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Engineering Evaluation of the Current Deflector Wall for Navigation Channel Maintenance

by Michael P. Alexander

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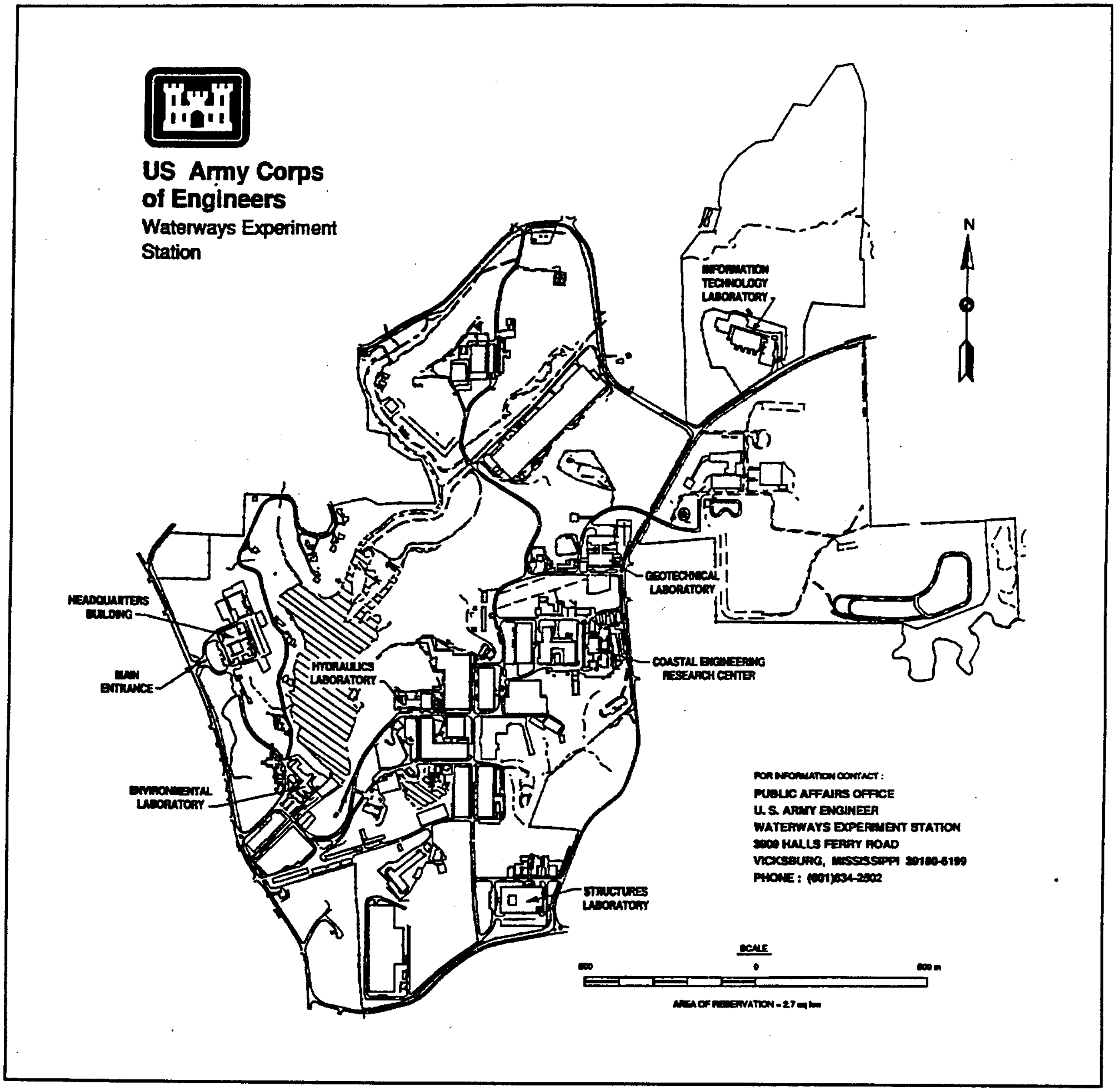

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Preface

The study described in this report was sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). This study was a research effort under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program for which Mr. Michael P. Alexander, Sedimentation, Engineering, and Dredging Group, Waterways and Estuaries Division, Hydraulics Laboratory (HL), U.S. Army Engineer Waterways Experiment Station (WES), was the Principal Investigator.

This report was prepared by Mr. Alexander, under the general supervision of Dr. T. M. Parchure, leader of the Sedimentation Engineering and Dredging Group; Mr. William H. McAnally, Chief, Waterways and Estuaries Division; Mr. Robert F. Athow, Acting Assistant Director, HL; and Mr. Richard A. Sager, Acting Director, HL.

During the publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

1 Introduction

Background

Channel maintenance dredging and dredged material disposal comprise the bulk of maintenance costs for many navigation projects. Channel sedimentation volumes that result in a need for dredging can be controlled to a degree and reduced using flow training structures; therefore, many projects that require regular maintenance dredging have a long history of training structure design and implementation. Flow training structures can provide long-term cost savings by reducing sedimentation that would otherwise need to be actively removed by dredging. In addition to cost savings, structurally-induced maintenance does not have the negative environmental aspects sometimes associated with dredging. The advantages associated with structurally-induced channel maintenance prompted recent research that led to the development and design of a new type of training structure, the current deflector wall (CDW).

