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DESIGN CONCEPTS FOR IN-WATER CONTAINMENT STRUCTURES FOR MARSH H--ETC(U)
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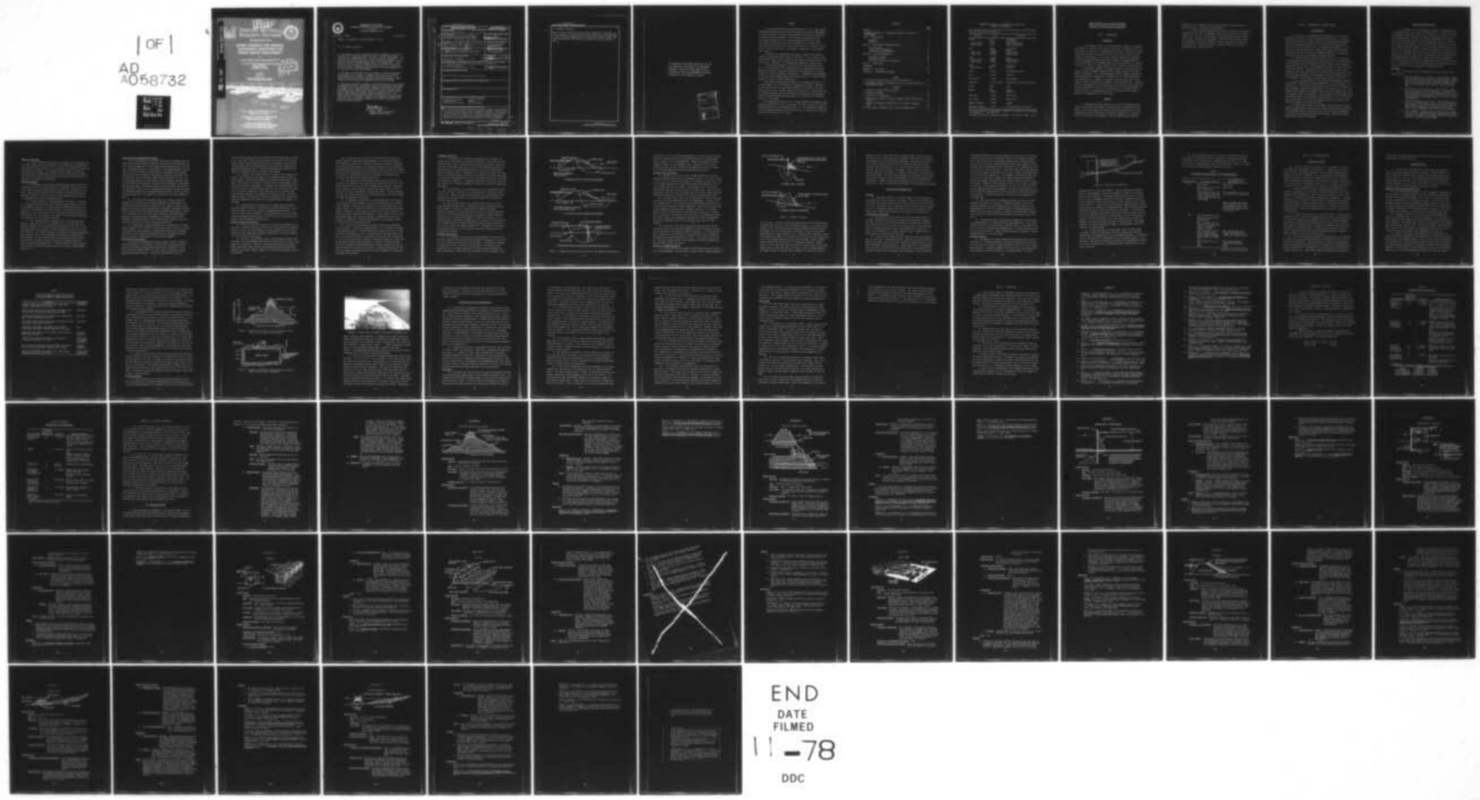

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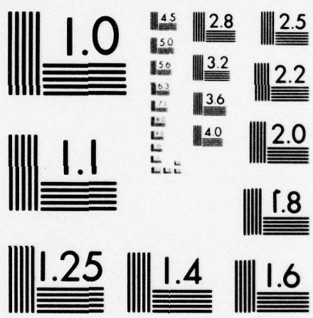
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DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-31

DESIGN CONCEPTS FOR IN-WATER CONTAINMENT STRUCTURES FOR MARSH HABITAT DEVELOPMENT

by

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July 1978

Final Report

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SUBJECT: Transmittal of Technical Report D-78-31

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of Work Unit 4A07A regarding design concepts for in-water containment structures for dredged material to be used in habitat development. This work unit was conducted as part of Task 4A (Marsh Development) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 4A was part of the Habitat Development Project of the DMRP and was concerned with the development, testing, and evaluation of the environmental, economic, and engineering feasibility of using dredged material as a substrate for marsh development.

2. The report on this work unit was intended to provide planning and design concepts for in-water containment structures for use in the development of marsh habitats. Various types of structures are reviewed, discussed, and, where applicable, presented in detail. Site, structural, and construction considerations are also discussed.

3. This report provides a synthesis of the state-of-the-art in in-water containment structures. Additional supportive and pertinent information is available in the summary reports of habitat development field sites at Windmill Point, Virginia (4A11); Buttermilk Sound, Georgia (4A12); Bolivar Peninsula, Texas (4A13); Pond No. 3, California (4A18); Miller Sands, Oregon (4B05); and Rennie Island, Washington (4A14). The feasibility and detailed design studies for Dyke Marsh, Virginia (4A17, 4A17A) are also of interest. Together these research products provide the Corps with a comprehensive basis for the selection and design of marsh development projects.

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

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

This report provides general guidance for structure selection and development of structure design concepts for use in habitat development. Various types of structures were reviewed, based on available literature, to determine which would be applicable to habitat use. Planning and design concepts are presented for use of the potential structure types for habitat development. References are provided for detailed design and construction guidelines.

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20. ABSTRACT (Continued).

CONT

Case histories of structures used for habitat development are discussed. A list is provided of the known projects, their locations, and structural types. It was found that, to date, very few structures have been built specifically to retain or protect dredged material for purposes of habitat creation. However, the predominant structures used for habitat creation have been sand dikes.

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PREFACE

The study reported herein was performed at the U. S. Army Coastal Engineering Research Center (CERC), under work unit U01084, "Development of Design Concepts for In-Water Retaining and/or Protective Structures for Marsh Habitat Development." The research was sponsored by the Environmental Laboratory (EL), Waterways Experiment Station, under the Dredged Material Research Program (DMRP) work unit WESRF 77-125. This work has been under the general supervision of Dr. Hanley K. Smith and Dr. John Harrison of EL. Mr. Raymond L. Montgomery of EL managed the contract.

The report was prepared by LCDR James W. Eckert, CEC, USN, Geotechnical Engineering Branch, CERC; Mr. Michael L. Giles, Coastal Structures Branch, CERC; and Mr. Gerald M. Smith, Facilities Engineering, Fort Belvoir, Va., formerly of the Geotechnical Engineering Branch, CERC.

During the development of this study, Mr. Jack Lapouraille and Mr. D. W. Puffenbarger of the Estimating Section, Engineering Division, Baltimore District, significantly aided in the assembling of the representative cost data contained in Appendix A. Information and photographs of the Core Sound dredge islands were supplied by Mr. J. C. Wells of the Wilmington District, Corps of Engineers.

The authors acknowledge and appreciate the patient assistance of several members of the CERC staff in preparing this report: drafting--Mr. Herb Bruder and Mr. Jake Speraw; typing--Ms. Patricia Davis, Mrs. Linda Clark, and Miss Virginia Posey; the reviewers--Dr. Craig Everts and Mr. Robert Jachowski; and the CERC Publications Branch who prepared and edited the final camera-ready copy--Mrs. B. R. Hall, Mrs. M. I. Nodurft and Mrs. O. M. Vrooman.

The Commander and Director of the Coastal Engineering Research Center during the preparation of this report was COL John H. Cousins, CE, and the Technical Director, Mr. Thorndike Saville, Jr. The Commander and Director of the Waterways Experiment Station was COL John L. Cannon, CE. Technical Director of WES was Mr. F. R. Brown.

CONTENTS

TABLES

FIGURES

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

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

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.8532	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.1745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: C = (5/9) (F -32).

To obtain Kelvin (K) readings, use formula: K = (5/9) (F -32) + 273.15.

DESIGN CONCEPTS FOR IN-WATER CONTAINMENT STRUCTURES FOR MARSH HABITAT DEVELOPMENT

PART I: INTRODUCTION

Background

1. Of the many factors to be evaluated when dredging is proposed, the method and location of the disposal operation is certainly one of the most difficult to resolve. Dredged material disposal sites may be readily classified as upland or in-water with the latter type of major national concern in recent years. In the past, in-water disposal was frequently utilized and generally meant open-water placement of dredged material with no confinement. The dredged material then shifted about in response to the site's wave and current pattern until it reached a stable profile.

2. Alternative methods of in-water disposal, now being frequently used, are land reclamation along the shore, island creation, and marsh habitat development. In an environmentally balanced dredging program all three methods may be employed at a single site. The three methods have one characteristic in common; a land-water interface which must be kept stable in order to maintain the integrity of the disposal site. Depending on the characteristics of the material and the local wave and current conditions, some means of protection or retention of the dredged material may be required. A containment structure as defined in this report is intended to accomplish both of these tasks.

Purpose

3. Planning and design concepts for in-water containment structures for use in the development of marsh habitats are presented in this report. The various types of structures that have potential for use in marsh habitats are reviewed and illustrated in Appendix B; a data sheet on each is included in the Appendix. The data sheets provide general

guidelines to the design and use of the structures, and references to specific sources of design data and guidance.

4. Current methods and materials have been reviewed, using readily available publications, to determine which would be applicable to marsh habitat use. This is a survey study to catalog available types of structures, and it includes no new research. However, where data and results were available, this study attempts to reflect experience to date with a given structure. Structures which are currently being used in marsh development are listed in Part III.

PART II: DEVELOPMENT OF DESIGN CONCEPTS

Site Selection

5. Selection of a dredged material disposal site is often predetermined by factors over which the planner has little or no control. Factors such as land-use zoning, ownership, distance from the dredging site and environmental impact will often limit the available sites. Within the bounds of these factors, the planner must optimize the disposal area by proper selection of areal size, shape, and orientation. The planner must also consider the offshore water depth, the placement method, and the type of containment structure required.

6. Since waves and currents are major factors in the stability of dredged material, the areal extent and orientation of the disposal site must be examined from the standpoint of fetch length in the direction of predominant winds or swell, and alignment with respect to river, estuary or littoral currents. Locating the site in the area of lowest water energy will also have benefits such as ease of disposal operations, less turbidity during disposal, lower sediment losses, and possible reduction or elimination of any need for a retaining or protective structure.

7. As in all maintenance or new construction dredging, unobstructed navigation channels are of prime importance. Close proximity of the disposal site to the channel being dredged is beneficial for pumping or haul distances. However, the possibility of a slope failure, which could release large quantities of dredged slurry back into a channel, must also be evaluated during site selection. In this regard both the height of the dike and the depth of the adjacent dredged channel, as well as the engineering properties of the fill and foundation material, should be considered in analyzing the slope stability.

8. While other reports in the Dredged Material Research Program (DMRP) series discuss site selection in detail (Johnson and McGuinness[1]), it is important here to stress that the need for a costly containment structure at any proposed disposal site is a major factor that must be known before final site selection.

Structural Considerations

9. The design for any containment structure is intertwined with the planning process for the entire dredging project. Each site should be evaluated to determine the need for a structure to retain or protect the dredged material. Because of the mutual dependence, as outlined below, the structural selection and design process should be iterative with total project planning. Since any structural design is site critical, adequate engineering data on each site under consideration are required for preliminary structural selection and design. However, due to the cost of a complete study of waves and currents, and foundation soil properties at a site, limited data are generally collected at several of the representative proposed sites. From these data the preliminary structural design and costing is completed and used for final site selection. Following site selection a more thorough engineering data collection effort at the site is required for detailed design.

Site data

10. The following data are required for detailed design at the selected site:

- a. Dredged material to be deposited: size gradation, consolidation characteristics, and total expected volume. These data are used in establishing stable dike slopes, expected structural settlement, and the required volumetric geometry of the disposal site required to hold the design fill.
- b. Disposal site's in situ soils: shear strength, consolidation characteristics, and erodibility. From this test data dike stability can be evaluated against slope failure, dike settlement, and toe erosion. A discussion of soil investigations for containment dikes is included in Hammer and Blackburn.[2]
- c. Hydraulic conditions at the site: including historical data on wind and ship waves, water surface elevation (tide, surge height, flood stage) and river or estuary currents. These data are required to estimate wave runup, dike height, erosion potential, and construction difficulties.
- d. Site ecosystem: including species present, bottom community locations, migration patterns, and expected impact of structure. The planner and designer should work with the ecologist to minimize adverse impact.

Height of structure

11. After establishing the need for a structure at a proposed site, the design height, width and length of the structure can be established based on the volume of material to be confined, the local water depth, and the design wave climate. The distance from the dredge is a factor in determining the optimum height to which material can be readily pumped. The final height selected may eliminate some structure types listed in Appendix B from further consideration.

Material placement

12. The method of placing the dredged material must be planned to efficiently utilize the area available, to adequately control the loss of fines, and to minimize earth pressures acting on the containment structure. Johnson and McGuinness[1] present detailed information on material placement; however, a brief discussion of how placement methods impact on containment structures is appropriate here.

