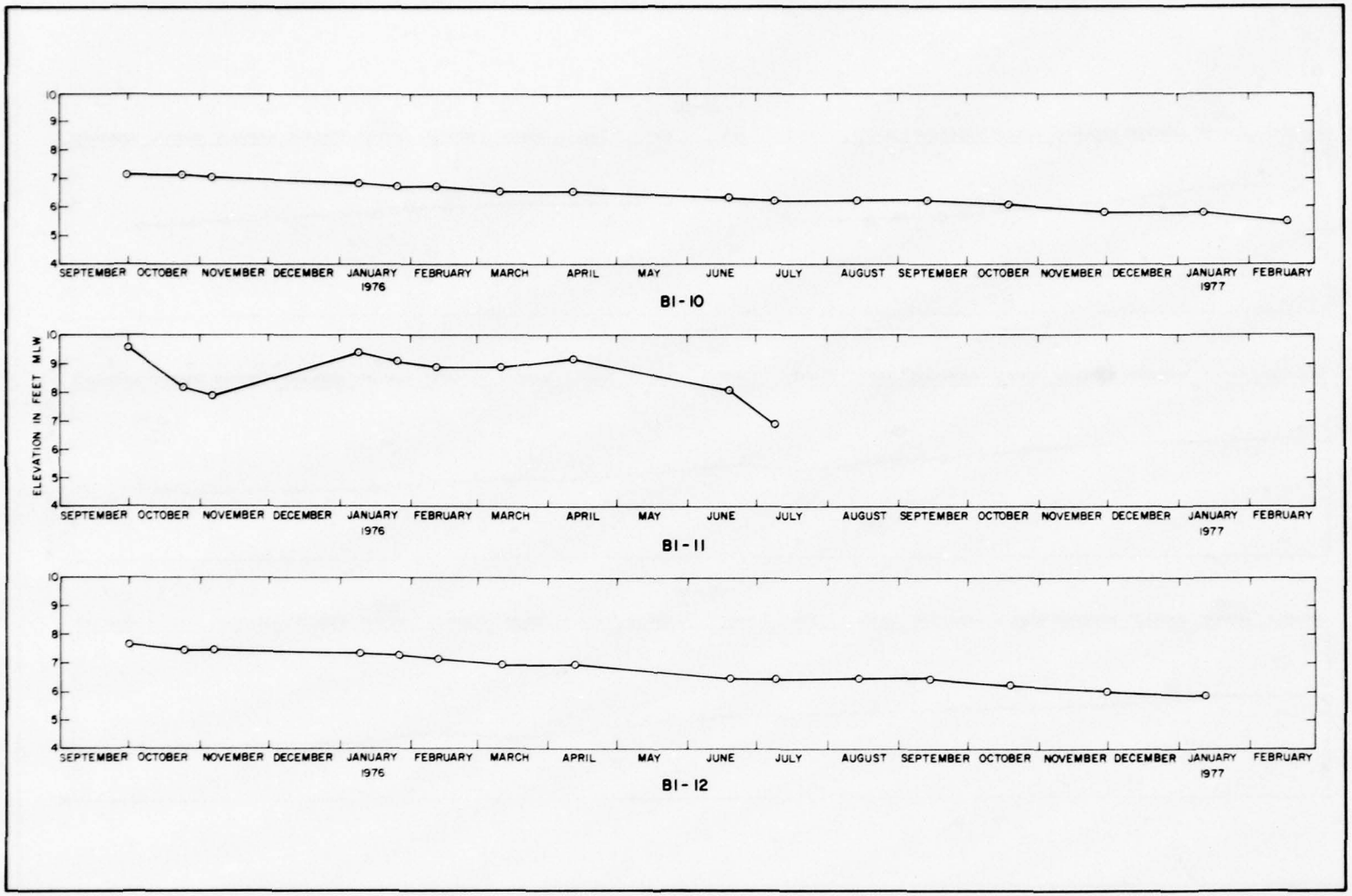

ELEVATION IN FEET M.L.W
10
9
8
7
6
5
4
SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY
1976
1977
B1-3
B1-4
B1-9

PLATE C1


ELEVATION IN FEET MLW
10
9
8
7
6
5
4
SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY
1976
1977
B1 - 10
B1 - 11
B1 - 12