Flow training structures in waterways can generally be classified as bank stabilization structures, channel stabilization structures, and channel depth maintenance structures. The CDW is a flow training structure designed to assist with project depth maintenance. The more common lateral dike training structures have long been designed and applied to channel maintenance. Lateral dikes can be designed to constrict flow through a channel reach to increase sediment-carrying flow velocities in the channel. In contrast, the CDW was designed to eliminate the channel shoaling associated with the formation of large-scale eddies. The CDW concept originated from a study of shoaling mitigation methods for the Port of Hamburg, Germany (Christiansen and Kirby 1991). The CDW was one of several sedimentation reduction measures considered, and the CDW prototype became the showcase shoaling reduction alternative for the Port.

Purpose

The purpose of this report is to describe and explain eddy-generated shoaling patterns, their significance to channel maintenance, and to provide an engineering evaluation of a new type of training structure, the CDW, designed to eliminate eddy-generated shoaling. The CDW evaluation contained in this report is based on the prototype design and application in the Port of Hamburg, Germany.

Scope

This report is divided into six chapters. Chapter 2 describes the flow patterns associated with eddy currents that can cause shoaling and other problems in navigation channels. Chapter 3 describes the CDW theory of operation and design, and Chapter 4 describes the prototype CDW installation and performance. Chapter 5 outlines a preliminary site evaluation procedure for potential CDW applications. Conclusions are presented in Chapter 6.

2 Eddy-Generated Navigation Problems

Eddy Current Description

An eddy current can be defined as a rotational flow field about a vertical axis (Figure 1) with secondary currents directed inward from the bottom of the eddy toward its axis. The highest current velocities within the eddy are associated with the rotating flow. The inward-flowing secondary currents are strongest near the bottom. These secondary currents enter the rotating flow field near the bottom and turn about the axis as they flow vertically upward. The velocity of the secondary currents diminishes as they rise. A quiescent region is formed underneath the eddy where no significant current activity exists. Figure 1 shows the directions and relative velocity distributions throughout an eddy.

Eddies tend to form in waterways where bottom depth gradients, flow velocity gradients, or a combination of flow and velocity gradients occur. Eddies can occur naturally or be influenced by channelization and structural modifications to waterways. Channel branches along a larger, or main waterway often develop eddies because of the confluence of depth and velocity gradients at the bifurcation (Figure 2). Harbor entrances and berthing slips along a waterway are other forms of channel branches conducive to eddy formations.

Eddy-Generated Shoaling

The significance of the eddy to channel depth maintenance depends on its size, location, and area sediment transport patterns. Where sediment migration along the bottom of a channel encounters the secondary near-bottom currents of an eddy, shoal material that may otherwise pass through the area can be drawn in toward the eddy axis. As the secondary current captures sediment and turns upward about the eddy axis, its diminishing velocity allows sediment particles to settle out into the quiescent zone underneath. A mound of material is eventually formed (Figure 3). If the eddy diameter extends across a channel, for instance, a significant shoal can develop. Navigation