13. Proper placement of dredged material presupposes a knowledge of the engineering properties of the material being dredged, as listed in paragraph 10.a above. The coarser grained dredged materials may be utilized as dike material or placed behind the containment structure as appropriate. The soft cohesive soils are generally deposited away from these structures. This selective placement of dredged material improves the stability of the containment structure.

14. When dredged material containing both coarse-grained sands, cohesive clays, and silts is to be pumped into a contained marsh site, careful placement of the discharge pipe and grading of the site can significantly improve the quality of material deposited behind the containment structure. The dredged material is discharged through trap pipelines laid along the crest of the containment structure, and runoff forms a graded deposit of coarse material near the discharge and progressively finer material toward the center of the site as suspended fines are carried toward the discharge weir. Further discussion of this technique can be found in Turnbull and Mansur's[3] review of several hydraulically placed fills.

Earth forces on containment structures

15. In the design of containment structures the designer must consider all the water and earth pressure forces acting on the structure as well as any surcharge that is anticipated during construction or in later use. The earth pressure is time-varying as the dredged material consolidates. The worst condition, which should be considered in the design calculations, occurs during or immediately following the filling of the disposal site and is frequently termed "end-of-construction" case. As the retaining structure is being built, equal hydrostatic pressure acts on both sides of the structure. However, after placement of the dredged material has begun, an unbalanced force is exerted against the inside of the structure. This force is a maximum when hydraulic filling has raised the contained material to the maximum design elevation, and the surrounding water level is at its lowest, i.e., low tide, a low river stage, or both.

16. The active earth pressure forces on a structure caused by dredge fill on one side vary not only temporally, as cited above, but spatially with factors such as duration of fill, rate of filling, stoppages in filling, location and direction of pipeline discharge, and variations in grain size of the dredged material behind the structure. While it is desirable to place the best quality material available directly behind the structure, this is frequently not achieved in the field. Therefore, reasonable values of active earth loads, based on field construction results, must be used in design calculations.

17. In designing of marsh habitats the new substrate will be generally composed of soft cohesive clays and silts which remain in a slurry-like state with zero strength for a significant period after placement. They exert a fluid pressure distribution on the containment structure until it begins to consolidate and develop shear strength.

Wave forces on structures

18. Wind-wave characteristics such as height, period, direction, and the probability of occurrence of these can be found using locally collected data and hindcasting methods described in Chapter 3 of the Shore Protection Manual (SPM) (U.S. Army, Corps of Engineers, Coastal Engineering Research Center[4]). With these design wave values the

wave-structure interaction can be predicted using methods given in Chapter 7 of the SPM[4]. Where wind waves appear to be a major consideration, early recognition may permit relocation of the disposal area to reduce the open-water fetch in predominant wind direction, thus limiting the maximum wind-generated wave. In shallow back bays and estuaries water depth will frequently limit the growth of wind waves.

19. Because of the erosive effects of waves on soft dredged substrate, wave runup and overtopping of a containment structure can be a major problem. Wave runup is dependent on several interrelated factors, each of which must be considered in establishing the safe height of the structure to prevent overtopping. The slope of the wave-exposed face of the structure, the bottom slope and depth of water in front of the structure, the surface roughness of this structure, and the incident wave characteristics must all be considered in evaluating runup. Structure heights should be established to prevent overtopping of the design wave. Tables and graphs for the prediction of runup are found in Chapter 7 of the SPM[4].

20. Ship-generated waves may also be a major cause of erosion along the edges of marshes. Sorensen[5] describes the generation of ship waves and gives a table of selected ship-generated wave heights. If there is a ship channel adjacent to the proposed marsh site, a few days of wave measurement properly timed to ship traffic at the dike site will suffice for establishing a design value.

Erosion, scour, and deflation

21. Erosion, scour, and deflation all involve the removal of soil particles by natural mechanical action, and in this report are defined as follows: erosion and scour--removal of soil particles by water action, above and below normal water surfaces, respectively; deflation--removal of soil particles by wind action.

22. Deflation will probably not be a major problem in marsh creation since the fine sediments most subject to removal by wind will be submerged or at least wet. However, dry cohesionless material on dikes or other areas above normal wetted elevations may be moved by high winds. Vegetation provides a simple solution to wind erosion (Woodhouse, Seneca, and Broome[6]).

23. Erosion and scour can cause structural failure and must be guarded against by properly designed measures. The erosive ability of water waves and currents at a potential disposal site must be considered in the selection and design of a retaining structure and its foundation. Using available empirical rules of sediment transport, a range of "pickup" velocities can be developed which will indicate if erosion or scour is to be a problem. The SPM[4] provides tables and charts of sediment motion initiation velocities, and discusses their use.

24. The turbulence of wave-induced water motion at the toe of a structure will generally cause sand motion at velocities less than 1 fps. Bottom velocities vary with the ever-changing wave and water conditions and a combination which produces a bottom velocity of about 0.5 fps is sufficient to cause entrainment of medium beach sands. Detailed analyses of tidal and littoral currents, wave height prediction, and other coastal problems are presented in the SPM.[4]

25. An important consideration in determining water velocity must be the effect the fill placement will have on altering the flow regimen of the waterway. When the fill decreases the cross-sectional area of a channel there will be resulting increases in flow velocities and/or water surface elevations. These should be estimated and used to evaluate the erosion potential (see Rouse[7] and Vanoni[8]). Scour potential of the existing channel banks should also be examined if significant velocity increases are predicted. Additional information on open channel flow can be found in Chow[9] and EM-1110-2-1601.[10]

26. Erosion can be minimized by proper location and orientation of the structure. Locating the disposal site in a low-energy environment is the optimal solution. Flattening the outer slopes of the fill or dike will reduce turbulence and scour. Streamlining the upstream face of the fill will also lessen erosion. Protection of inner and outer surfaces by the use of filter cloth and revetment or antiscour blankets of rubble may be required in higher energy situations. Protection created by breakwaters or floating wave attenuating devices is also possible, but due to high cost may not be economically feasible. Detailed discussions on site location, shape, and erosion control are found in Johnson and McGuinness[1] and Hammer and Blackburn.[2]

Foundation stability

27. The failure of an in-water containment dike is usually the result of an overstressing of foundation materials, rather than the structure materials. This is because the soft plastic and organic clays and silts most frequently found in the types of bottom areas associated with marsh habitats are unconsolidated and have very little shear strength. When the foundation soil is homogenous this failure will usually be rotational in character (Figure 1a), while a stratified soil with a weak layer will lead to a translating failure, with the failure plane passing through the weak layer (Figure 1b). A complete description of the dike stability as it applies to a dredge confinement structure is contained in Hammer and Blackburn.[2]

28. The stability of a retaining wall, i.e., a cantilevered sheet-pile wall as shown in Figure 1c, is also principally a function of the in situ soil. Since the shear failure surface will typically pass below the pile tip, driving the piles to a firmer bearing will increase the stability to the wall.

29. When an earth dike or other retaining structure is used a slope stability analysis must be performed to ensure an adequate safety factor against the typical failure modes illustrated in Figure 1. Detailed discussions of slope stability are found in Lambe and Whitman.[11] Stability chart solutions which give good accuracy for many conditions are presented in Duncan and Buchignani.[12] Graphical solutions of the Modified Swedish Method and the Wedge Method are given in EM 1110-2-1902.[13] The Waterways Experiment Station (WES) has computer-aided solutions for each of these latter two methods (Cheek[14,15]). Refinement in the method of analysis should not be at a higher level than the accuracy the soil strength data warrants.

Foundation settlement

30. The evaluation of the soil's bearing capacity, the stress distribution caused by the structure and the expected settlement of the structure are essential information for the designer. Information on methods to evaluate the above is covered in most texts on soil mechanics and foundations; e.g., Terzaghi and Peck.[16] Various influence diagrams and stress distribution curves have been developed to aid the engineer in his

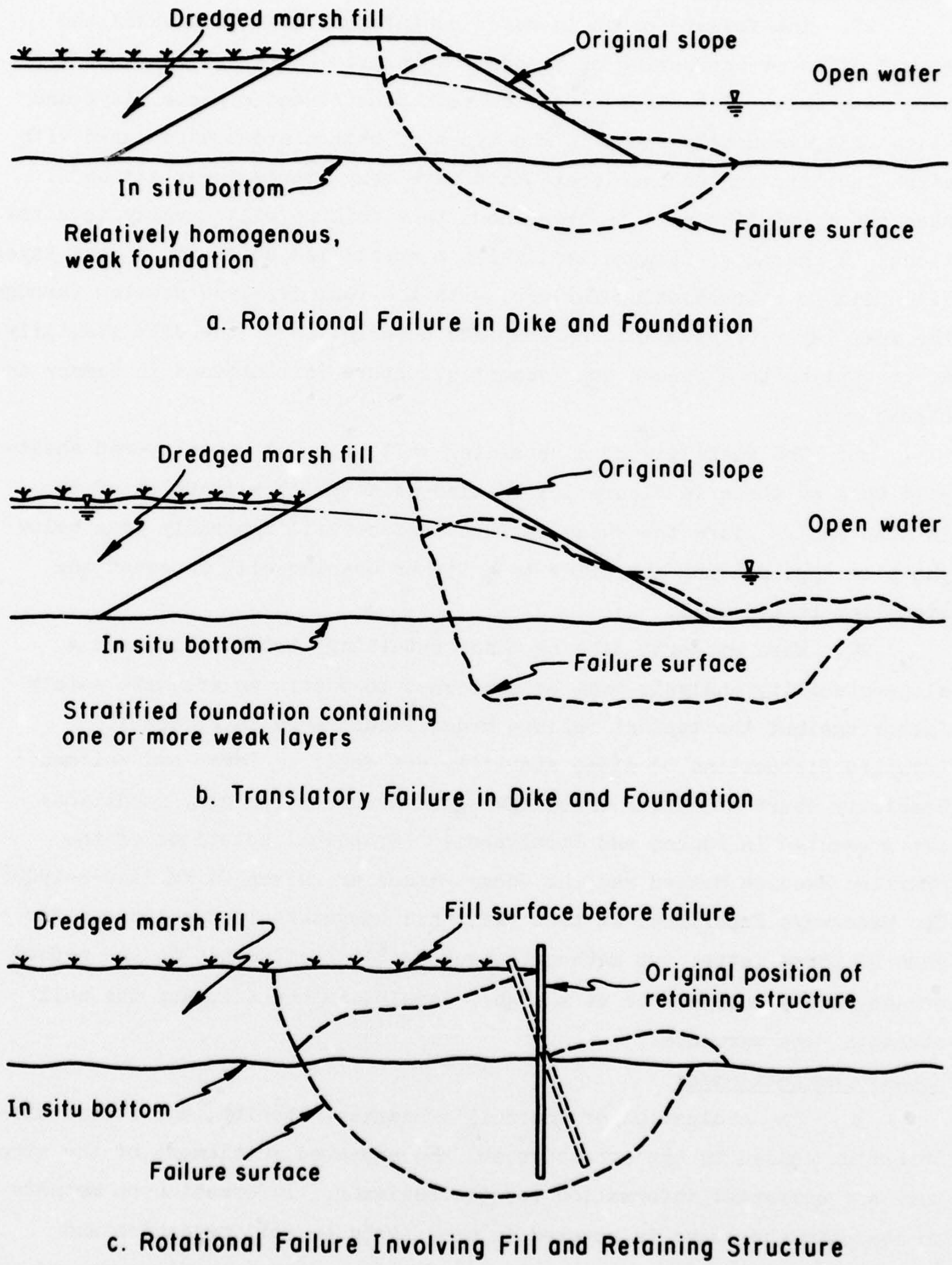

Figure 1. Examples of typical slope failures (after Hammer and Blackburn[2]).

calculations. Use of the Boussinesq analysis for infinitely long foundations is a common procedure for determining stresses at varying depths under footings, walls, and embankments. Hammer and Blackburn[2] present example problems for the embankment case. Sowers and Sowers[17] give a Boussinesg chart for other foundation configurations as well as charts for the Terzaghi-Meyerhof general bearing capacity equation.

Seepage forces and piping

31. Seepage is the flow of water through a saturated soil mass caused by unequal heads between two boundary surfaces. The water follows a "flow line" as illustrated in Figure 2. The amount of water which flows in this matter depends on the head differential and permeability of the soil through which the flow occurs. The seepage "force" is the head differential minus the frictional head lost during flow. Since the head differential will be set by the design conditions for the marsh, only the permeability remains a variable factor which the designer may control.

32. In upland areas, dikes can be constructed of clays, which when properly placed and compacted will be very impermeable. In-water dikes will normally need to be constructed from coarser grained materials since clays cannot be compacted in place underwater. Sand dikes typically have a high permeability and may require seepage protection, i.e., graded gravel filters or filter cloth to avoid erosion of the dike. If waterflow is sufficient to remove the sand at a point on the downstream boundary surface, head loss is gradually decreased and erosion retrogresses through the embankment like an ever-enlarging pipe, hence the term "piping."

33. Uplift will occur under these same situations when the flow lines exist under some structural component as shown in Figure 2a, where the toe protection is subjected to uplift pressures. If the quantity of flow is sufficient such that there is zero effective stress between the sand particles, a quick condition will exist. If the sand at the base of a structure becomes "quick," both lateral and vertical strengths are lost and major failure can result.