C3

PLATE C2

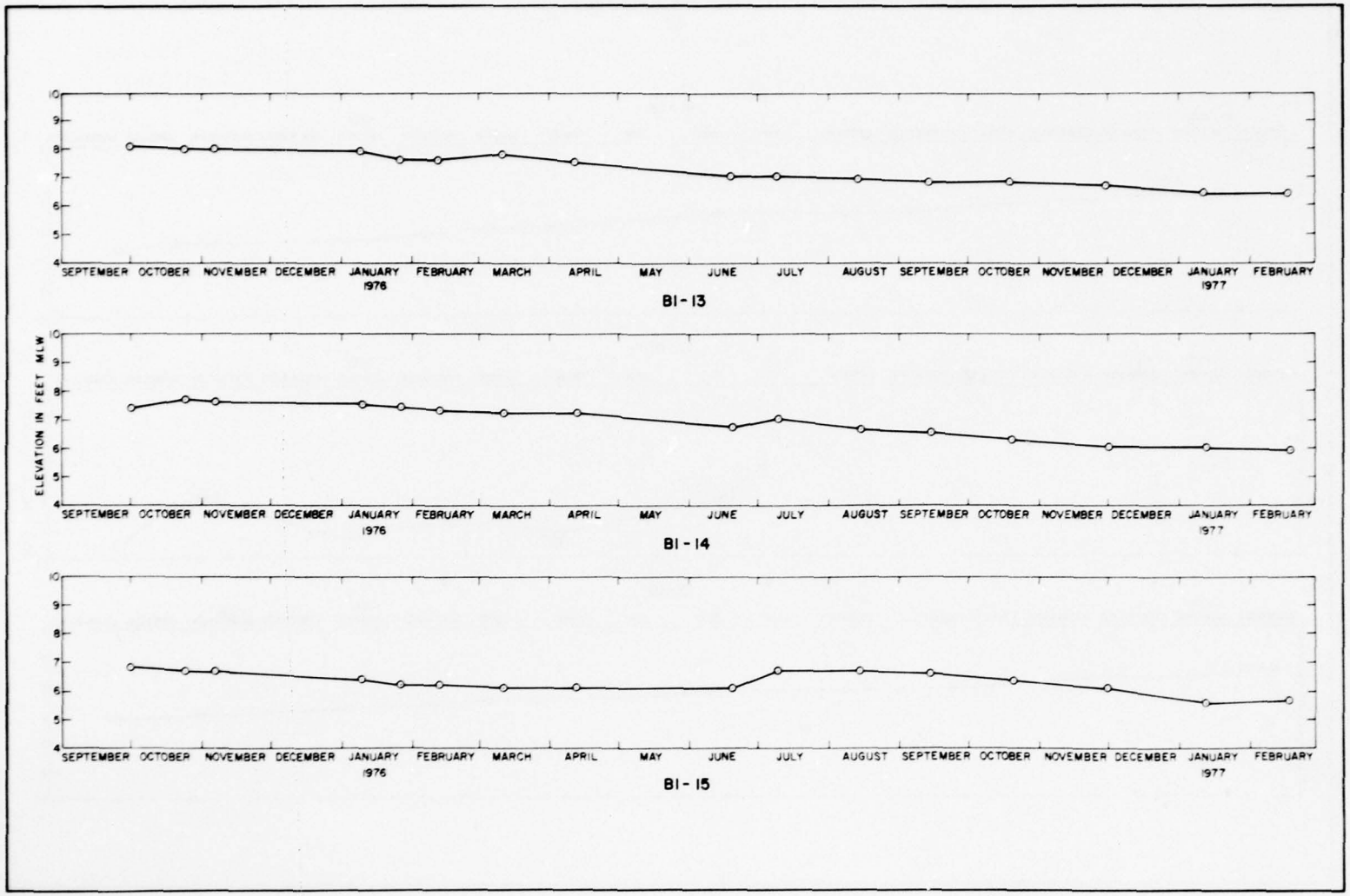
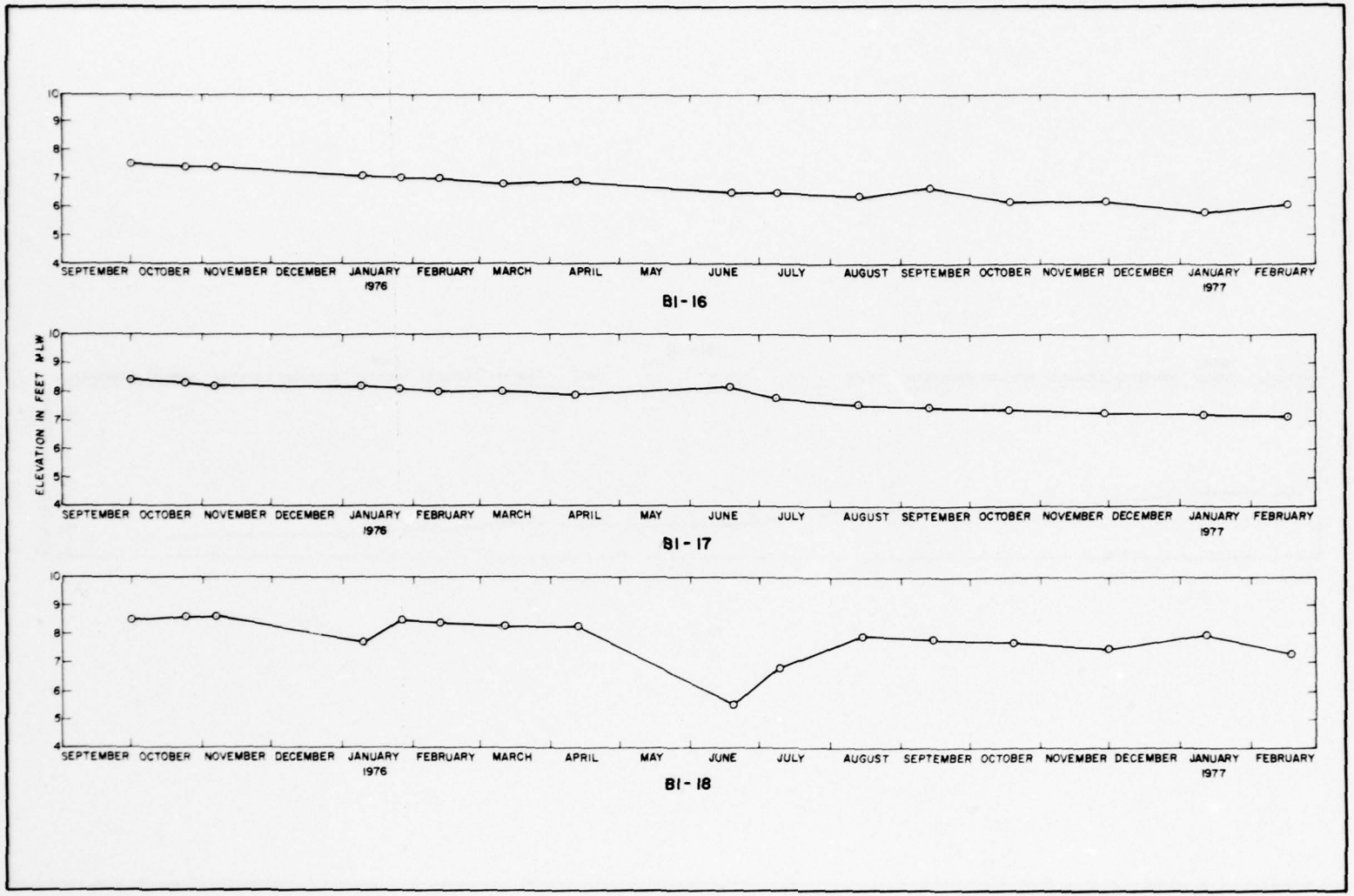