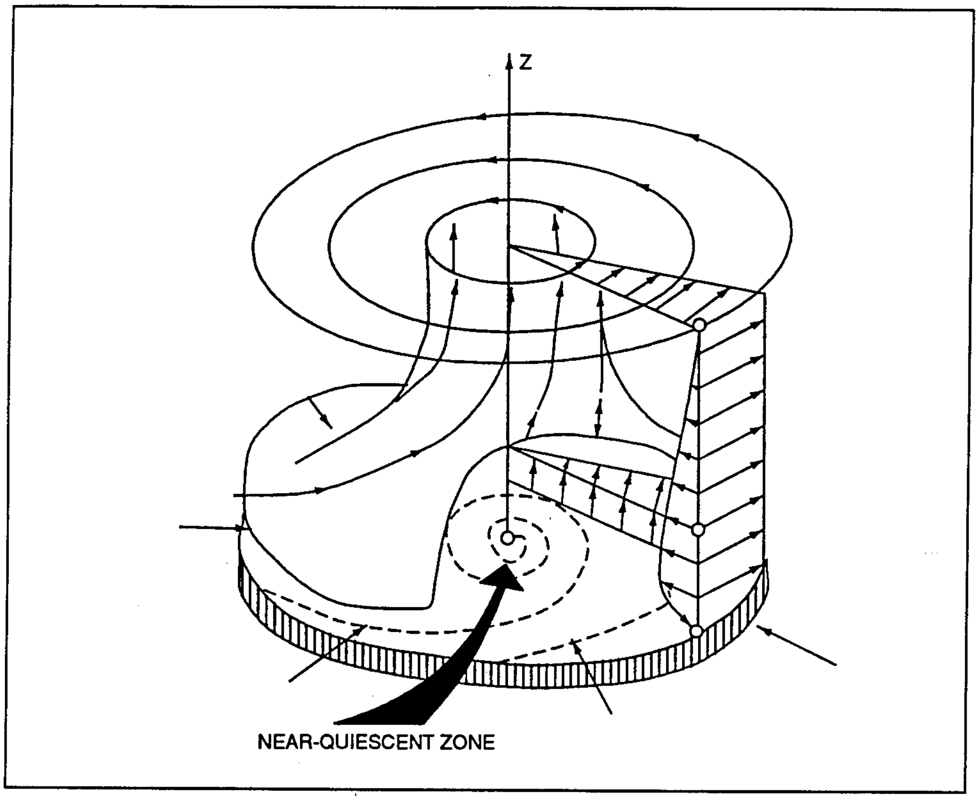

Figure 1. Eddy current patterns and relative velocity distributions

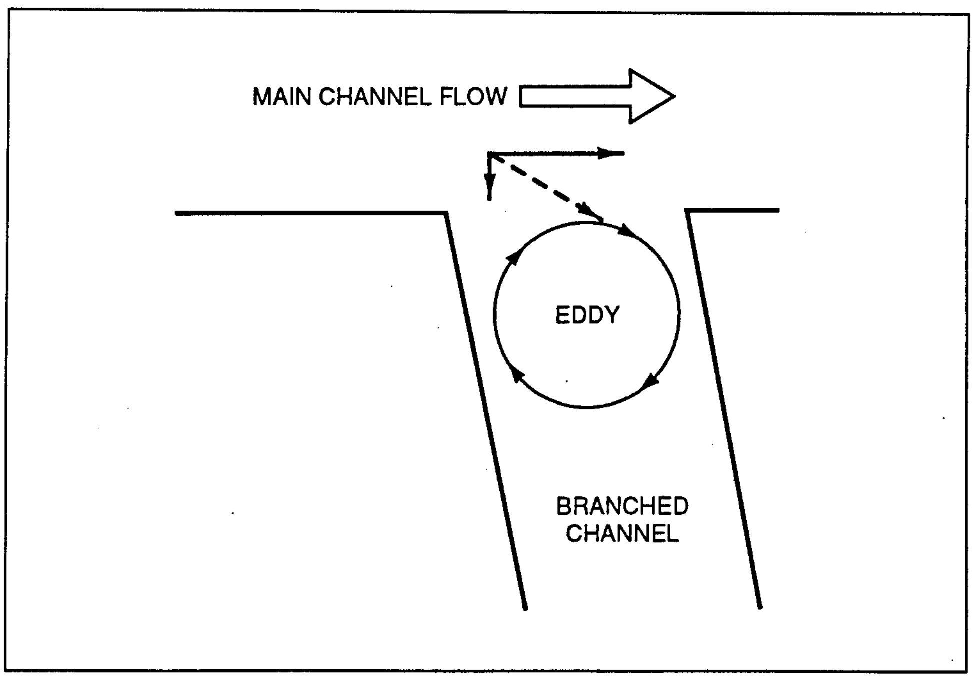

Figure 2. Flow component generating eddy at a channel bifurcation

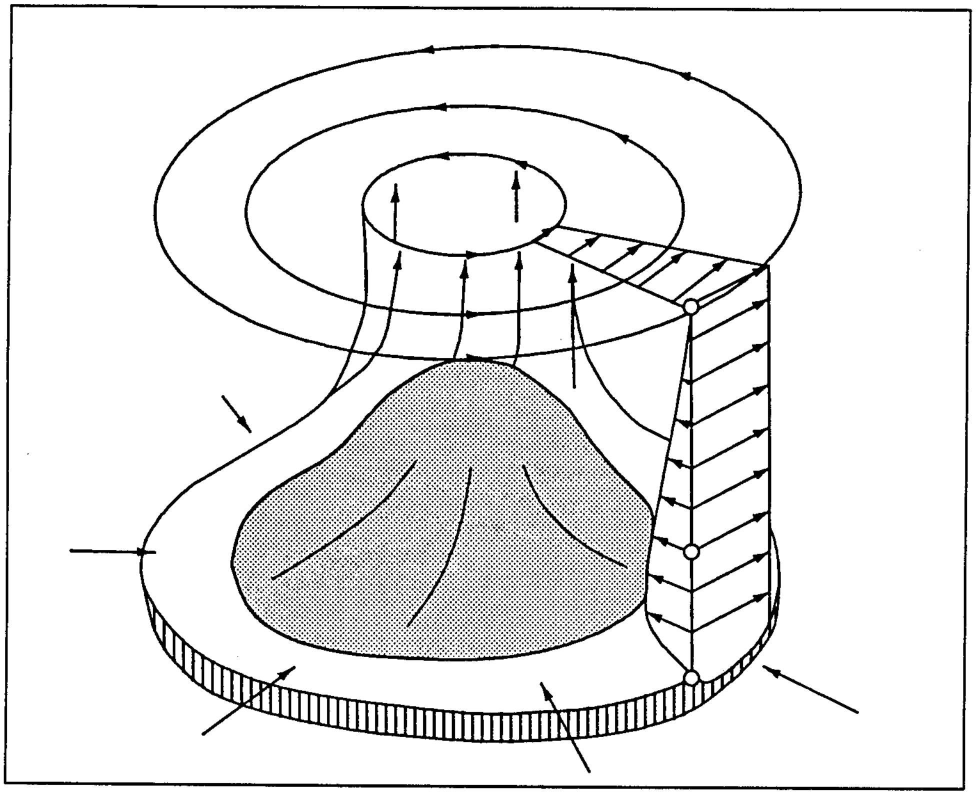

Figure 3. Eddy-generated sediment buildup

depth over the eddy-generated shoal can be much less than in the surrounding channel.