Control of seepage and uplift

34. In dam construction seepage is controlled by careful construction of an impermeable core and usually a grout curtain extending downward

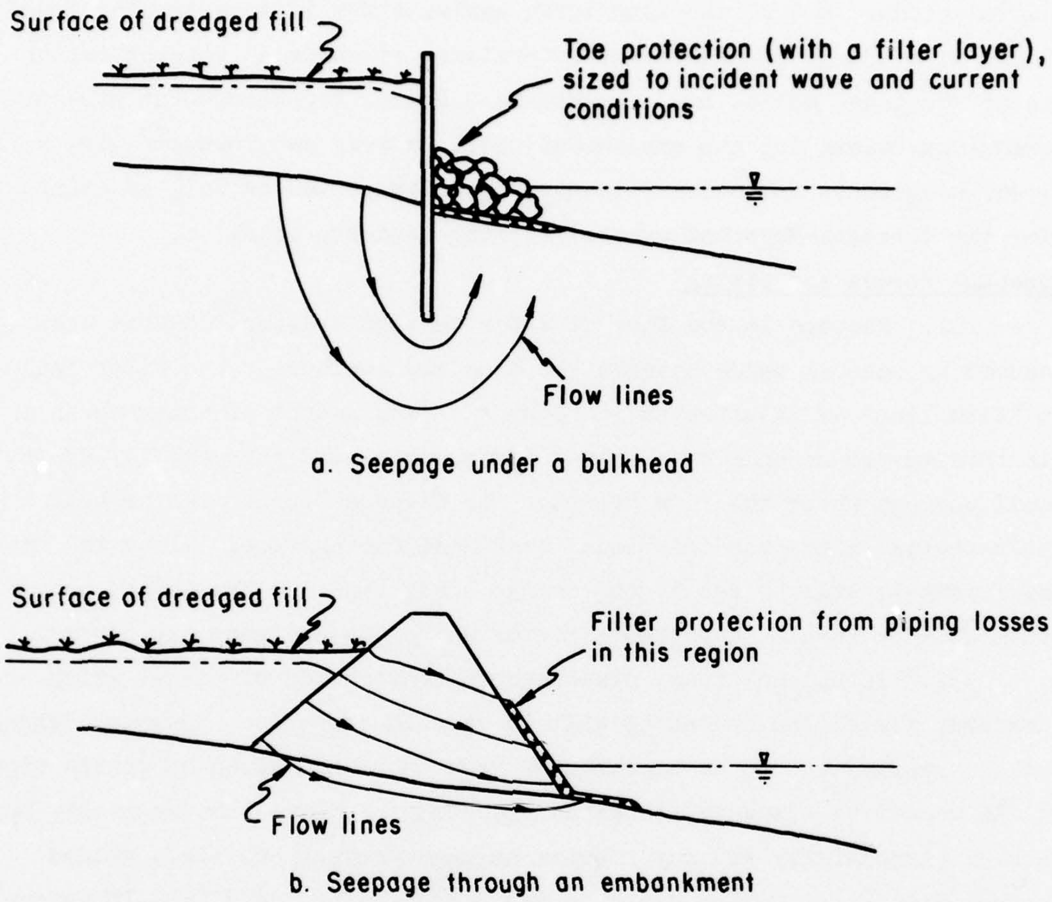

Figure 2. Seepage flow paths

below the dam. A properly designed drainage blanket and horizontal drain of graded stone will direct the inevitable seepage to a controlled outlet. Dikes or other structures used for retaining dredged material for marsh development are not so elaborately constructed, because the hydraulic head differential rarely exceeds 10 ft. Seepage control normally consists of increasing the length or the resistance of a flow line and sizing material at the seepage discharge point to resist piping. Common seepage control methods include the use of an impermeable membrane, usually plastic, on the inner dike surface or by use of filter cloth on the outer surface under a protective layer of riprap or other revetment material. The former method will greatly reduce seepage, the latter will prevent piping, the loss of dike soils due to seepage outflow. Filter cloth on the inner side of fabric bag walls and similar structures will also prevent sediment loss through any small openings. Increasing the length of flow lines by widening the dike crest, flattening outer dike slopes, driving sheet piling deeper, or by constructing toe berms will reduce both the quantity and velocity of seepage. Uplift under relatively impervious layers or structures is countered the easiest by increasing the overburden weight. For safe design seepage exit gradients and net uplift forces used in design should be 50% greater than calculated (Hammer and Blackburn[2]). Complete discussions on seepage, flow net analysis, and control can be found in EM-1110-2-1901,[18] Taylor,[19] and Winterkorn and Fang.[20]

Construction Considerations

Location

35. The actual location of a dredge disposal site is generally established by factors previously discussed. However, the planner should not forget that characteristics of the final site selected will be reflected in the construction bids. Among the location factors which influence costs are: equipment accessibility, wave and current conditions, tidal range, water depth, bottom conditions, and distance from dredge site.

Environmental constraints

36. Environmental constraints which limit the adverse impact on existing vegetation and wildlife, including bottom-dwelling organisms, and water turbidity may limit mobilization and storage space, restrict site access, prohibit or restrict use of earth dikes, and set detention times for dredge discharge slurry in containment area. Turbidity, because of its visibility, is a major problem of most dredging projects where hydraulically placed dikes are used.

37. Once turbidity limits are set, several construction variables must be considered. Assuming mechanical separators or chemical flocculants are not used, water clarity will depend on sediment particle size, water turbulence, and settling time. Coarse sand with no fine material can be placed in relatively turbulent water and it will quickly settle without the need for any turbidity control measures. On the other hand,

fine-grained sediment will nearly always require some type of retaining structure to ensure that the sediment stays in the designated disposal area. Settling time for fine-grained sediment must be carefully determined and will vary with dredge discharge volume, water depth inside the disposal area, wind-generated water circulation in the disposal area, and the distance to outlet structures. The planner must choose some optimum construction sequence consistent with the most critical controllable factors for any given disposal site. For example, additional storage capacity for the slurry may be obtained by constructing the dikes higher during the original construction or by raising them after some fill has been placed. Raising the dike elevation can be done by using a clamshell or dragline to remove deposited material and place it on the dike or by using a temporary method like sandbags. The total storage capacity must allow sufficient dredged material to be retained to produce the required fill elevation. Elevation control as a construction consideration is discussed below.

38. When other types of retaining structures are used, a similar construction sequence is followed. Stability requires that the best available material be placed directly behind retaining structure, but preferably not in one lift. Staged loading of the retaining structure permits the first-placed material to dewater and develop shear strength. This reduces the total one-time peakload which the structure must sustain.

39. Settling time may be controlled by changing the rate at which the dredged material is placed inside the confinement area. The design disposal rate will have an important economic impact on the project since it is a factor in determining the maximum size of dredge plant which can be utilized effectively. A large dredge plant may be required to operate intermittently or at a reduced rate.

Elevation control

40. Development of a viable marsh habitat requires that the final elevation of the dredge substrate be carefully established in the field. The first step is to select a design elevation for the top of the containment structure. As shown in Figure 3 the first step in the selection is establishing the desired elevation of the proposed marsh (a), after

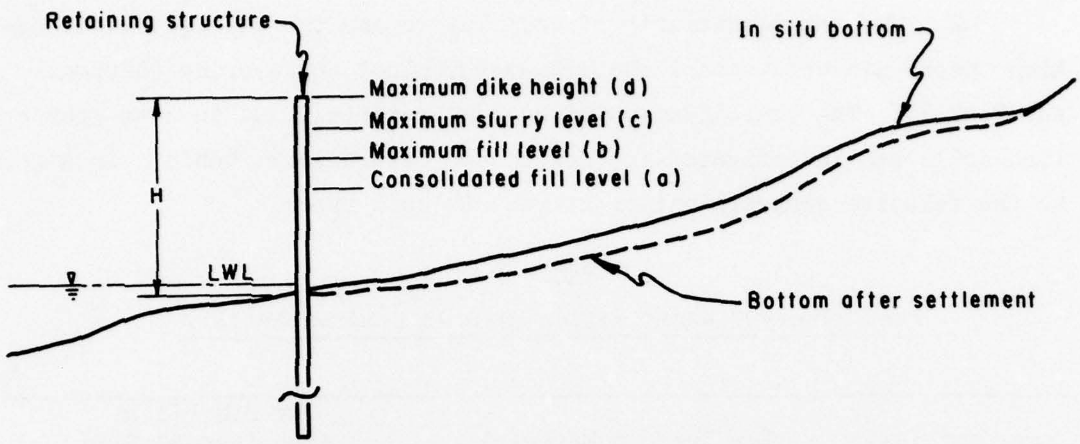

Figure 3. Definition of elevations

foundation and fill have consolidated. Add the anticipated foundation and fill consolidation to obtain the maximum fill level (b) after disposal has been completed. The maximum slurry level (c) must be sufficient to provide adequate ponding for retention of suspended solids in the low density (≃ 15% solids by weight) slurry to attain a final elevation at level (b). Level (d) is the theoretical maximum height of structure required for retention of dredged material. This includes additional freeboard that may be required to prevent overtopping. Wind waves may even cause overtopping from inside when water levels are high. This can result in turbidity and erosion of outer slopes of sand or earth dikes. Heights of tides, storm surge, waves, and runup must be calculated to determine the required protective height of the structure. The highest elevation of either the retaining height or the protective height will establish the design height.

41. Gravity structures including sand, earth, or stone dikes, cofferdams, cribwalls, and similar structures which attain stability through their mass, may settle into the foundation material. In addition, sand or earth dikes will consolidate with a resulting decrease in crest elevation. Therefore, for gravity structures, this supplementary consolidation and settlement must be determined before establishing the final crest elevation.

42. The compressibility of soil layers and the general consolidation theory are well established in geotechnical engineering (Terzaghi and Peck[16]). The consolidation of dredged materials and in situ foundation soils was investigated in Johnson and McGuinness[1] Table 1 is a guide to the relative compressibility of various soil types.

Table 1

Preliminary Classification of Soil Compressibility

Compressibility	For Dredged Material	For Subsoil at the Disposal Site
Low	•All gravel	•All gravel
	•All sand with less than 30 percent fines	•All sand
	•All inorganic silt and clay of liquid limit less than 50 and excavated in large clumps by a mechanical dredge	•All inorganic silt and clay of liquid limit less than 50
		•All other material except peat if known to have been precompressed under a load greater than contemplated by the proposed fill
High	All other material, i.e.:	
	•Sand with more than 30 percent fines	
	•All inorganic silt and clay of liquid limit less than 50 excavated by hydraulic dredge	
	•All inorganic silt and clay of liquid limit greater than 50, regardless of means of excavation	•All nonprecompressed inorganic silt and clay of liquid limit higher than 50
	•All organic silt and clay	•All nonprecompressed organic silt and clay
	•Peat	•Peat

(From Johnson and McGuinness[1])

PART III: STRUCTURE SELECTION

Evaluation of Need

43. The first step in the selection of a containment structure is to validate the requirement for a structure. To establish the requirement an initial engineering analysis of each potential dredge material disposal site must be completed. This early analysis in the planning process, before site selection, is necessary since the cost of any required containment structure may severely impact the economic feasibility of a proposed site. A containment structure at a specific site is justified by the need for protection and/or retention of dredged material.

44. Dredge disposal sites may require perimeter protection from currents, ocean waves, or ship waves. Structures required for such purposes are termed protective. Particular concern should be given to the effects of the proposed structure on current or wave patterns. Structures positioned so as to constrict the waterflow will increase local current velocities and thus tend to increase erosion. Such an event may create a new requirement for some revetment protection. Location of protective structures which reflect wave energy may also create new or intensified erosion zones.

45. A second principal use of a structure around a dredged material disposal area is to retain the dredged substrate until it consolidates and to control the migration of suspended fines from the dredged discharge. Such control is particularly necessary when the disposal area is near a ship channel or harbor and there is danger of suspended fines recirculating back into the dredged area. A retaining structure may also be required to prevent fines from causing environmental damage to adjacent waters, marshes, or the fauna in these areas.

46. Site hydraulics and the grain-size distribution of the dredged substrate are closely interrelated in the determination of the need for protection and retention. Large quantities of fines are suspended when clays are hydraulically placed, and if the discharge is not properly contained a "dredgetail" of suspended fines will be carried far beyond the dredge disposal area. Consolidated clays are normally more resistant to

erosion and for many applications will require limited diking only during establishment of marsh vegetation.

Structures in Use

47. To date very few structures have been built specifically to retain or protect dredged material for purposes of marsh creation. A list of the known projects, their location, and structural type used is given in Table 2. Thus far, the predominant structures used for marsh establishment have been sand dikes. Two DMRP projects are discussed below as examples of a sand dike (Windmill Point, Virginia) and a fabric bag dike (Bolivar Peninsula, Texas) containment structure.

Windmill Point marsh development site

48. The Windmill Point project is a good example of many site conditions typical of dredging projects the Corps of Engineers undertakes. The James River navigation channel, in the vicinity of Windmill Point, has been maintained at a 25-ft depth since 1931. In that time it has required repeated maintenance dredging, averaging every 1.8 years, with the dredged material being pumped overboard 1000 ft off the centerline of the channel (Whitehurst[21]). The marsh habitat, located just 1000 ft off the channel axis, appears to be situated on an old dredge spoil bank.

49. Foundation conditions at the site studied by Cheng[22] were found to be generally poor. A very soft clayey silt layer, about 30 ft thick overlays a loose gray fine sand which extends to below the boring limit (Cheng[22]). The natural water content of all samples tested significantly exceeded the liquid limits. Such poor foundation conditions ruled out the use of any concentrated load containment structure and a flat-sloped sand dike was selected as most appropriate for the site.