ELEVATION IN FEET MLW
10
9
8
7
6
5
4
SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY
1976
1977
B1-13
B1-14
B1-15

PLATE C3


ELEVATION IN FEET M.L.W.
10
9
8
7
6
5
4
SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY
1976
1977
B1 - 16
B1 - 17
B1 - 18

C5

PLATE C4

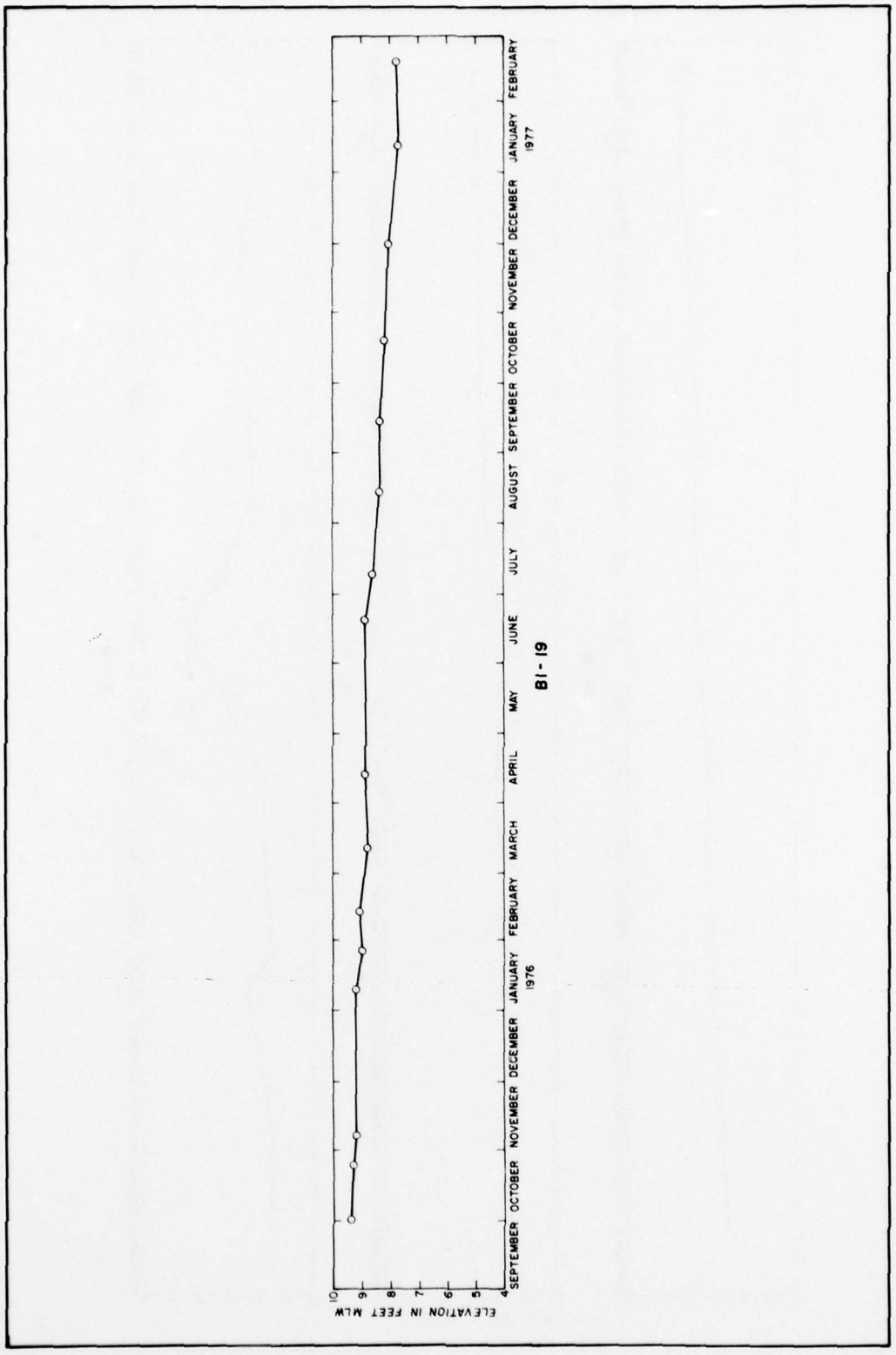

ELEVATION IN FEET MLW
10
9
8
7
6
5
4
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
1976
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
1977
FEBRUARY
B1 - 19

PLATE C5

APPENDIX D:

FIELD SETTLEMENT DATA

1. This appendix contains cross sections showing ground surface elevations within the progressive trenching study area. Locations of the sections are shown in Figure 28 of the main text.

2. The initial survey was taken in July 1975 previous to any field trenching operations. Subsequent surveys were made periodically during the course of the study. Later surveys indicate the depths of the trenches, placement of dredged material, and the degree of dredged material densification within the progressive trenching study area.