In areas of regular or frequent water level change, eddy formation in a branched channel entrance can compound sedimentation problems behind the eddy and farther along the branched channel. The magnitude of flow velocities entering the branched channel due to rising main channel water levels is a function (in part) of the cross-sectional area at the branch. The presence of an eddy blocks a portion of the available cross-sectional area, essentially constricting incoming flow. This results in higher velocities adjacent to the eddy. These higher velocities promote water and sediment mixing that can extend shoaling behind the eddy and farther along the branched channel. Figure 4 depicts this situation.

Branched Channel Navigation

Another concern stemming from eddy formations in channel branches involves the current forces, or cross-currents, that vessels must negotiate. Eddy current directions are perpendicular to the direction of the branched channel. This can impart a turning motion to the vessel and make navigation more difficult. Such difficulty with navigation can also affect insurance costs and liability for vessels using the channel.

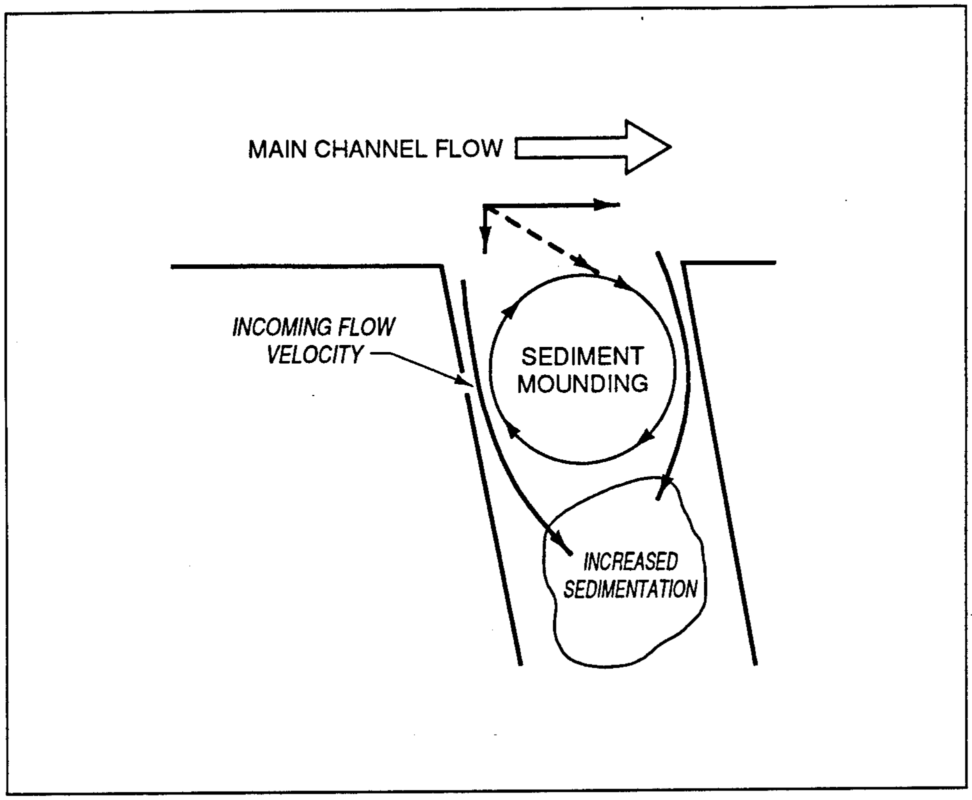

Figure 4. Increased sedimentation along branched channel

3 CDW Application and Theory of Operation

Structural Description and Application

The CDW (Figure 5) is a fixed vertical wall training structure that provides a smooth flow transition across the branched channel entrance. It is designed