50. Because the Windmill Point project was associated with the regular maintenance dredging of the James River, its construction timing was related to the dredging schedule. This too was a major consideration in the selection of a hydraulically placed sand dike, since it utilized the dredge already available and eliminated any delays for construction materials. The necessity for rapid planning of the dike to fit dredging schedules led to its being designed even before the tests on boring

Table 2

Structures Planned or Constructed for Use in the Development of Marsh Habitat Sites

Location	Structure
Windmill Point Marsh Development Site, James River, Virginia (DMRP Work Unit No. 4A11).	Sand dike
Miller Sands Marsh and Upland Habitat Development Site, Columbia River, Washington (DMRP Work Unit 4B05).	Sand dike
Apalachicola Bay Marsh Demonstration Area, Apalachicola Bay, Florida (DMRP Work Unit 4A19).	Sand dike
Pond Number Three Demonstration Area, San Francisco Bay, California (DMRP Work Unit 4A18).	Sand dike
Buttermilk Sound Marsh Development Site, Georgia Intercoastal Waterway, Georgia (DMRP Work Unit 4A12).	None
Dyke Marsh Demonstration Area, Potomac River, Virginia (DMRP Work Unit 4A17).	Sand dike (proposed)
Branford Harbor Marsh Development Site, Branford, Connecticut (DMRP Work Unit 4A10).	Timber pile and lagging (proposed)
Bolivar Peninsula Marshland Upland Habitat Development Site, Galveston Bay, Texas (DMRP Work Unit 4A13).	Sandbag breakwater
Rennie Island Habitat Development Site, Grays Harbor, Washington (DMRP Work Unit 4A14).	Several types (proposed)

samples were completed. The construction plans were for a sand berm with 1 on 15 slopes and a crest elevation of +4.5 ft above Corps of Engineers datum, which is 1.5 ft below Sea Level Datum of 1929 (Whitehurst[21]). The dike's crest elevation was established based on an estimated 1.6 ft of settlement due to consolidation of the soft in situ substrate. The slopes were then dressed by a dragline to their final design configuration. Figure 4, showing the typical cross section, is adapted from the foundation analysis report (Cheng[22]).

51. Investigation of the project dredging site did not reveal any sand suitable for dike construction; therefore, a nearby borrow source of fine to medium sand was located in the river off Buckler's Point. On 15 December 1974, the dredging was begun and the sand was placed along the centerline of the north dike. The dike construction began, according to plan, from the northern tip of the existing dredged material island and proceeded counterclockwise around the dike (see Figure 5). However, as the dredge pipeline got progressively longer, dredge production decreased markedly and led to a decision to break off the continuous dike at point A (Figure 5), and start the western dike on 4 January 1975. The gap was filled on 15 January without prior mucking out of the soft mud waves which would normally be expected to be present at this section. On 20 January a dike failure was apparent at this same site, which was repaired by the addition of more sand to return the dike crest to design elevation (Whitehurst[21]).

52. Periodic inspections reveal that the dike has been essentially stable (Figure 6) with some migration of its upstream end into the marsh, and the erosion of its sides to produce two tails at its downstream end. The dike has been breached at one point by natural action, either settlement or slope failure. The breach has presented no problems since it is along the protected side of the island and allows flow in and out of the marsh. The marsh has developed, without artificial seeding, a very thick foliage of assorted plants.

<u>Bolivar Peninsula</u>

53. This DMRP test site, located on Bolivar Peninsula 9 miles (14.5 km) northeast of Galveston and bordering on Galveston Bay and the Gulf Intercoastal Waterway, is an example of the use of sand-filled fabric

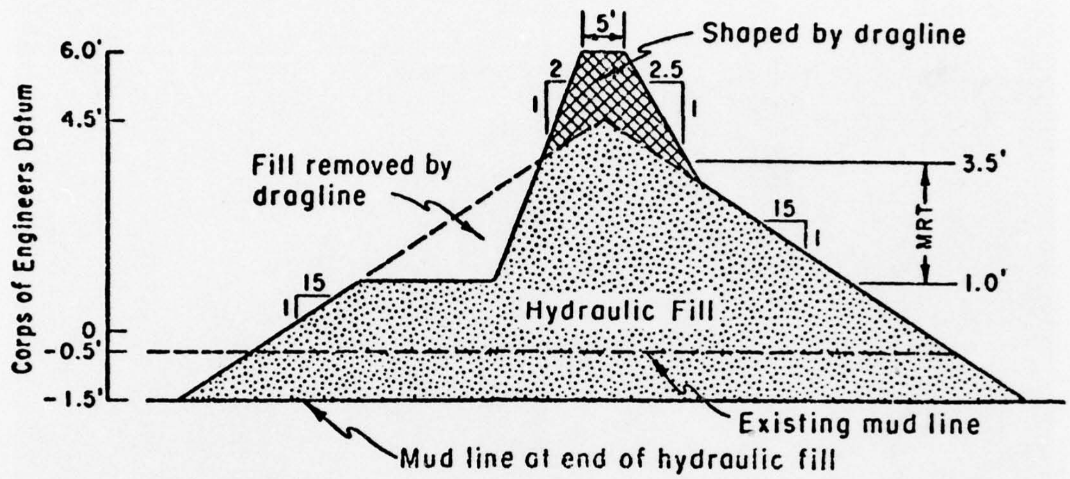

Figure 4. Typical cross section of dike at Windmill Point, James River, Virginia (After Cheng[22])

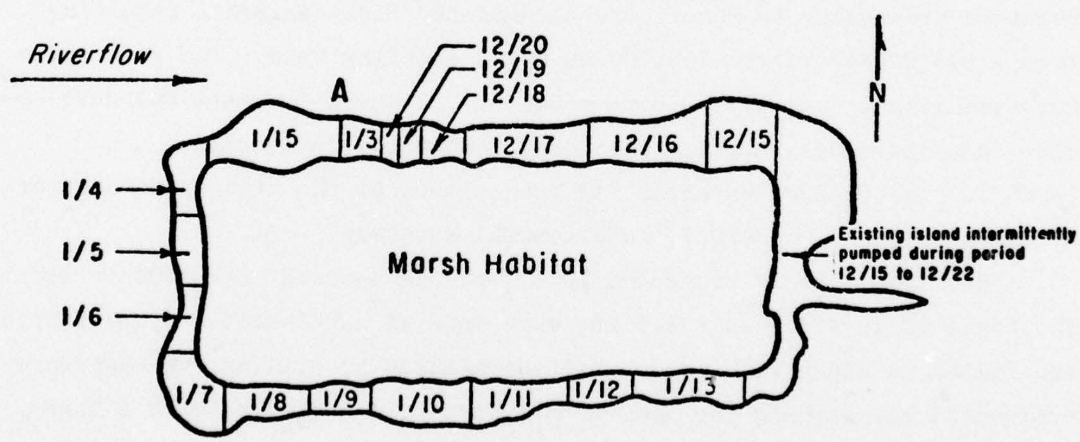

Figure 5. Sequence of hydraulic construction of the dike at Windmill Point (After Whitehurst[21])

Figure 6. Stable dikes at Windmill Point marsh development site

bags to protect a marsh substrate. Dredging on the nearby waterway is required biannually to remove the accumulated fine sediments resulting from a 994,000-cu yd/yr (760,000 cu m/yr) shoaling rate. The first site was established in early 1976 to study ". . . marsh (vegetation) development in a low-tidal-range, high-energy, estuarine environment. . . " (WES[23]). The dredged material had been placed at the site by an earlier dredging project on the Gulf Intercoastal Waterway.

54. The site is protected by a U-shaped sandbag dike 1700 ft long. The bags, 10 ft × 4.5 ft × 1.5 ft, were made of a PVC-coated nylon fabric and filled in place with sand. Various methods of filling the bags were evaluated, and washing the sand from a hopper into the bag with a hand-held hose proved the most successful. The bags were initially placed directly on the fine silty sand substrate without any filter cloth or filter layer. However, even before completion of the dike there was significant evidence of scour between and in front of the bags. Some bags were also losing their very fine sandfill. To correct this condition the remaining 278 ft of dike was placed on a plastic filter cloth, and the base layer was made four instead of two bags wide (WES[24]). Eventually, a

sizable part of the originally built dike was also placed in filter cloth and widened. In May 1977, the site was visited by one of the authors who found about 90% of the bags were in place and intact after 1 year's exposure.

Structure Selection Considerations

55. Selection of a containment structure to protect and/or retain dredged material during marsh habitat development is a many faceted problem. The selection is based on the criteria discussed in Part II, and all criteria are never satisfied. The considerations include: material retained or protected; maximum height of dredged material retained above the firm bottom; required degree of protection from waves and currents; permanence of the structure; foundation conditions at site; and the availability of materials. These criteria may be collected into the following four practical concerns which should guide selection of a containment structure: constructability of the structure to the project objectives, suitability of the structure to the project objectives, maintainability of the structure over its usable life, and its total life cycle cost. Most of these selection factors are site critical and require engineering data on the proposed site.

56. The practical options in containment structures can be divided into three classes for discussion: sand dikes; proprietory building unit structures, i.e., gabions or fabric bags; and sheet-pile structures. Revetments represent an addition to sand dikes for erosion protection, and sills and floating breakwaters are special purpose structures. Each class of structure has its advantages and disadvantages which are covered in greater detail in the data sheets in Appendix B. However, the principal choices, sand dikes and fabric bag dikes, are discussed below.

Sand dikes

57. Sand dikes have long been the most common containment structure for confined dredge disposal areas at both upland and in-water sites. The primary reason for their continuing appeal is their proven economy of construction at most sites. In 1974 a survey by WES (Snethen and Patin[25]) found that for in-water structures the dike was used almost exclusively

for confinement of dredged material. The survey also found only two marsh habitats that had been created with other types of retaining structures. Since then, seven marsh habitat projects (listed in Table 2) have been developed by the Corps of Engineers. Six of these were built under the guidance of the DMRP, and five of the six have been designed with sand dikes. The dikes, chosen for their adaptability and low cost, are simply sand embankments with some unique problems for the designer.

58. The first problem relates to their siting. Because the sand dike is a gravity structure it bears heavily on the soft, relatively unconsolidated alluvial clays and silt typical of many potential marsh habitat sites. In the design of a dike one of the major concerns is the rapid increase in the overburden which occurs when the dike is built and the containment area is filled with dredged material. The stability of the foundation soils with respect to shear failure is most critical at this "end-of-construction" time, because the strength of the foundation soils is minimal. As the increased overburden pushes water from the soil pores and the soil consolidates, there will be an increase in soil strength.

59. One alternative used in many upland dredged material containment sites is to build the dikes in stages as more storage capacity for dredged material is required. This solution is less desirable in marsh habitats because it delays achieving the proper elevation of dredged substrate for marsh creation.

60. The dike must be designed to accept significant settlement as the foundation soils consolidate. This generally entails building the dikes extra high based on an estimation of total expected settlement. When the estimate proves in error, sand dikes can be modified relatively easily to achieve design crest elevations.

61. If the in situ foundation soils prove inadequate for the dike planned, one alternative is to excavate the too soft substrate and replace it with an acceptable borrow. However, if acceptable borrow is not nearby, obtaining it can add greatly to the cost of the project. The soft material is most efficiently excavated by a hydraulic dredge if it can access the marsh site. In many cases this would entail dredging its way in to the site. Since the material is of such low strength the area

dredged will have very flat cut slopes adding greatly to the volume removed. The less expensive solution, if feasible, is to flatten the side slopes of the dike until it is stable.

62. In the case of very soft substrates the foundation soils frequently can be mud-waved, i.e., progressively failed and caused to flow before the dike's advance. This method works best with end-dumped construction technique which permits steeper dike profiles than can be obtained with hydraulic fill methods. This method is discussed in detail in Hammer and Blackburn[2].

63. The source of sand from which to build the dike is frequently another problem. Unlike dikes built at upland sites, dikes built in water cannot be readily compacted to achieve greater stability. Therefore, a relatively clean, free-draining, cohesionless sand is desirable. If such material is available within the dredge project area, construction of a dike by hydraulic fill is very attractive. However, about 80% of the dredged material processed each year is from maintenance work (Johnson and McGuinness[1]), and is generally a mixture of fine-grained silts and clays, with very little sand. Only in new dredge work are the required dike materials usually available in the project dredge area.

64. Two additional sources of sand are dredging from nearby borrow areas, such as was utilized at the Windmill Point project or excavation from an upland site and truck haul of the sand to the marsh habitat. Since in dredging, the excavation and transportation are combined, it will normally give a significant cost savings over the upland excavation and truck haul solution. A hydraulically placed dike will have very flat slopes (see Appendix B, Data Sheet 1), which can be modified by a dragline as at Windmill Point, or left on a flat slope to accommodate weak foundation soils as discussed in paragraph 61.

65. A third problem occurs when the dike is constructed in an area where its exposed surface must be protected from erosion by waves and/or currents. The slope of the dike may be faced with a revetment as discussed in Appendix B, Data Sheet 8. However, it should be stressed that the integrity of the revetment is dependent on the stability of the dike it rests on. The dike should be protected from erosion through the revetment by placing a filter cloth or filter gravel beneath or as part

of the revetment surface. Also, where major settlement of the structure occurs, there can be sufficient disturbance of the revetment to expose the dike to wave attack. Several types of revetments are covered in the data sheet. The revetment should be selected to fit the specific need of the marsh and to reflect the local variation in material availability.

Fabric bags

66. The term "fabric bag" covers any of the products of several producers of sacklike containers which can be filled with sand, sand-cement, or concrete and used as building blocks for breakwaters, groins, revetments, or containment dikes. To date many projects have been constructed using fabric bags in the above-mentioned structures, and two recent Corps of Engineers projects have used fabric bags to retain dredged material.

67. The feasibility of using fabric bags in coastal structures was studied by the Coastal Engineering Research Center (CERC) (Ray[26]) in a series of laboratory tests. The report recommends that such bags be filled with saturated sand as tests revealed that air retained in interparticle voids causes a buoyant uplift force on the bags when submerged in water, which reduces the bags' stability under wave attack. Also, field experience with the bags has been reported by Machemehl[27] and others. The consensus of these reports are that the bags are susceptible to damage by sharp objects. Their life expectancy is about 2 to 3 years, depending principally on site accessibility (vandalism) and depending on the bag material protection from sunlight (ultraviolet rays degradate fabric rapidly).