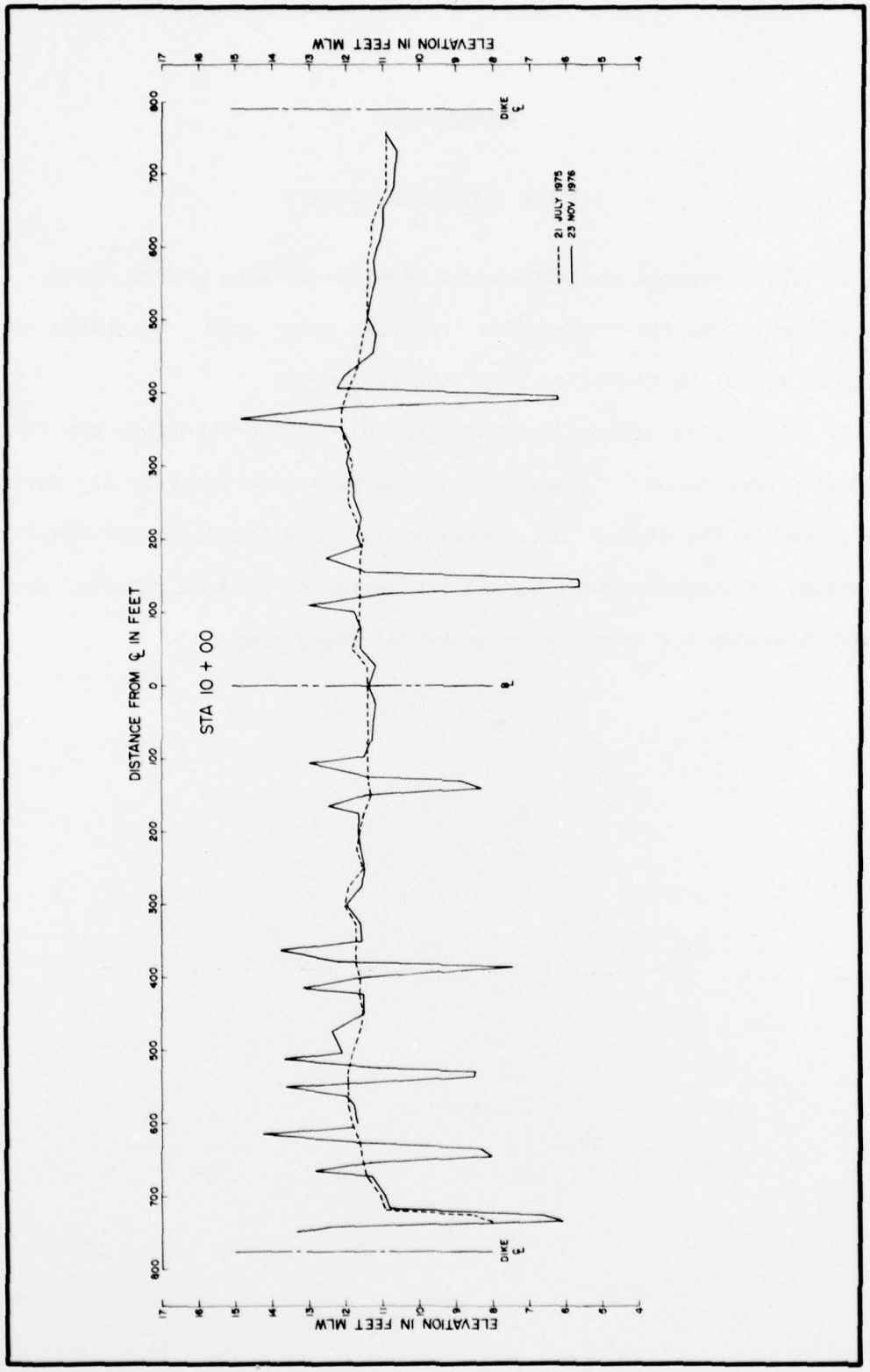

ELEVATION IN FEET MLW
DIKE ℄
21 JULY 1975
23 NOV 1976
DISTANCE FROM ℄ IN FEET
STA 10 + 00
℄
DIKE ℄
ELEVATION IN FEET MLW

PLATE D1

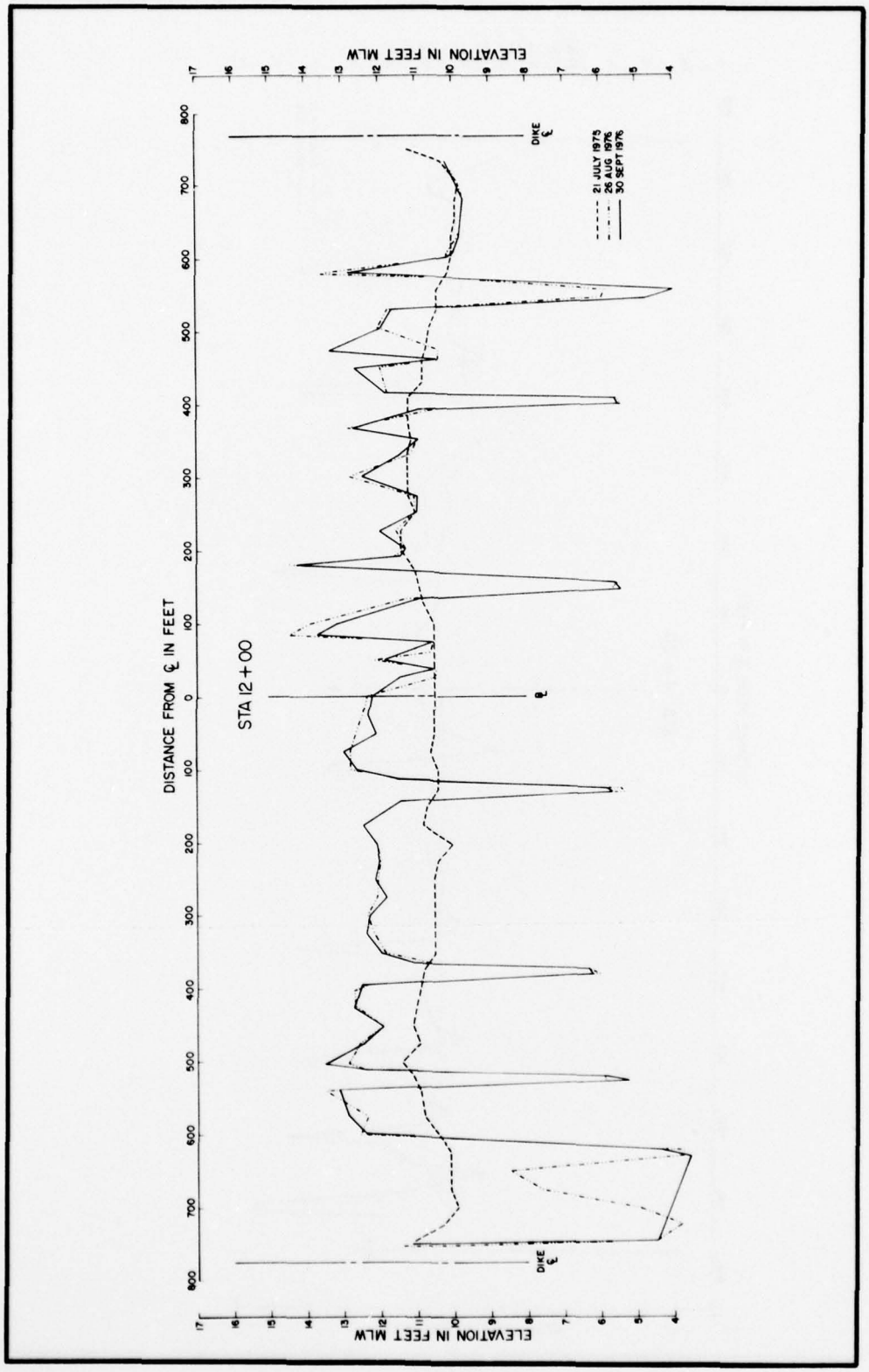

ELEVATION IN FEET MLW
DIKE ℄
21 JULY 1975
26 AUG 1976
30 SEPT 1976
STA 12+00
DISTANCE FROM ℄ IN FEET
℄
DIKE ℄
ELEVATION IN FEET MLW