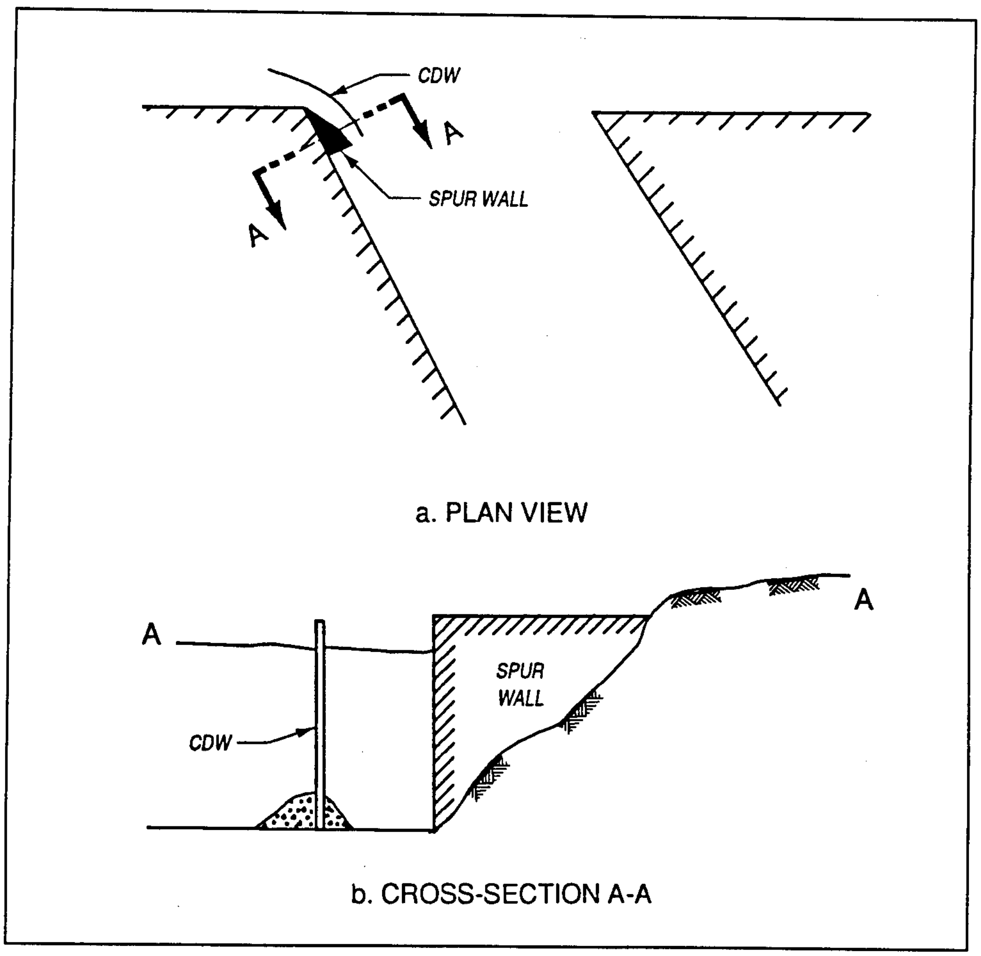

Figure 5. Plan and cross-sectional CDW schematics

to function at the upstream corner of a branched channel. The deflector wall is curved and extends through the full depth of water. A rounded vertical-walled addition to the existing upstream entrance corner will usually be required to compliment the CDW. This spur wall is considered a part of the overall CDW structure. The CDW captures approaching flow and re-routes it parallel with the branched channel direction (Figure 6) (Ravensrodd Consultants 1992). It is also conceivable to construct a CDW at both sides of a branched channel entrance where bi-directional tidal flows in the main channel develop eddy problems.

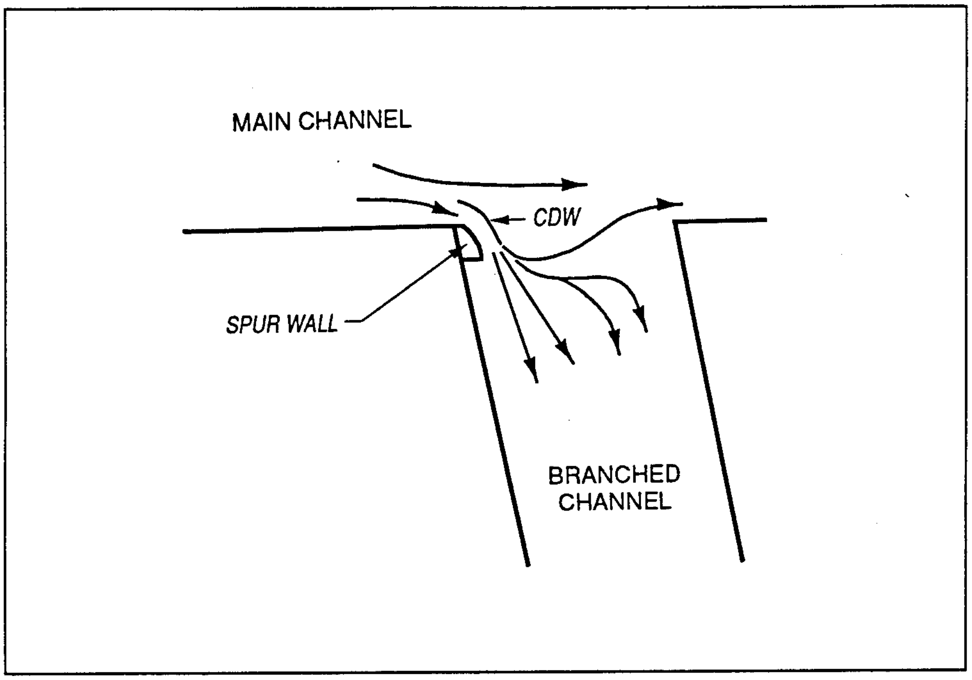

Figure 6. CDW principle of operation

Operating Concept

An early concept of the CDW operating principle was that the structure would capture an equal and opposite flow to cancel that of the eddy rotation. Continued study and prototype evaluation led to the understanding that the CDW simply aligns the flow vectors entering the basin with the basin walls and thus removes the eddy-generating force. Vortex currents can be prevented at a channel branch if a smooth transition is provided for the incoming flow velocity vectors (Ravensrodd Consultants 1992). This is the function of the CDW: to create a smooth transition that eliminates most of eddy-generating velocity gradients.