68. The use of a fabric bag structure is extremely useful where site access is difficult for heavy construction equipment. This is particularly true where the sandfill for the bags can be pumped off the bottom; e.g., at the Bolivar Peninsula site. Another fabric bag dike project built at Core Sound, North Carolina, used a pump floating on a makeshift barge of 55-gal drums to pump sand off the bottom to fill the bags.

69. As a general practice fabric bag dikes should be backed up with a filter cloth to ensure that the dredged materials are not lost through the openings between bags. While the placement of a filter adds

to the complexity of the dike installation, the Bolivar Peninsula experience confirms the need for such a filter. The filter should pass under the base bag and extend up the back of the dike (see Appendix B, Data Sheet 7). If an apron is used to prevent scour in front of the dike the filter should also extend under it. A flexible apron, i.e., a sand-filled fabric mat, serves very well for this use, as long as it is not torn open.

PART IV: CONCLUSIONS

70. While several types of containment structures are applicable to marsh habitat development, each adds significantly to the cost of the marsh and should only be used where justified. When used, the structure should be selected and designed to enhance its constructability, maintainability, and usability while minimizing its total life cycle cost.

71. Sand dikes have been the most commonly utilized solution to the retention problem of containing dredged material. If acceptable material from which to form them is available at the site they are simple to build by controlled dredge discharge. The adaptability of sand dikes to future modifications of the containment area is a great advantage. Sand dikes, hydraulically placed or built by haul-dump methods, should generally be the least expensive containment structure and are the most common choice.

72. Sandbag dikes have been used in only a few marsh habitats. Like the sand dike they are easily modified or removed, and if protected from wave and current scour they can be effective at low energy sites. However, bag life limits their use in long-term projects unless concrete or sand-cement fill is used.

73. The need for safe outflow structures through the dikes was observed at all of the enclosed sites. Care should be taken to provide adequately for the discharge volumes expected at maximum tides, storm tides, and heavy rainfall runoff.

74. Ease of repair or alteration should be considered in planning any marsh containment structure. Structures built high during disposal to contain slurry must be lowered to create a viable marsh habitat, and the remobilization of a major construction force to alter some containment structures, i.e., cofferdams, anchored bulkheads, is very costly.

75. The very slow consolidation of the dredged substrate in newly created marshes requires that the containment structure be designed to retain what is initially a "heavy fluid" slurry.

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APPENDIX A: COST DATA

1. Since any estimate of construction costs is site critical, there is no attempt to provide exhaustive cost data on the types of structures reviewed in this report. Instead, a table of typical costs for the various types of structures has been assembled with the help of personnel from the U.S. Army Engineer District, Baltimore. These costs must be adjusted to reflect conditions unique to a particular project, i.e., dredge line distance, quality of natural materials, accessibility of job sites.

2. In Table A1 costs are generally given in dollars per linear foot of containment structure except where noted and are established for July 1977 at Baltimore, Maryland. Costs should be modified by an appropriate index for other areas of the United States. These costs were used to develop the low, moderate, or high cost factors given in the data sheets in Appendix B.

3. Filter blankets or filter cloth must be placed under all revetments of rock or sandbags, and the cost is in addition to the estimates given for revetments. The estimated costs are:

Filter blanket (1' thick):	\$6.00/SY
Filter cloth	\$3.15/SY

Table A1

Estimated Cost of Construction

Structure Type	Structure Height Above Bottom (ft)	Cost/lin ft	Remarks/Assumptions
Sand dike hydraulically placed (1:3 slope)	10 20	$ 40.00* $ 115.00*	For all construction in water. • Low to moderate wave climate. See notes below for costs of dredge mobilization, not included in these figures.* • Does not include any stone protection, nor establishment of vegetative cover.
Earth dike, end-dumped construction (1:3 slope)	10 20	$ 80.00 $ 290.00	• Method requires truck haul link to land, available material within a reasonable distance, and easy access to work site. • Does not include any stone protection nor establishment of vegetative cover. • Length and width of dike are critical factors in truck cycle time and thus in cost.
Rock dike, end-dumped 1-1/2 ton max (1:1 slope)	10 20	$ 400.00 $1,500.00	• Material is quarry-run rock, not graded; placed as single layer.
Steel sheet-pile bulkhead anchored wall	20	$ 480.00	• Estimated PZ-27 sheets 30 ft in length. • Sheets are mild steel with no corrosion protection.

*Dredge mobilization must be added to cost of all dredging projects.

Dredge	Distance to Worksite 1/2 Mile	Distance to Worksite 2 Miles
12-in ϕ pipeline	$ 33,000.00	$ 43,000.00
20-in ϕ pipeline	$129.000.00	$145,000.00

Table A1--Continued

Estimated Cost of Construction

Structure Type	Structure Height Above Bottom (ft)	Cost/lin ft	Remarks/Assumptions
Wood sheeting bulkhead	10	$ 560.00	• Treated timber piles, walers and wood plank sheeting. • Price will vary greatly with location and availability of timber.
Gabions	--	$ 65.00/CY	Cost is in dollars per cubic yard. • Need to include volume of flexible apron in estimate. • Price very dependent on availability of rock fill.
Sandbag dike	5 10	$ 77.00 $275.00	• Constructed in shallow water.
Revetment:** Low energy, rock gradation	--	$ 9.00/SY	• Small-size rock blanket, placed from land. • Assumes locally available source.
Revetment:** High energy, rock gradation	--	$ 38.00/SY	• Large stones placed by barge. • 100-mile haul distance.
Revetment:** Sandbags in single layer	--	$ 6.00/SY	• Conventional sandbags, no grout in fill.
Revetment: Gabion blanket 1 ft thick		$ 25.00/SY	Price is for freshwater gabion.

**This revetment requires a filter.

APPENDIX B: STRUCTURE DATA SHEETS

1. The data sheets included here describe the potential of a specific structural type to solve the problems of retention and protection of dredged material during marsh creation. As such there has been a tendency to stress inexpensive, short-life structures (1-3 years). However, some longer life options have been included in recognition of the fact that even in tidal marshes a certain amount of high ground permanently maintained above the sea level is needed to establish the full range of marsh bioculture. Also, when marshes are built on more exposed fetches some permanent wave protection will be necessary to ensure the marshes' survival.

2. The first seven data sheets detail types of structural solutions to the dredged material retention and protection problem. They vary from short to long life with some indication of how the lives of some could be greatly extended. Data Sheet 8 describes the most common revetment types. Revetments can be used to protect a sand containment dike from wave or current erosion. Data Sheet 9 is an offshore sill which protects the marsh from large waves while permitting the smaller waves to pass over. Such a structure has application where the marsh is in a low wave climate and exposed to only an occasional storm wave. The last data sheet describes a floating breakwater which may be used as a temporary protection device to permit the marsh or its dike time to develop a strong stand of vegetation.

3. In selecting the most cost-effective marsh design the total life cycle costs of the various options should be considered. Included in this must be the costs of any extraction, modification, or removal of the structure, after initial marsh establishment, that is necessary to establish the marsh balance with the adjacent open water.

The Data Sheet Format

4. The data sheets are assembled in the following format to give the planner-designer sufficient information for making initial judgments of what type of structure would be most suitable for a given site-specific

situation. They are not intended to substitute for proper engineering design, nor even to serve as engineering design guidelines.

a. Classification: Each sheet classifies the structure by five factors as follows:

Function: The structure's function is described as retaining and/or protective. Retaining--the structure's capacity to keep typical dredge-size materials within its bounds, particularly during filling. Protective--the capacity to prevent the incident water waves and currents from eroding the substrate.

Type: Flexible or rigid is used to describe the relative ability of a structure to respond to foundation settlement or active loads from new marsh substrate.

Material: Major compositional materials used in the structure.

Size: Limiting wall heights above the firm bottom as per common practice.

Material retained: Discusses types of dredged material retained by the structure and any special steps needed to ensure retention; e.g., filter cloth.

b. Design factors: The design factors given in the data sheets are really warning flags to call the planner-designer's attention to those unique features of each structure which require special consideration or limit its use. The factors considered vary with each data sheet and are self explanatory except for permanence and cost.

Permanence: The permanence evaluation of a structure considers first the probability that the structure will retain and/or protect the new marsh substrate until sufficient consolidation has occurred to allow the removal of the structure. Secondly, the effort required to repair, modify, or remove the structure is considered. In measuring permanence the minimum desirable life is taken as 2 years since results to date indicate that this will allow time for sufficient consolidation and for the establishment of stabilizing vegetation in the marsh. The structural life rating system is: short (less than 2 years), moderate (2 to 4 years), long (5 years or more). The effort required to modify or remove a structure is measured relative to the first cost of construction. The removal rating system is: low (<25% first cost), medium (about 50%), and high (>100%). This rating is very general since local conditions and initial construction can radically change the costs of removal.

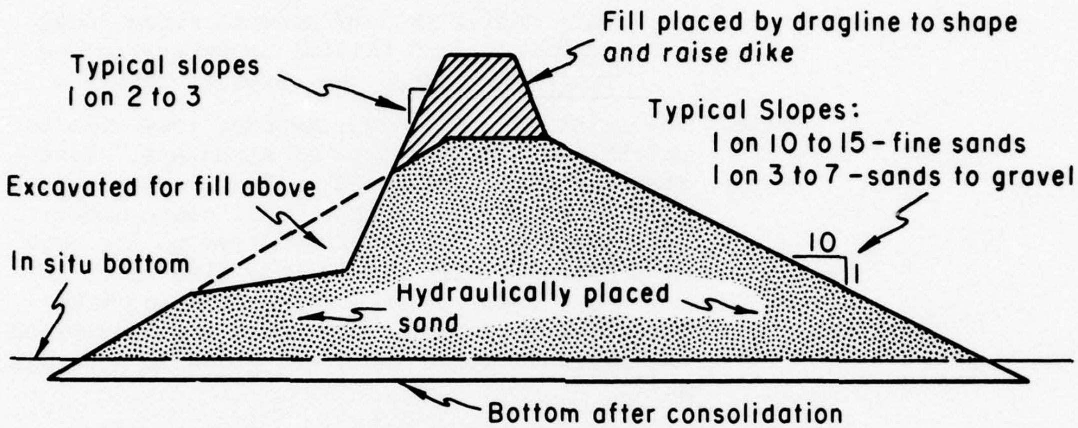
Costs: The relative cost (high, medium, low) will be determined for each type of structure. Revetment costs will be based on dollars per square yard of protected surface. All containment structures will be rated relative to the cost of a hydraulically placed sand dike which is rated as "low." Some construction and site variables which affect the cost are identified and representative costs are given in Appendix A.

c. Remarks: This section highlights some of the subject structure's advantages or disadvantages as they apply to use for marsh habitat containment.

d. References: References to pertinent sources of design information for each structural type are given.

Data Sheet 1

Sand Dike (hydraulically placed)



Classification

Function: Retaining and protective; dike may require additional protection by revetment.

Type: Flexible, gravity structure.

Materials: Sands or gravels, less than 15% passing No. 200 sieve.

Size range: The height limit for a sand dike is generally established by the stability of underlying foundation materials. However, with flat slopes, material volumes increase rapidly with height and establish an economic size limit.

Material retained: All sizes of typical dredged material.

Design factors

Foundation conditions: Since most marsh habitats exist or are likely to be built at sites with soft alluvial bottoms, some dike settlement is likely to occur. If good soil data are available the designer can estimate and plan for the settlement. The dike must also be designed for overall cross-sectional stability against a failure surface through the soft bottom material.

Structural settlement: If built with coarse clean sands, hydraulically placed, there will be little settlement of the structure. Such sands will have a medium relative density. However, if sand contains significant fines the loss of pore water will be slowed and some long-term consolidation may be evidenced.

Tidal effects: Moderate. Maximum tidal range should be considered in developing maximum loads for stability conditions, and in determining the extent of revetment protection.

Wave and current effects: Erosion susceptibility is a function of the sand characteristics such as particle size, shape, gradation, particle density and compactness. Therefore, it is difficult to give general criteria; however, the waves and currents to be considered should be those of the larger storms or current flows and not the average values. Where significant erosion can be expected, revetments should be included to prevent damage.

Permanence:

a. Structural life: (Rating: long) Dikes protected and maintained as appropriate have an almost unlimited life. Unprotected dikes can accommodate some degree of scour in low wave climates.

b. Removal: (Rating: medium) Dikes can be easily removed or modified with a dragline to meet the development requirements of the marsh.

Costs: A sand dike is the cheapest solution when material is readily available at economic prices. If the dike requires revetting to prevent its erosion, costs can almost double and the size of construction plant to be mobilized is increased (see Data Sheet 8, Revetments).

Remarks

a. Sand dikes should be built from the coarsest material that is economically available. Preferably, this material would come from the site to be dredged but frequently in maintenance dredging, the project material is not coarse enough or exceeds 10% to 15% fines (passing No. 200 sieve), and other borrow sites must be found.

b. The extra costs in borrowing from a nonproject site are somewhat offset by the costs of extra material that must be used in flatter slope dikes which result from using finer grain and/or plastic materials found at the project dredge site.

References

Lowe, J. III, "Stability Analysis of Embankments," Conference on Stability and Performance of Slopes and Embankments, American Society of Civil Engineers, 1966.