PLATE D2

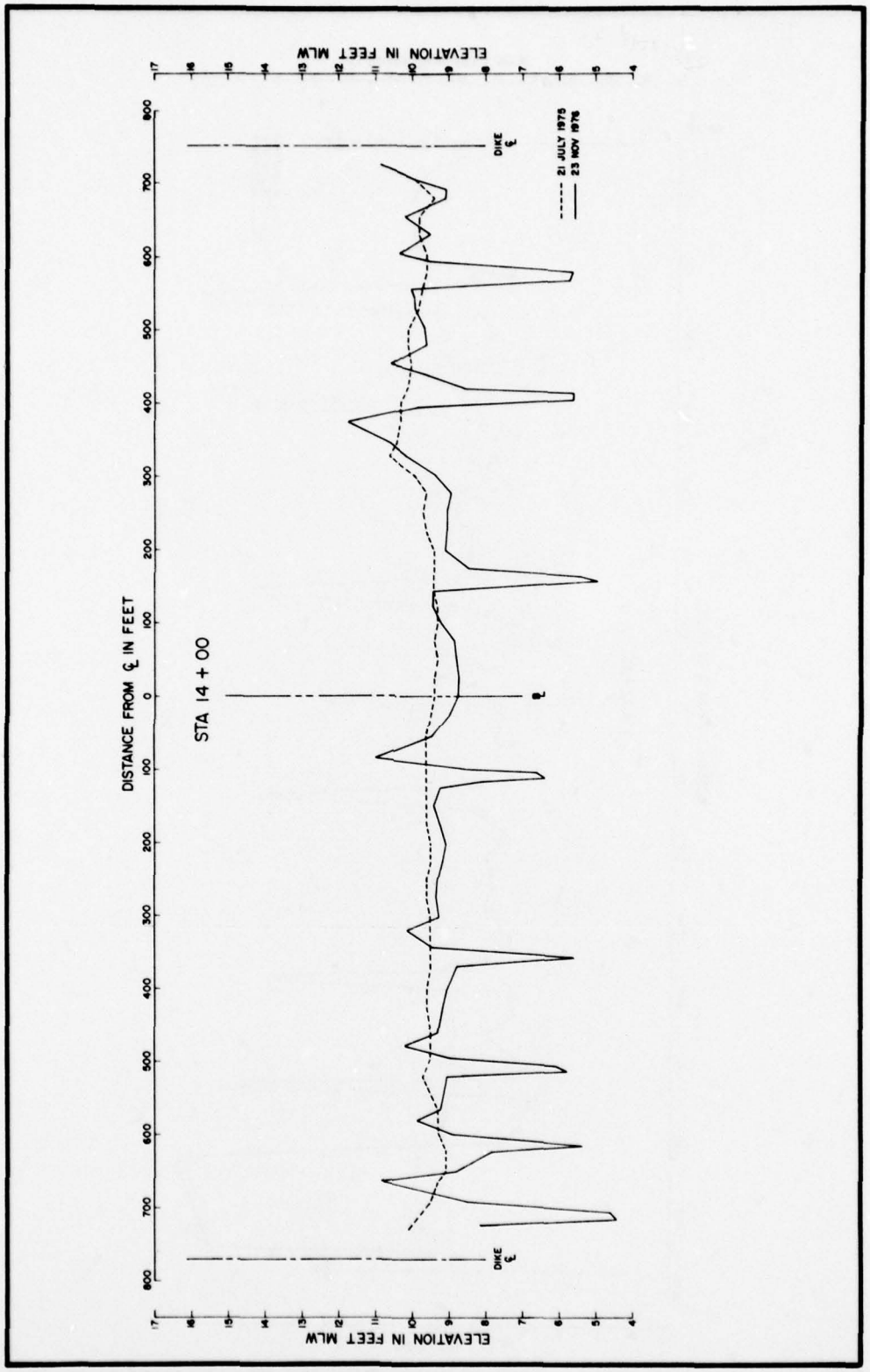

ELEVATION IN FEET MLW
DIKE ℄
21 JULY 1975
23 NOV 1976
DISTANCE FROM ℄ IN FEET
STA 14 + 00
℄
DIKE ℄
ELEVATION IN FEET MLW

PLATE D3

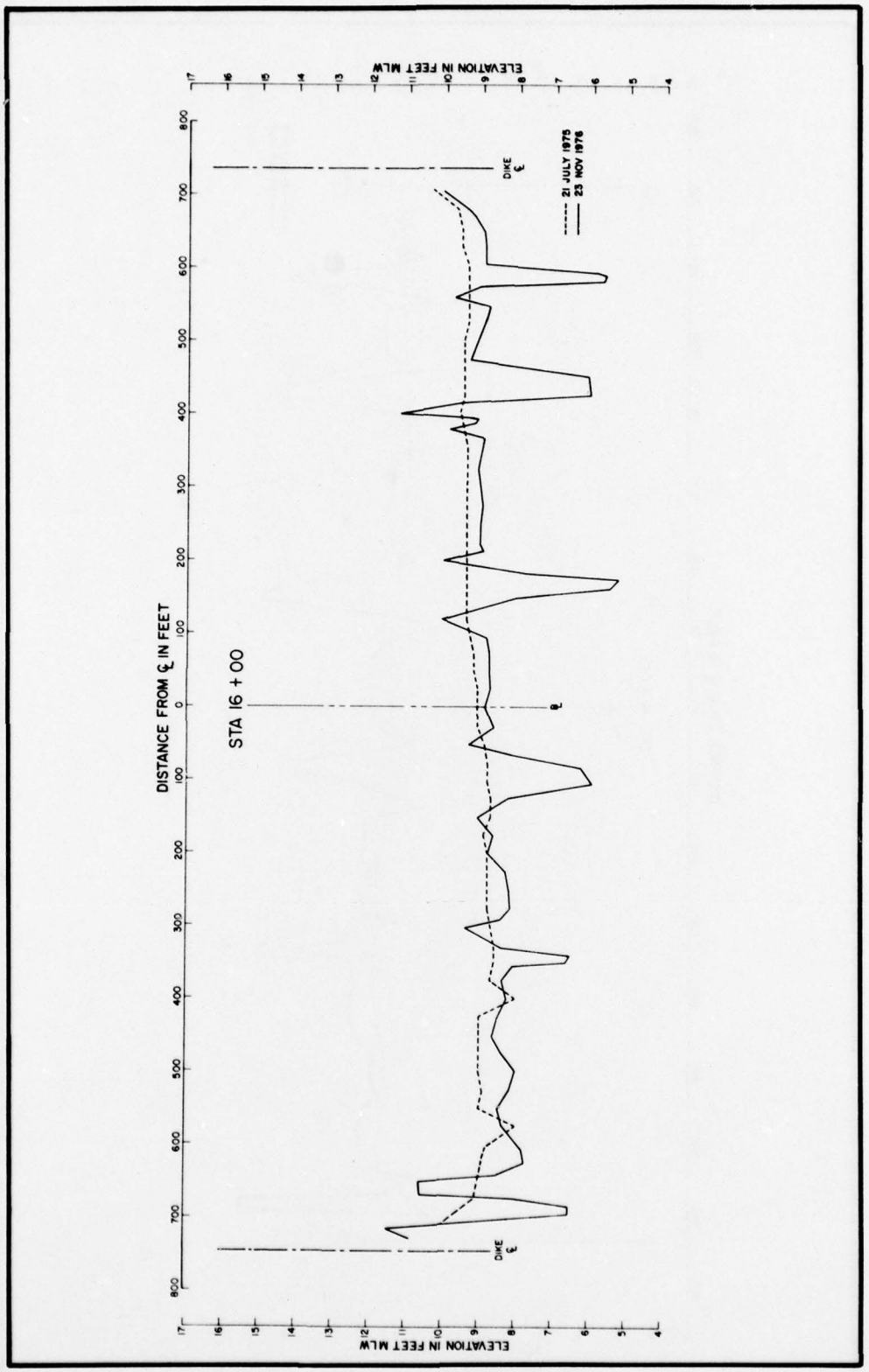

ELEVATION IN FEET MLW
DIKE ℄
21 JULY 1975
23 NOV 1976