The CDW was designed to extend maintenance dredging intervals, resulting in more efficient project management. It does not eliminate sediment transport across a channel branch, but prevention of the eddy with its associated sediment mounding mechanism can result in a diminished and more uniform overall shoaling rate.

Patent Information

The CDW design is protected under United States Patent Number 4,884,917 (dated 5 December 1989) through Ravensrodd Consultants[1]. This report serves to describe a successful application of the CDW without any commercial endorsement. The decision to follow the preliminary CDW site evaluation (Chapter 5) and to pursue construction of a CDW with Ravensrodd Consultants is left to the sole discretion of project sponsors.

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[1] Ravensrodd Consultants, Limited, 6 Queens Drive, Taunton, Somerset, TA1 4XW, United Kingdom.

4 Prototype Evaluation

Eddy-Generated Shoaling in the Port of Hamburg

The Port of Hamburg is located along the Elbe River about 100 kilometers (62 miles) from the North Sea. The port water is fresh with a mean tidal range of 3.5 meters (11.5 ft) (Figure 7). The Port area is close to the nodal point of the estuarine system where riverine sediments approach from the east and ocean sediments approach from the west. The fine sediment deposition rate is high, and the mean annual dredging is roughly 1.8 million cubic meters (2.35 million cubic yards) per year. The material is also contaminated and must be deposited in a restricted, land disposal site in the state of Hamburg. Since the material is contaminated and is such a large annual quantity, excessive dredging and disposal costs have long been a problem for the Port. High maintenance costs at the Port prompted research to identify shoaling reduction measures (Christiansen and Kirby 1991).

Kohlfleet Harbor

Kohlfleet is one of several major harbors in the Port of Hamburg. Extensive sedimentation and processes studies through the early 1980's identified a large, clockwise rotating eddy in the entrance to Kohlfleet Harbor. The studies revealed that 85 percent of the shoaling in Kohlfleet Harbor was focussed in the entrance channel as a result of the eddy current. A scaled hydraulic model of the harbor was constructed at the Franzius Hydraulics Institute in Hannover, Germany, to evaluate modifications to reduce sedimentation. Of the possibilities studied, the CDW proved to be the most effective approach for reducing the eddy-generated shoaling. Physical model studies determined that a CDW could reduce Kohlfleet Harbor entrance channel shoaling by 30-50 percent.

Prototype CDW

Based on the model studies, a prototype CDW was constructed at the Kohlfleet Harbor during August-November, 1990. Figure 8 shows an aerial

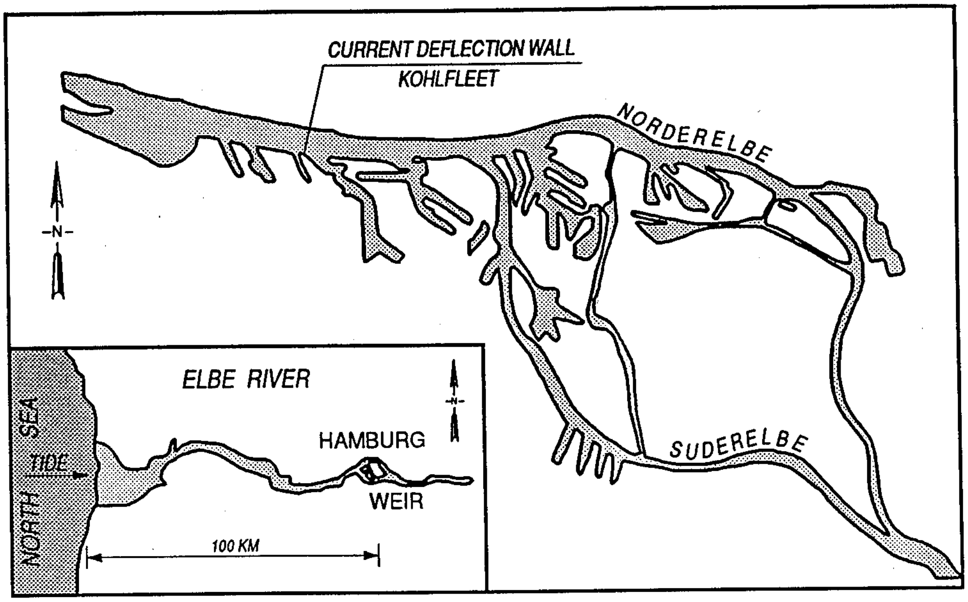

Figure 7. Port of Hamburg area showing Kohlfleet Harbor and CDW location (Christiansen and Kirby 1991)