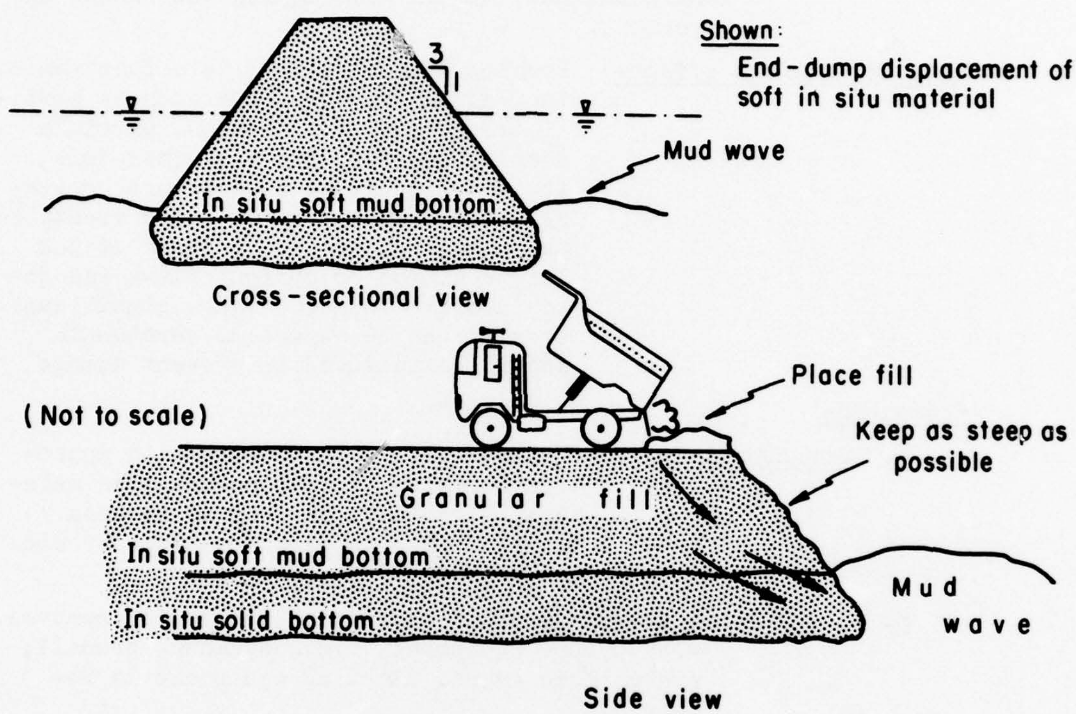
Ladd, C. C. and Foott, R., "New Design Procedure for Stability of Soft Clays," Journal, Geotechnical Engineering Division, American Society of Civil Engineers, Vol 100, GT7, Jul 1974, pp 763-786.

NAVFAC, "Soil Mechanics Foundation and Earth Structures," NAVDOCKS Design Manual DM7, U. S. Navy, 1971.

Whitman, R. V., "Hydraulic Fills to Support Structural Labs," Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol 96, No. SM1, Jan 1970, pp 1-54.

Data Sheet 2

Sand Dike (dumped in place)



Classification

Function: Retaining and protective; dike may require a revetment as additional protection from erosion.

Type: Flexible, gravity structures.

Materials: Silty or clayey sand, sand, gravel.

Size range: Since greater height can be achieved by flattening the side slopes of dikes, any practical height is possible.

Material retained: All typical sizes of dredged material.

Design factors

Foundation conditions: Since marshes tend to be built on soft, organic soils, foundation settlement can frequently be built by the displacement method; however, care must be exercised to avoid entrapping the soft mud wave under the fill.

Structural settlement: If material has a significant clay content the dike may undergo significant consolidation depending on the water content at placement.

Tidal effects: Moderate. Maximum tidal range should be considered in developing maximum loads for stability considerations, and in determining the extent of revetment.

Wave and current effects: Erosion susceptibility is a function of the sand characteristics such as particle size, shape, gradation, particle density and compactness. Therefore, it is difficult to give general criteria; however, the waves and currents to be considered should be those of the larger storms or current flows and not the average values. Where significant erosion can be expected, revetments should be included to prevent damage.

Permanence:

a. Structural life: (Rating: long) Sand dikes with appropriate riprap protection and some maintenance can last as long as necessary. The principal dangers are slope erosion and toe scour.

b. Removal: (Rating: medium) Sand dikes are easily removed with proper equipment, i.e., backhoe, gradall, and in some cases, floating equipment is required.

Costs: Low. About double those for a hydraulically placed dike; however, the cost is quite dependent on the specific site conditions, i.e., haul distances from source to dike, land access to dike, quality of fill used.

Remarks

When the marsh habitat is a planned disposal for soft maintenance dredged material and no acceptable dike material is available in the project, land borrow of dike material may be available. Where this can be delivered and end-dumped into place, this type of dike becomes cost competitive.

References

Bjerrum, L., "Embankments on Soft Ground," Proceedings, Specialty Conference on Performance of Earth and Earth-Supported Structures, American Society of Civil Engineers, Vol II, 1972, pp 1-54.

Duncan, J. M. and Buchignani, A. L., "An Engineering Manual for Slope Stability Studies," University of California, Berkeley, Calif. 1975.

Hammer, D. P. and Blackburn, E. D., "Development and Construction of Retaining Dikes for Containment of Dredged Material," Technical

Report D-77-9, Aug 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

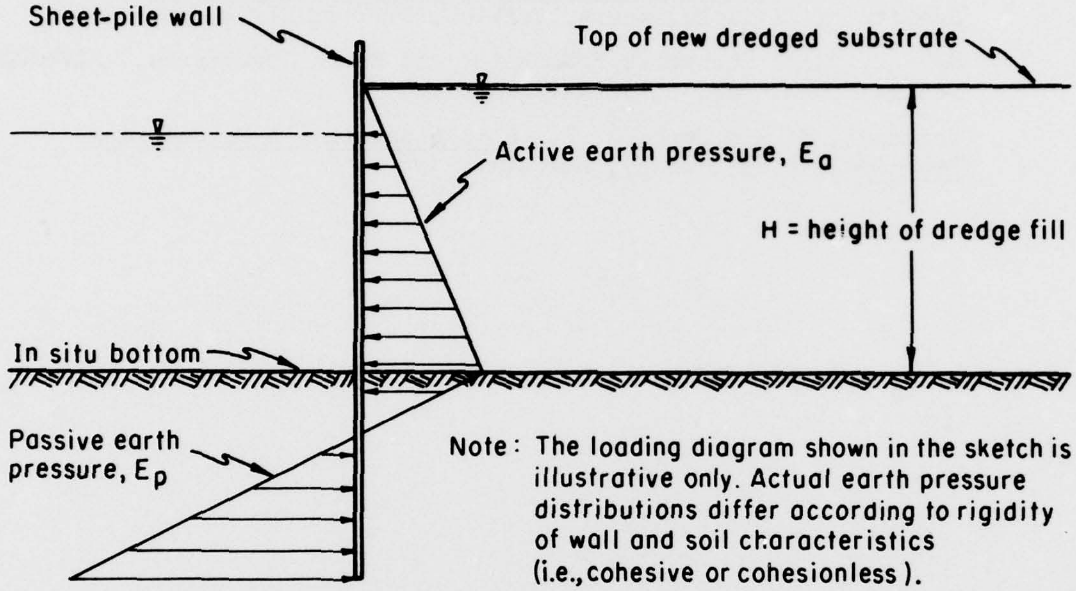
Ladd, C. C. and Foott, R., "New Design Procedure for Stability of Soft Clays," Journal, Geotechnical Engineering Division, American Society of Civil Engineers, Vol 100, GT7, Jul 1974, pp 763-786.

NAVFAC, "Soil Mechanics Foundation and Earth Structures," NAVDOCKS Design Manual DM7, U. S. Navy, 1971.

Terzaghi, K. and Peck, R. P., Soil Mechanics in Engineering Practice, 2d ed., Wiley, New York, 1967.

Data Sheet 3

Retaining Wall (cantilevered)



Classification

Function: Retaining and protective.

Type: Flexible laterally loaded structure.

Materials: Arch web or Z-type steel sheet piles.

Size range: Wall heights limited to about 15 ft maximum. Above this height anchored walls (Data Sheet 4) are recommended up to a maximum height of 40 ft. However, where the use of an anchored wall is considered infeasible special means are available to modify cantilevered walls to sustain additional height, i.e., king piles, counterfort sections, etc.

Material retained: All sizes, total barrier to all dredge solids.

Design factors

Foundation conditions: Cantilevered walls require adequate embedment in a firm bottom strata to develop the passive earth support necessary to counter the high active soil loading pressure of low strength, soft dredged materials. Therefore, it is not advisable to use cantilevered walls at sites where the bottom is rocky (driving difficulty), or has soft unconsolidated sediments (insufficient passive support).

Wall rotation: Sheet piling must rotate outward at top in order to develop full strength capacity of soil. To improve the aesthetics of the finished project, drive sheet piles with slight inboard batter, so final wall position after initial movement will be approximately vertical.

Tidal effects: Minimal; however, designer should include tides in calculating greatest wall loading case.

Wave and current effects:

a. Erosion resistance: Good. Inspection must ensure that no handling holes are left uncovered in driven sheet piles, as piping losses through such holes can be very large and may precipitate failure.

b. Toe scour: Significant scour of the bottom immediately in front of any wall may occur if water depth is less than twice wave height. Design wave height should include both the incident wave height plus a reflective wave height estimated for a vertical wall. Toe scour is a particular concern with cantilevered walls since the bottom material removed from in front of the wall is in the passive earth zone that supports the wall (see figure above).

Permanence:

a. Structural life: (Rating: long) The structural life can be extended by proper corrosion protection, i.e., coatings, or special corrosion-resistant steel sheeting.

b. Removal: (Rating: medium) Comparatively simple with crane and pile extractor. Overdriving during placement which causes sheet deflections and interlock separations adds great difficulty to extraction. As an alternative to removal, piling can be cut off to any convenient height, and abandoned.

Costs: Moderate to low. A cantilevered wall is one of the less expensive structural retaining devices in this report, when reasonable reuse of material is planned.

Remarks

a. Permits installation of entire wall before any dredging. This reduces the problem of a tail of dredge discharge fines moving out of discharge area.

b. Materials and construction technology are readily available. Sheet piles can even be rented from commercial sources when considered cost effective.

c. Construction requires some floating plant such as a piledriver, pile barge, and pusher boat. Water depths at the time of construction must be deep enough to permit construction operations.

d. The key to constructing a successful cantilevered sheet-pile retaining wall is adequate penetration of the piling below the firm bottom, allowing for possible scour. Cantilevered sheet piles must be driven deeper than for similar wall heights of anchored sheet piles.

References

Bowles, J. E., Foundation Analysis and Design, McGraw-Hill, New York, 1968, Ch 8.

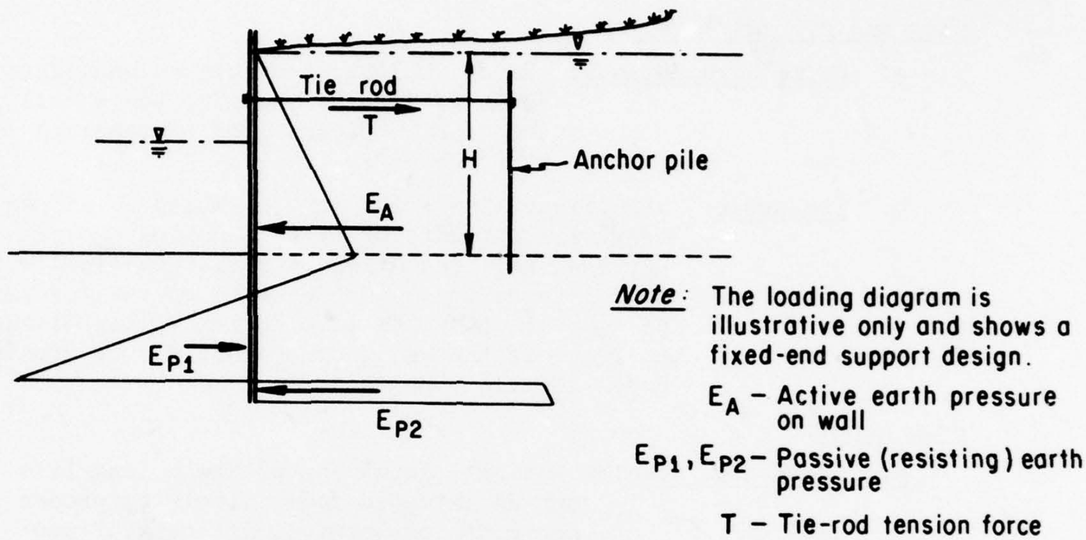
NAVFAC, "Soil Mechanics Foundation and Earth Structures," NAVDOCKS Design Manual DM7, U. S. Navy, 1971, Ch 10.

Teng, W. C., Foundation Design, Prentice Hall, Englewood Cliffs, N. J., 1962, Ch 12.

Winterkorn, H. F., and Fang, H. Y., ed., Foundation Engineering Handbook, Van Nostrand-Reinhold, New York, 1975, Ch 13.

Data Sheet 4

Retaining Wall (anchored)



Classification

Function: Retaining and protective.

Type: Flexible laterally loaded structure.

Materials: Arch web or Z-sectioned steel sheet piles.

Size range: Wall heights up to 40 ft above firm bottom.

Material retained: All sizes, total barrier to all dredge solids.

Design factors

Foundation conditions: Requires adequate embedment in a firm bottom strata of sand, clay, and/or small gravel. Larger size gravel and rock may prevent driving to acceptable depth, and unconsolidated bottom sediments provide little shear strength for the passive support zone.

Anchor support: The material wallward of the anchor structure whatever anchor is used, must be of adequate passive shear strength to resist the anchor load. If anchors are set in a select dredge-fill mound, before general filling, then as common dredged material is placed in the discharge area care should be taken to place the best available dredged material in the area between anchor and wall. Use of as clean a coarse sand material as possible will facilitate drainage of the fill behind the wall.

Tidal effects: Minimal; however, tides should be included in design calculations of worst wall loading.

Wave and current effects:

a. Erosion resistance: Good. Unless an uncovered handling hole is left in sheeting there will be no significant loss of material through wall.

b. Toe scour: Significant toe scour may be caused by strong long wall currents or by wave action against a vertical wall resulting in reflective incident wave interaction. Such erosion at the toe can be controlled by use of a bottom filter blanket in front of the wall, or planned for by greater depth of pile embedment.