DISTANCE FROM ℄ IN FEET
STA 16 + 00
℄
DIKE ℄
ELEVATION IN FEET MLW

PLATE D4

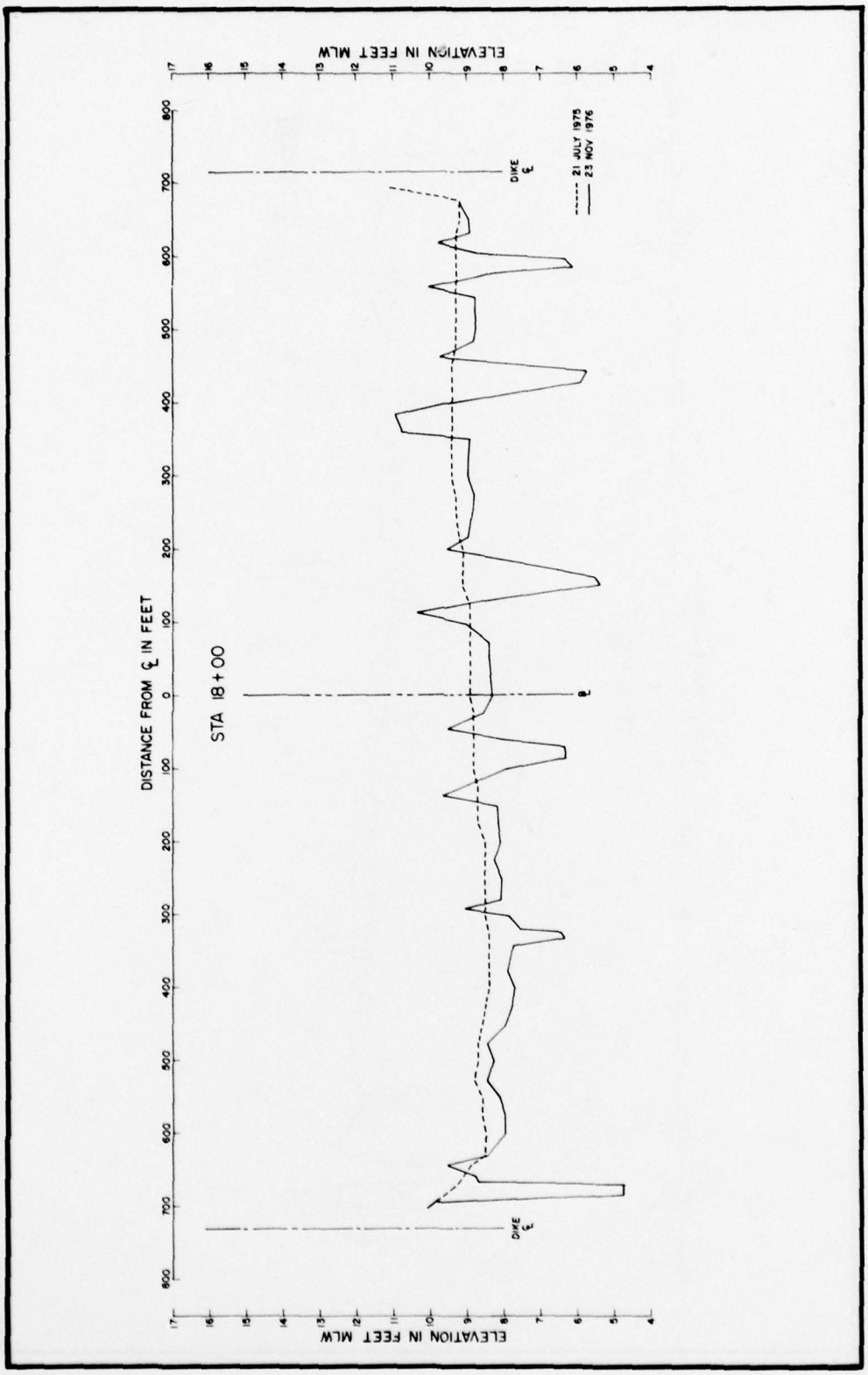

ELEVATION IN FEET MLW
DIKE ℄
21 JULY 1975
23 NOV 1976
DISTANCE FROM ℄ IN FEET
STA 18+00
℄
DIKE ℄
ELEVATION IN FEET MLW

PLATE D5

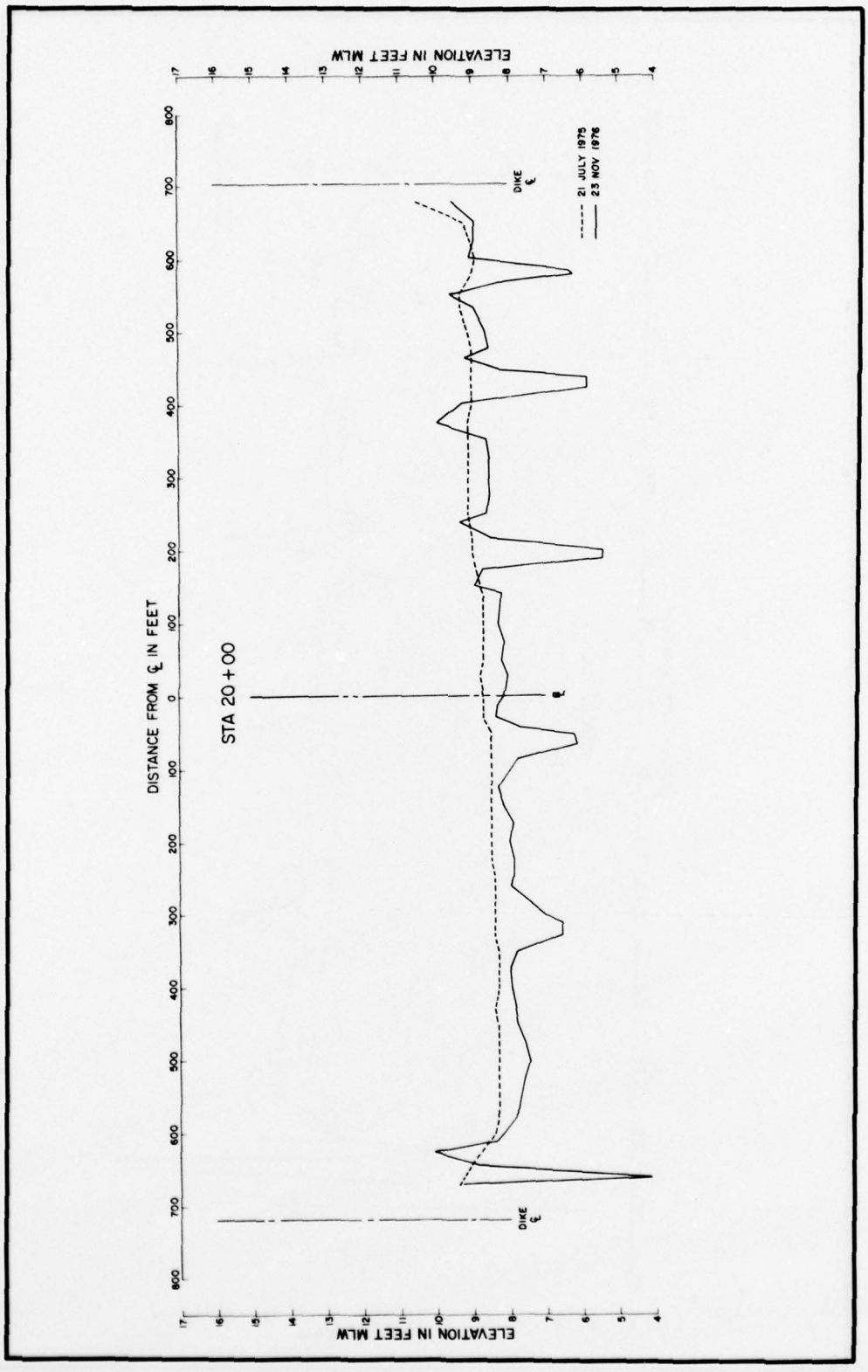

ELEVATION IN FEET MLW
17 16 15 14 13 12 11 10 9 8 7 6 5 4
800 700 600 500 400 300 200 100 0 100 200 300 400 500 600 700 800
DISTANCE FROM ℄ IN FEET
STA 20+00
℄
DIKE ℄
DIKE ℄
21 JULY 1975
23 NOV 1976
ELEVATION IN FEET MLW
17 16 15 14 13 12 11 10 9 8 7 6 5 4