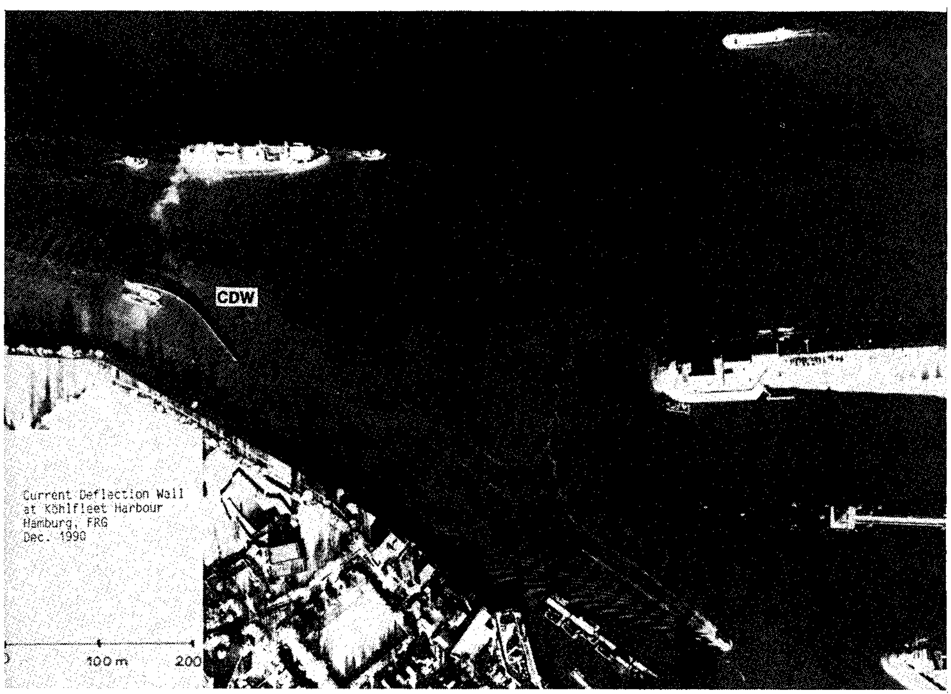

Figure 8. Aerial view of CDW prototype in Kohlfleet Harbor, Port of Hamburg, Germany (courtesy of Dr. Robert Kirby, Ravensrodd Consultants, Ltd.)

photograph of the CDW. The structure is 150 meters (492 ft) long. Pilings 27 meters (89 ft) long were driven 10 meters (33 ft) into the harbor bottom to provide the foundation for the structure. Flanged steel uprights and sliding pre-fabricated wooden panel sections constitute the wall itself, which extends 1 meter (3.3 ft) above mean high tide. Kohlfleet harbor sidewalls were vertical along the entrance channel, and this pre-existing condition simplified the prototype CDW spur wall design and construction. (Spur wall construction at other, more naturally-contoured entrance channel embankments such as shown in Figure 5 would require more effort.) The prototype CDW was constructed with a 2-year design life so that the operating principle could be demonstrated and verified before a permanent structure was built.

Prototype Evaluation

Current pattern studies were repeated at the Kohlfleet harbor entrance immediately following CDW construction. The same type of field exercise that identified the eddy was repeated to evaluate the CDW's success at eliminating the eddy. The exercise involved releasing radar reflectors attached to variable depth drogues. This procedure outlined in plan view the surface and mid-depth current patterns. Post-construction reflectors were released in the Elbe River (main channel), along the Kohlfleet Harbor channel (branched channel), and across the harbor entrance. This evaluation showed that the CDW had successfully eliminated formation of the large, stable eddy in the harbor entrance. CDW construction also resulted in improved navigation through the harbor entrance by reducing cross-currents. This over-compensated for the marginal CDW entrance obstruction and slight width reduction. Project evaluation then focussed on the anticipated shoaling reduction.

Long-Term Shoaling Rates

Careful attention was applied to shoaling rate calculations since CDW construction in 1990. The Port of Hamburg has experienced much greater than average shoaling in recent years. This increased shoaling has been a result of unusually low discharges along the Elbe River since 1990, which allows the fine sediment circulation nodal point to migrate into the Hamburg area. Extensive survey data were available, and Kohlfleet Entrance sedimentation was related to Elbe River discharge using pre-CDW hydrographic survey data from 1982-1989 and post-CDW installation survey data from 1990-1993 (Kirby 1994). These data are shown in Table 1, quantifying CDW effectiveness at Kohlfleet. When the entire Kohlfleet Harbor is considered, the overall benefit of the CDW is an approximate 33 percent reduction by volume of maintenance material (Kirby 1994). The inverse relationship between river discharge and sedimentation rates at Kohlfleet make the CDW benefit more significant at lower river flows.

Table 1 Kohlfleet Harbor Entrance Sedimentation Rates			
Mean River Discharge m^3/sec	Sedimentation Rate cm/yr Before CDW Installation	Sedimentation Rate cm/yr After CDW Installation	Percent Reduction
600	115	67	43
550	127	75	41
500	143	83	42
450	169	97	43
400	190	118	38
350	260	160	39

Example CDW Engineering Economy

The CDW design and construction for the Kohlfleet cost approximately $1.65 million. However, the cost of dredging the contaminated sediments at Hamburg is high, and costs to dredge and dispose the sedimentation prevented by the CDW would have likely approached $ 8 million within the first two years of CDW operation. Other locations will likely require longer intervals before a positive return is realized. For example, assuming the Kohlfleet Harbor material encountered was non-contaminated and could be dredged and disposed at a price of $3 per cubic yard, it would take longer to realize a net benefit. The following sample engineering economic analysis is based on an estimated cost of $3 per cubic yard to dredge and dispose a typical low Elbe river flow sedimentation volume of 150,000 cubic meters (196,000 cubic yards) per year of material that would deposit without the CDW in place. Dredging costs per unit volume vary significantly among US maintenance projects, but this sample analysis indicates that the CDW can result in a positive economic return within a few years. Long-term savings could be substantial.