Permanence:

a. Structural life: (Rating: long) The piling's long life may be extended indefinitely by proper corrosion protection, if costs of protection are justified by the benefits. Major problem may be near bottom line if sand scour of the corrosion protection occurs.

b. Removal: (Rating: medium to high) Requires mobilization of crane with extractor. Can present considerable difficulty where anchor cable tensions are high. If reusable, net removal costs would be lower. Where extraction is difficult piling may be cut off in place at top of fill.

Costs: Moderate to high. Final net cost depends on probable reuse of sheet piling.

Remarks

a. Major causes of failure in anchored sheet-pile walls are anchorage failures due to excessive movement of anchor pile, increased downdrag on anchor cable due to settlement of fill (can be solved by placing cables in hollow conduits), and anchors not being far enough behind wall.

b. Construction usually requires mobilization of a floating plant including piledriver, pile barge, crane barge, etc. This requires an adequate operating water depth for equipment.

References

Bowles, J. E., Foundation Analysis and Design, McGraw-Hill, New York, 1968, Ch 8.

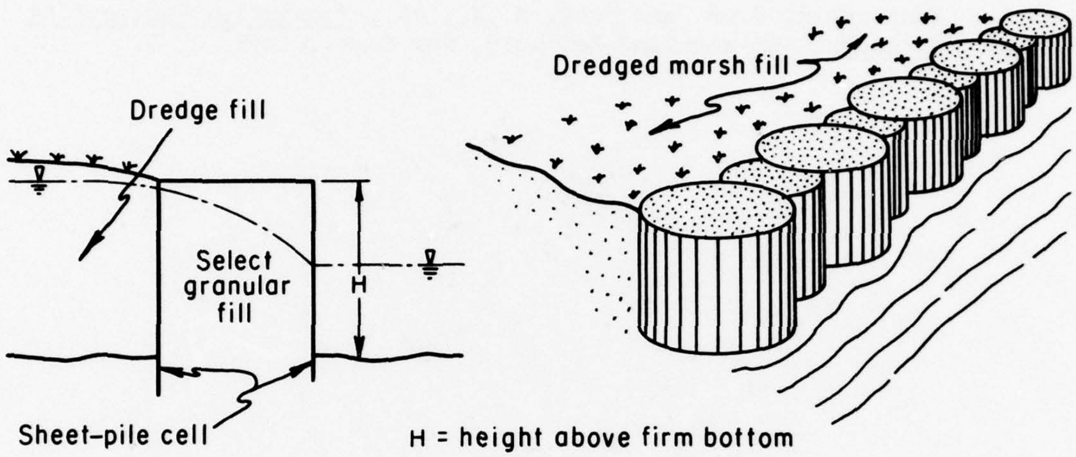
NAVFAC, "Soil Mechanics Foundation and Earth Structures," NAVDOCKS Design Manual DM7, U. S. Navy, 1971, Ch 10.

Teng, W. C., Foundation Design, Prentice Hall, Englewood Cliffs, N. J., 1962, Ch 12.

Winterkorn, J. F. and Fang, H. Y., ed., Foundation Engineering Handbook, Van Nostrand-Reinhold, New York., 1975, Ch 3.

Data Sheet 5

Cofferdam



Classification

Function: Retaining and protective.

Type: Flexible gravity structure, self supporting when filled with granular material.

Materials: Steel sheet-piling cell filled with granular materials (i.e., sand, gravel).

Size range: Heights up to 60 ft; however, generally limited to heights of 20 ft and greater due to cost.

Circular: Cell diameter is 1.25H; range of diameters 15 to 60 ft. Smaller diameters are possible with bent web sheets.

Diaphragm: Diaphragm cells have an average diameter of 0.75 times the cell height above the bottom.

Material retained: All sizes, total barrier.

Design factors

Expected structural settlement: Fill in cell will densify, especially if overtopped.

Tolerance to foundation settlement: Good.

Tidal effects: Minimal for free-draining cell fill.

Maximum range: All practical ranges; however, large tidal ranges will rapidly increase costs as higher cells must also increase in diameter.

Wave and current effects:

a. Erosion resistance: Good.

b. Toe scour susceptibility: High. If water depth is less than twice incident wave height, scour may be avoided by placing riprap apron in front of cells.

Permanence:

a. Structural life: (Rating: long) Life can be extended by proper corrosion protection. Corrosion most apparent in the intertidal and splash zone, and immediately above a sand bottom. The latter high corrosion zone is due to sand scour of steel corrosion products accelerating the corrosion rate.

b. Removal: (Rating: high) Removal of a cellular structure is accomplished by partially emptying the fill from the cell until ring tension is removed, and extracting the sheet piles. Requires crane with pile extractor. Extraction is more difficult for piling driven in a clay bottom, or where sheet piles are frequently bent or misaligned.

Costs: High.

Remarks

a. While coarse, clean, free-draining materials are preferred for cellular fills, silty sand or gravel may be used with proper precautions.

b. Major advantage is that cellular cofferdams can be founded on bare rock if necessary precautions are observed.

c. Cellular cofferdams are very expensive and require mobilization of a considerable construction plant. Would be used only in very unique circumstances.

References

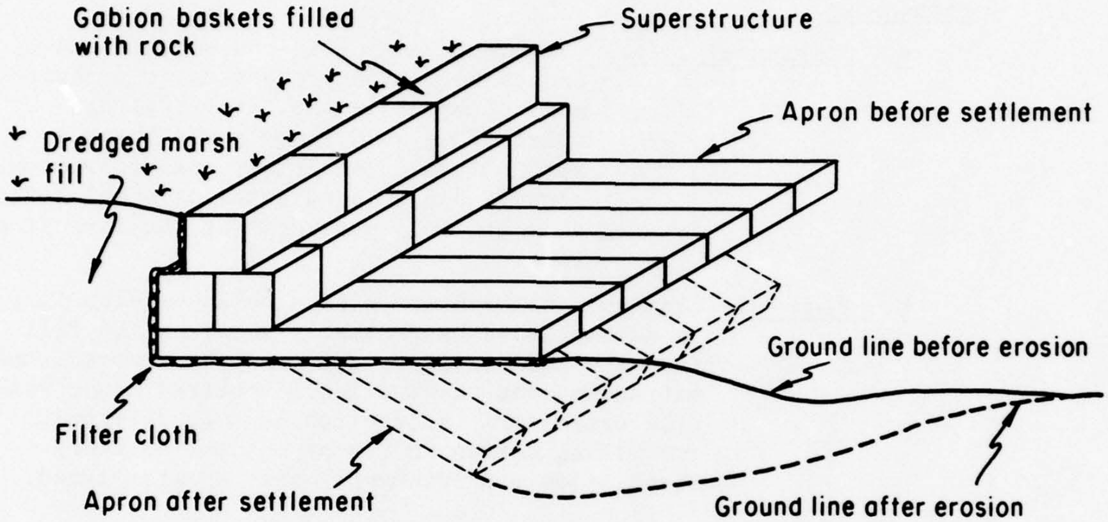
TVA, "Steel Sheet Piling Cellular Cofferdams on Rock," Tennessee Valley Authority Technical Monograph No. 75, Dec 1975.

Bowles, J. E., Foundation Analysis and Design, McGraw-Hill, New York, 1968, Ch 8.

Teng, W. C., Foundation Design, Prentice Hall, Englewood Cliffs, N. J., 1962, Ch 14.

Data Sheet 6

Gabions



Classification

Function: Retaining and protective.

Type: Flexible gravity structure, self-supporting.

Materials: Heavy galvanized wire basket (PVC-coated for seawater application) filled with small rock of 4- to 10-in. diameter. Baskets are stacked and wired together.

Size range: Heights up to approximately 10 ft, with multiple thicknesses of gabions and/or counterforting.

Material retained: All sizes, but may require filtering for fines.

Design factors

Structural settlement: Very little densification of rock within baskets. Baskets will tend to squash down and bulge out if internal tie wires are not correctly placed.

Foundation settlement: Due to the gabion's weight, approximately $125^{16}/ft^3$ (2000 kg/m^3), there will frequently be some settlement associated with their installation. However, being very flexible, settlement will not be serious unless wall crest drops too low for intended use. Gabions are very tolerant of foundation settlement.

Tidal effects: The impact of tidal range is dependent on the permeability of the gabion's rockfill and of the retained dredged material. If the permeability of either is low, the elevation of the water table in the retained subgrade should be the design high tide elevation. Also, seepage forces should be based on maximum tidal range.

Wave and current effects:

a. Erosion resistance: Care should be taken to ensure that dredge fines are not lost by piping through the gabion. This can be done easily when multiple layers of gabions are used. The backup layer may be filled as a filter, and if necessary backed with filter cloth.

b. Toe scour susceptibility: Tests by WES indicate that gabion walls placed on an erodible substrate and not protected by any toe protection are very susceptible to toe scour. Uncorrected scouring will lead to collapse of the gabion wall into the scour hole. The proper placement of a flexible gabion apron will lead to a sealing off of most undermining action, as the apron folds down into the hole until scouring is halted. The apron should extend in front of the structure at least one and one half times the predicted scour depth.

Permanence:

a. Structural life: (Rating: moderate) Long experience in freshwater applications indicates gabions have life expectancies in excess of 20 years. While the permanence of sea-type gabions is less well established it should be in excess of the 2 years required for temporary stabilization of dredged material.

b. Removal: (Rating: low) Reducing wall height is simple, just cut wires of gabions and dump the rock. Gabions not removed will tend to become vegetated, water depths permitting, and need not be removed for aesthetics.

Costs: Moderate; approximately $65.00/cy of wall, depending on rock costs.

ks

a. Major advantages exist for this type of structure where small rock is readily available, and can be cheaply delivered to the work site.

b. Assembly and filling of gabion baskets requires care and some experience. Internal ties are critical to basket retaining its shape, and to the overall stability of a gabion wall.

c. Permeability of gabions can be helpful in more rapid consolidation of dredge fills.

d. Gabions may be used as a revetment on a sand dike. A filter layer of filter cloth or graded aggregate is needed to prevent erosion.

e. There was little actual experience with sea gabions in saltwater available. However, what experience is available indicates there may be a corrosion problem in the saltwater environment which severely limits the useful life of a gabion wall.

References

Brater, E. F., et al., "The Michigan Demonstration Erosion Control Program in 1976," Technical Report No. 55, University of Michigan, Sea Grant Program, Feb 1977.

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McCartney, B. L., "Survey of Coastal Revetment Types," MR 76-7, U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., [illegible] 1976.

Terra Aqua Conservation, "Bekaert Gabions Technical Handbook," Bekaert Steel Wire Corp., Nov [illegible]

Remarks

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b. Assembly and filling of gabion baskets requires care and some experience. Internal ties are critical to basket retaining its shape, and to the overall stability of a gabion wall.

c. Permeability of gabions can be helpful in more rapid consolidation of dredge fills.

d. Gabions may be used as a revetment on a sand dike. A filter layer of filter cloth or graded aggregate is needed to prevent erosion.

e. There was little actual experience with sea gabions in saltwater available. However, what experience is available indicates there may be a corrosion problem in the saltwater environment which severely limits the useful life of a gabion wall.

References

Brater, E. F., et al., "The Michigan Demonstration Erosion Control Program in 1976," Technical Report No. 55, University of Michigan, Sea Grant Program, Feb 1977.

Maccaferri, "Gabions Technical Handbook," Maccaferri Gabions of America, Inc., N. Y.

McCartney, B. L., "Survey of Coastal Revetment Types," MR 76-7, U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., May 1976.

Terra Aqua Conservation, "Bekaert Gabions Technical Handbook," Bekaert Steel Wire Corp., Nov 1977.

Data Sheet 7

Fabric Bags

Classification

Function: Retaining and protective.

Type: Flexible gravity structure composed of discrete, sand-filled fabric bags.

Materials: Synthetic fabric (generally nylon) bags employed as flexible forms for a variety of fill materials: sand, sand-cement, concrete. The bags are laid in place, then filled with the slurry. If filled with sand-cement or concrete the fill is cured in place.

Size range: Unit size is variable. Since larger units are filled in place, they present little difficulty in handling. While the structure height could be extended as high as desired, most free-standing installations to date have been of 16 ft or less.

Material retained: To retain fines typical of dredged material, a filter cloth or stone filter layer should be placed behind the fabric bag structure.

Design factors

Foundation conditions: As is typical of all gravity structures, some foundation settlement will occur when the weight of the stacked fabric bags exceeds the bearing capacity of the soils on which they are placed. However, the flexibility of this structure can adjust for some differential settlement.

Tolerance to foundation settlement: Good.

Expected structural settlement: Since the bags are filled with sand, sand-cement, or concrete, almost no settlement of structure is expected.

Tidal effects: Minimal.

Maximum range: All practical ranges; however, the larger ranges will expose more of structure's fabric bags to sun's ultraviolet radiation.

Wave and current effects:

a. Structural movement: Fabric bags move under medium to large wave forces, see Ray 1977, for more specific details.

b. Erosion resistance: Good.

c. Toe scour susceptibility: Most vendors recommend articulated mattress at the toe, which will bend down into a scour hole and shut off scour before it endangers the structure.

Permanence:

a. Structural life: (Rating: long--concrete filled; moderate --sand-cement filled; short--sand only filled.) This factor is very dependent on the kind of fill placed in fabric bags. As noted in the permanence rating, bags filled with good concrete have a long life and should be considered as permanent structures of manmade rock. The sandfill is held together only by the bag so the life of a sand-filled fabric bag structure is 3 to 5 years depending mostly on the weathering and UV resistance characteristics of the fabric. Sand-cement falls in between these and depends on the quantity of cement used. This flexibility of fill permits the designer to plan for "natural" removal of a part of the dyke in areas and to depths where free communication of marsh with open water is desired.

b. Removal: A major asset of sand-filled fabric bags is their potential for easy removal when desired.