PLATE D6

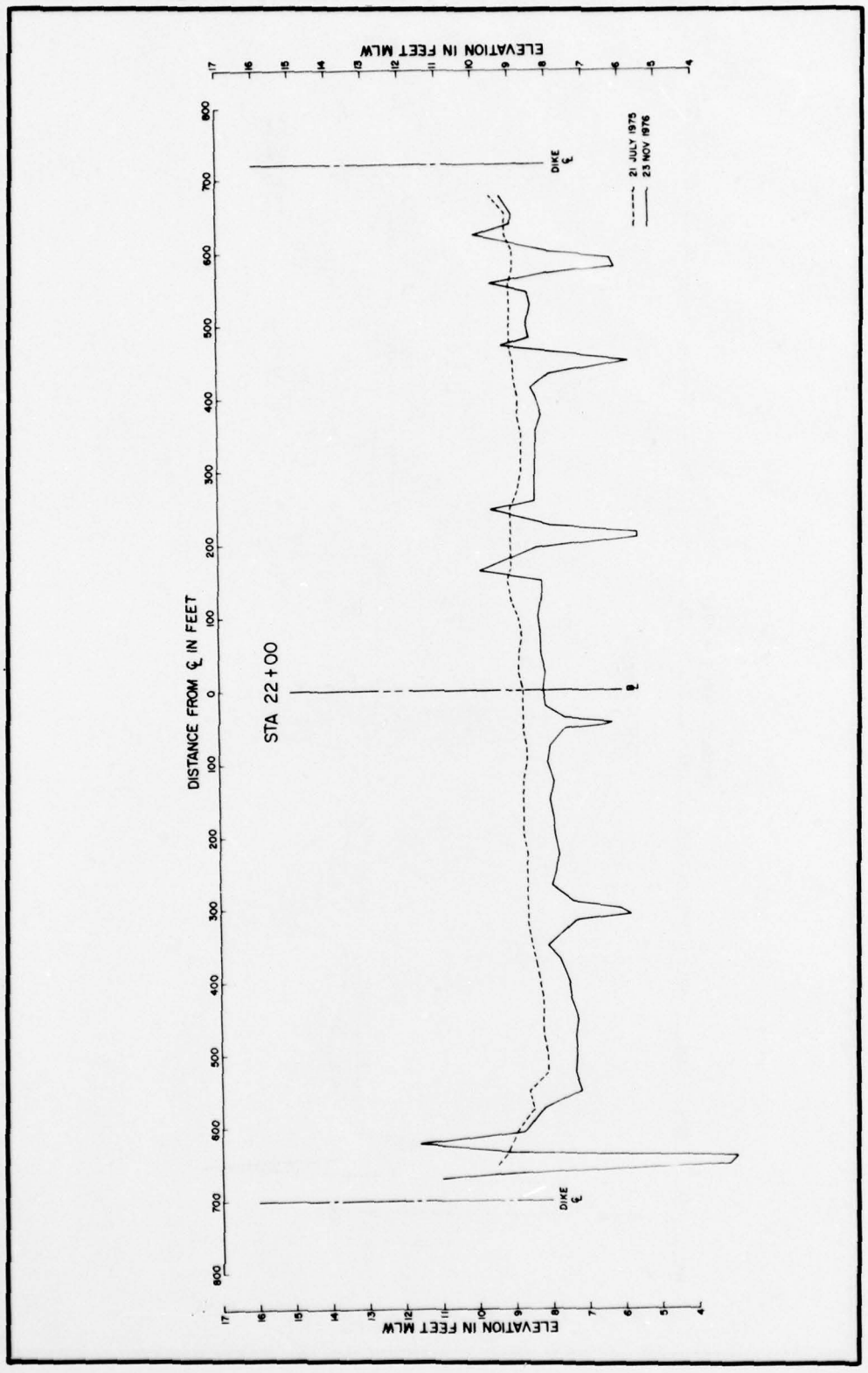

ELEVATION IN FEET MLW
DIKE ℄
21 JULY 1975
23 NOV 1976
STA 22+00
℄
DISTANCE FROM ℄ IN FEET
DIKE ℄
ELEVATION IN FEET MLW

PLATE D7

ELEVATION IN FEET MLW
DIKE ℄
21 JULY 1975
23 NOV 1976
DISTANCE FROM ℄ IN FEET
STA 24 + 00
℄
DIKE ℄
ELEVATION IN FEET MLW

PLATE D8

APPENDIX E: NOTATION

a_v	Slope of the void ratio-pressure curve for the initial load increment, cm^2/g
A	Cross-sectional area of riser, cm^2
Cc	Compression index
C_s	Coefficient of shrinkage
C_v	Coefficient of consolidation, cm^2/sec
e	Initial void ratio at pressure, P
e_1	Initial void ratio at pressure P_1
e_o	Initial void ratio
F	Shape factor for the wellpoint, cm
h/ho	Ratios of head to initial head
H	One-half the specimen height, cm Thickness of strata, ft
I_L	Liquidity Index, in percent
k	Coefficient of permeability
LL	Liquid Limit, in percent
P_1	Initial pressure at center of strata, tsf
P_2	Final pressure at center of strata, tsf
Pc	Preconsolidation pressure
PI	Plastic Index, in percent
PL	Plastic Limit, in percent
t	Time Time required for consolidation, sec
t_{50}	Elapsed time for 50 percent consolidation for the initial load increment, sec
T	Basic time lag, sec Time factor, constant for various degrees of consolidation

w	Water content
w_n	Natural water content, in percent
ΔH	Settlement due to shrinkage, ft
$\Delta V\%$	Change in volume expressed on a percent of original volume
Δw	Average change in water content, in percent
ΔW	Change in water content, in percent
γw	Unit weight of water, g/cm^3
$\%v$	Percent of initial volume

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Palermo, Michael R
An evaluation of progressive trenching as a technique for dewatering fine-grained dredged material / by Michael R. Palermo. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.
111, [63] p., 38 leaves of plates : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; D-77-4)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 5A08.
References: p. 109-111.

1. Consolidation (Soils). 2. Dewatering. 3. Disposal areas. 4. Polecat Bay, AL. 5. Dredged material. 6. Dredging. 7. Riverine Utility Craft. 8. Soil shrinkage. 9. Surface drainage. 10. Trenching. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; D-77-4.
TA7.W34m no.D-77-4