Design and Construction of prototype CDW	$1,650,000
Annual cost for removing the additional volume of material in the absence of the CDW ($3/$yd^3$ X 196,000 yd^3)	$ 588,000
Equivalent Uniform Annual Cost of CDW using a selected 6% interest rate and a 5 year design life (Lindeburg 1989)	$ 392,000
Annual CDW benefits - Annual CDW costs for the 5 year project life. ($588,000 - $392,000)	$ 196,000

Permanent Structure

Due to its success at reducing sedimentation, the Port of Hamburg plans to convert the Kohlfleet CDW into a permanent structure. The pilings and uprights are structurally sound and will remain in place as part of a planned permanent structure. However, the wooden panels are susceptible to ice-flow damage, and some require replacement following winter icing conditions. The permanent structure panels will be fabricated from steel sheathing welded to the existing uprights.

5 Site Evaluation for Potential CDW Applications

Introduction

The success of the Kohlfleet CDW has prompted Port of Hamburg authorities to pursue CDW designs for other Hamburg harbors that experience generally the same navigation maintenance problems. However, conditions at Hamburg possibly make the CDW more advantageous than average as a maintenance reduction feature. Although it is conceivable to apply the CDW to any eddy-generated shoaling problem, engineering economic analysis should ultimately decide feasible application. In summary, CDW application is limited to projects with sufficient cost attributed to eddy-generated shoals that make CDW design and construction feasible. The following outline should provide a basis for deciding to pursue further CDW design in conjunction with and using the developers' criteria.

Step-By-Step Procedures

A preliminary evaluation for CDW application can be based on the following procedure:

a. Identify the eddy-generated component of shoaling. Eddy formations are generally recognized by simple observation and ship captains' encounters. Survey records over the general area of the eddy currents will reveal mounding of material underneath the eddy. This volume of material should be estimated and compared with the overall regular maintenance schedule volume. Two important factors should be considered to determine the significance of any eddy-generated sediment accumulation:

(1) The annual unit cost per cubic yard for dredging and disposal.

(2) Any acceleration in the dredging cycle due to the eddy-generated hotspot, even though average overall shoaling is not critical.

b. Consider site bathymetry. Consider the possibility and feasibility of constructing a flow training structure at the site. The CDW would be situated at the side of the branched channel corresponding to incoming flow that generates the eddy. If site conditions appear to allow further consideration, preliminary length and sizing can be obtained through the CDW designers at Ravensrodd Consultants.

c. Economic Analysis. Site-specific conditions control project maintenance alternatives. A preliminary CDW size can lead to regional construction cost estimates. CDW benefits can be estimated based on sediment removal costs without the eddy-generated shoaling contribution.

d. Modeling. A final CDW design should be based on model evaluations. A physical model can maximize CDW effectiveness and refine the economic analysis prior to construction. In the future, mathematical models may be applicable to this purpose.

6 Conclusions and Recommendations

This report is intended to serve as a desk study reference for possible CDW applications. In considering the CDW alternative, it is important to distinguish eddy-generated problems that make such a structural alternative feasible. Kohlfleet Harbor is a near perfect example of site conditions that will make a CDW installation feasible and cost effective. Any estimated cost savings associated with eddy removal must be considered simultaneously with CDW construction costs. Local experience with marine construction and engineering judgement should be used to consider structure costs during a preliminary evaluation as outlined in this report.

Structural flow modifications are recommended for consideration where eddy-generated shoaling is a problem. The CDW has proven to be one such successful structural alternative. Where studies indicate that a CDW is the most viable sedimentation reduction measure, it is recommended. However, an intense evaluation of an eddy-generated shoaling problem could lead to a different structural shoaling abatement.

References

Christiansen, H., and Kirby, R. (1991). "Fluid mud intrusion and evaluation of a passive device to reduce mud deposition." *Proceedings, CEDA-PIANC Conference, Accessible Harbours,* 13-14 November 1991, Amsterdam, The Netherlands, Paper E1.

Kirby, R. (1994). "The current deflecting wall, a passive and environmentally-friendly dredging system." *Proceedings, Western Dredging Association,* WEDA 15, May 1994, San Diego, CA.

Lindeburg, M. R. (1989). "Civil engineering reference manual," Fifth Edition, Professional Publications, Inc., Belmont, CA.

Ravensrodd Consultants, Ltd. (1992). "Current deflecting wall - a report on its method of operation and design," Ravensrodd Consultants Limited, Queen's Drive, Taunton, United Kingdom.

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At many channel branches, harbor entrances, or other flow bifurcations, eddy currents form due to flow depth and velocity gradients. Several significant problems can result when an eddy current forms in a navigation route: (a) the eddy creates a quiescent region and its associated currents can trap and deposit a mound of material, shoaling the channel; (b) navigation can become more difficult due to the toroidal current pattern in the eddy; and (c) the presence of the eddy can promote water/sediment load mixing with greater adjacent velocities that carry sediment farther, extending the shoal along the channel. A new flow training structure, the current deflector wall (CDW), has successfully mitigated these navigation and maintenance problems at a major world port. This report describes the design, implementation, and effectiveness of the prototype CDW installation at the Port of Hamburg, Germany.

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