Costs: Low.

Remarks

a. Developed in the early 1960's, the fabric bags have received increased utilization, and are characterized by low labor and equipment requirements. Fabric bags are particularly well suited to underwater placement, since 6 to 12 in. of water protects them from the sun's ultraviolet rays, a major deteriorating factor.

b. Fabric bags offer benefits in the construction of temporary structures for dredged material containment. Fabric bags present the problem of frequent premature destruction due to snagging by floating debris or slashing by vandals in accessible areas. Life expectancies given above are based on "undisturbed" situations.

c. In special cases where current flow in one direction is the predominant cause of erosion (i.e., in rivers or estuaries), a partial enclosed dike (e.g., a groin) may be used to deflect currents.

References

Berg, D. W. and Watts, G. M., "Variations in Groin Design," Journal, Waterways and Harbors Division, American Society of Civil Engineers, WW2, 1967.

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Brater, E. F., et al., "The Michigan Demonstration Erosion Control Program in 1976," Technical Report No. 55, Feb 1977.

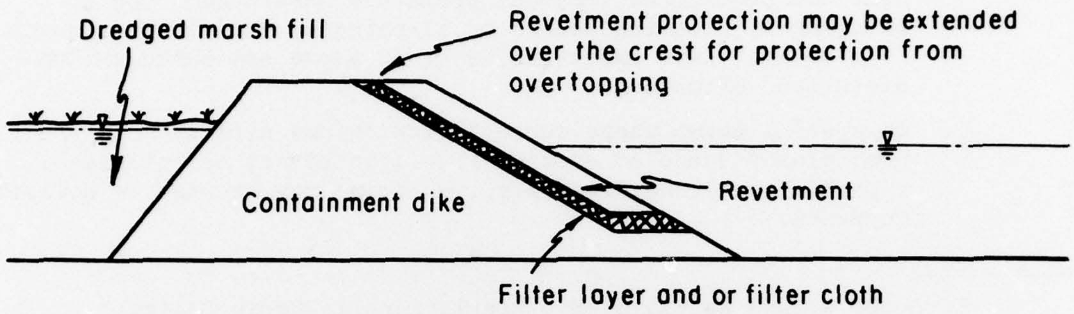
State of California, "Bank and Shore Protection in California Highway Practice," State of California, Department of Public Works, Division of Highways, Nov 1960.

McCartney, B. L., "Survey of Coastal Revetment Types," MR 76-7, U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., May 1976.

Ray, R. L., "A Laboratory Study of the Stability of Sand-Filled Nylon Bag Breakwater Structures," MR 77-4, U. S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., Mar 1977.

Data Sheet 8

Revetments



Classification

Function: Protective and nonretaining.

Type: Revetment protection for a containment dike.

Materials: Stone is preferred because its size variability allows its use over a wide range of wave conditions. However, if stone is not readily available and the breaking waves are predicted to be less than 3 ft (0.9 m), cinder blocks or sand-cement bags could be substituted for stone.

Size range: The area of the dike requiring protection depends upon the design wave height and runup characteristics of the dike slope and the protective material used. Usually, the revetment is carried to the top of the dike to prevent damage from overtopping of the revetment.

Material retained: Revetments alone are not designed to retain dredged material.

Material protected: Revetments can protect coarse sand, clays, or silts if an adequate filler layer is designed.

Design factors

Tolerance to settlement: Revetments employing stone as a protective layer can withstand considerable settlement as long as the filter layers remain continuous and are not exposed to wave action. Revetments employing cinder blocks and sand-cement bags do not tolerate differential settlement very well.

Tidal effects: Tidal ranges vary with structure location and are a design variable that must be considered. Revetments designed with adequate filters (which allows free drainage of water) are not affected by tidal action or currents. However, tidal currents can cause scouring at the toe of a revetment resulting in damage to the revetment. Increased stillwater levels up to high tides can allow larger than normal wave action to occur, and require an increase in structure height to keep the revetment from being overtopped.

Wave and current effects:

a. Maximum wave height: Revetments using stone can be designed to withstand wave impact for any size wave by varying the stone size used (see Hudson, 1974). Cinder blocks and sand-cement bags can be used for breaking wave heights less than 3 ft (0.90 m) (see Giles, 1977).

b. Wave runup: The maximum extent of wave runup on a structure determines the height to which a structure should be built. The extent of runup is a function of wave height, structure slope, wave period, and roughness (see Hudson, 1974). The design runup distance for stone is 80%, blocks 100%, and bags 95% of that for a smooth slope.

c. Erosion resistance: Good. Revetments prevent erosion of the dike material as long as an adequate filter is used to prevent the dike material from being pulled through the armor layers. Once this occurs a void is left behind the filter which leads to a loss of support for the revetment, its collapse and progressive failure.

d. Toe scour susceptibility: Toe scour could be high if the water depth is less than the maximum wave height. In such cases the toe should be extended beyond the extent of scour expected.

Permanence:

a. Structural life: (Rating: long) The life of the structure can be extended indefinitely by selecting the proper protective layer using the wave height criteria found in SPM, 1977, and designing the structure for non-overtopping.

b. Removal: (Rating: moderate) The protective layer can be removed with a crane using techniques similar to those used for placement of the stone, blocks, or bags. In addition, if stone is used as a protective layer, a dragline on a barge can pull the stone down to form a submerged rock toe.

Costs: Low to high. Costs for individual blocks and bags are relatively low but placement costs can be high. Stone is usually low in cost if available at or near the site selected. The cost of placement of the stone is low if it can be dumped from land but high if it has to be placed piece-by-piece using floating equipment, i.e., crane and barges.

Remarks

a. This structure is best used in conjunction with other non-overtopped structures such as dikes. For the structure to be effective both a good toe design and filter design must be incorporated.

b. Construction of a rock revetment requires that a crane have access to the slope for placing the stones. Thus, if the structure is completely in water, depths of 2 to 4 ft must be present to allow placement from a barge. In addition, an available supply of stone relatively close to the site must be present or costs will be high due to transportation charges.

c. The quality of stone should be such that the stone will not deteriorate with time; however, it does not have to be the highest quality available. Durability under wet-dry cycles is particularly important to long-term stability. This type of revetment is the easiest to design and the most frequently used.

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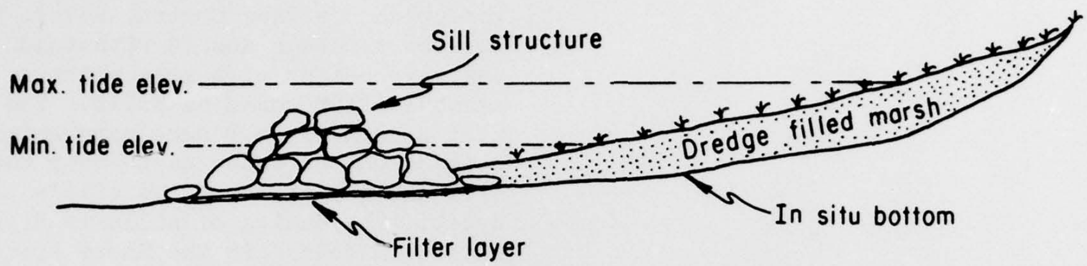
Data Sheet 9

Offshore Sill



Classification

Function: Protective and nonretaining.

Type: Offshore sill.

Materials: The sill can be constructed from dumped sand covered with stone, dump stone, or gabions. A sill constructed using filled in-place sandbags is probably the simplest to construct.

Size range: The sill is usually low in height with the crest at about low mean water. The width of the crest is 3 to 4 ft, which allows the wave to break on the sill and not on the dredged material behind it.

Material retained: Some sandy material could be retained because the sill would act like a toe for the dredged material. Suspended fines, however, will be flushed out with the backwash, over the sill.

Material protected: The sill will reduce the incident wave height by initiating wave breaking. However, there will still be some wave action on the dredged material so that only coarse to fine sands will remain on the exposed slope.

Design factors

Tolerance to foundation settlement: Sills can withstand considerable settlement and still remain useful. However, to prevent excessive settlement a good filter layer and toe protection design should be used.

Tidal effects: The purpose of the sill is to reduce the amount of wave energy reaching the marsh by causing the waves to break before reaching the marsh. Thus, a sill should be located in an area where the tidal fluctuation is 2 ft or less.

Wave and current effects:

a. Maximum wave height: The maximum wave height the structure can withstand is determined by the maximum size unit used to build the structure (see Hudson, 1974). Two-ton sandbags should withstand any wave height at a site where a marsh habitat would be built. The sill's ability to reduce wave heights depends on the water depth over the sill and the width of the sill's crest. The design of sills is discussed in detail in the Shore Protection Manual (SPM, 1977).

b. Erosion resistance: Medium. A well-designed sill will reduce the erosion rate of material stored behind it by causing incident waves to break on or immediately behind the sill. The area immediately behind the sill, therefore, may be subjected to erosion.

c. Toe scour susceptibility: High. Adequate toe protection must be included to prevent toe scour from undermining the sill.

Permanence:

a. Structural life: (Rating: long) The structure's life can be extended indefinitely by selecting the proper protective layer based on the above wave height criteria and designing an adequate toe protection or the structure life can be short by selecting a material which will degrade with time.

b. Removal: (Rating: moderate) The structure would have to be removed by clamshell and dredge, requiring the remobilization of a floating plant. However, once in place the structure would not normally have to be removed, if the marsh is permanent.

Costs: Low to medium. Structure costs are lower than breakwaters because of the lesser amount of material required. Bags are relatively cheap but placement costs can be high depending on site conditions. If stone is used it should be dumped so placement costs are lower than for individual placements. However, a floating plant is required to load, transport, and dump the stone into position. Costs for assembling and operating a floating plant are very site-specific.

Remarks

<u>a</u>. The purpose of the sill is to cause the wave to break on the sill instead of on the marsh slope.

<u>b</u>. An adequate toe and filter made from rock or filter cloth is required to prevent the substrate from eroding and causing the sill to fail.

<u>c</u>. Sills composed of sandbags are subject to vandalism and being cut by driftwood, or other debris. Those composed of gabions are subject to corrosion.

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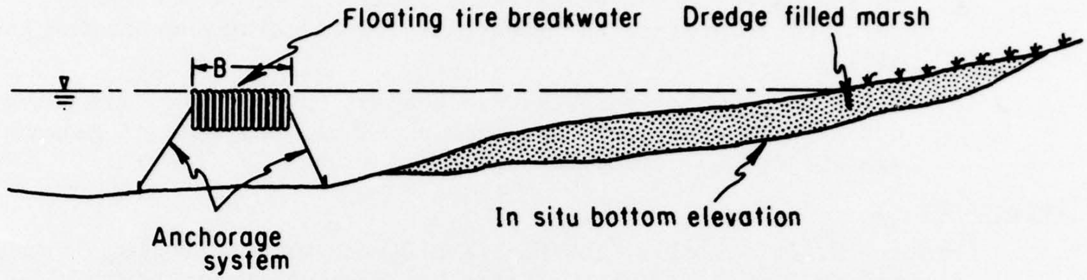
Data Sheet 10

Floating Breakwater



Classification

Function: Protective and nonretaining.

Type: Floating breakwater.

Materials: Tires.

Size range: The design width of the breakwater is a function of the length of the incident wave to be guarded against, and the desired degree of wave attenuation (see Giles and Sorensen, 1978).

Material retained: None.

Material protected: Sands. The material has to be relatively stable under some wave action because the breakwater will not eliminate all the incident waves, especially the long wavelengths.

Design factors

Tolerance to foundation settlement: Good. The breakwater design does not depend on bottom conditions except as the bottom affects anchor embedment.

Tidal effects: Mooring lines should have enough extra line to prevent the breakwater from being submerged at high tide. Also, the anchor line should have sufficient slack to maintain the proper cantenary consistent with the type of anchor used.

Effective wave height: Since the breakwater must be about twice the design wavelength to obtain 50% wave attenuation, the breakwater is most useful and economical in areas where the predominant wavelength is relatively short.

Anchors: The breakwater anchor will depend on the bottom conditions and the pulling stresses. The type of anchor used could vary from front to back (see NAVFAC DM-26 for anchor design information).

Permanence:

a. Structural life: (Rating: medium) Tires provide an ideal surface climate for plant growth and, thus, require removal at least once a year or the breakwater may sink from the additional weight of the growth. The tires will last indefinitely but any connecting line will have a life of 2 to 10 years depending on the type of line used and the environment the breakwater is placed in.

b. Removal: (Rating: low) The breakwater can be easily towed from one site to another. Removal of anchorage system may be more difficult but generally it could be abandoned.

Costs: Low. Tires are usually available at very small or no cost. However, the labor of assembling a structure can be high and the anchorage system required may be expensive to install.

Remarks

a. Floating tire breakwaters are more effective in low wave climates with short wavelengths. For effective wave attenuation the breakwater should be as wide (B in figure) as twice the wavelength. Also, the aquatic growth on the breakwater should be removed once a year.

b. Two basic tire configurations are possible: the Goodyear module design (see Candle and Fischer, 1977) which uses 18 tires to form a module 6.5 ft × 7 ft × 2.5 ft, or the "Wave-Maze" which is patented with Morgan Noble of Dames & Moore. (see Noble, 1969).

c. The most useful application of floating breakwaters would be to reduce the wave heights at a site until the marsh has a chance to become established.

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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.

Eckert, James W

Design concepts for in-water containment structures for marsh habitat development / by James W. Eckert, Michael L. Giles, Gerald M. Smith, U. S. Army Coastal Engineering Research Center, Fort Belvoir, Va. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

34, 3, 32 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-31)

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