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Use of a current deflector wall for eddy-generated shoaling in Kohlfleet Harbor, Germany

by
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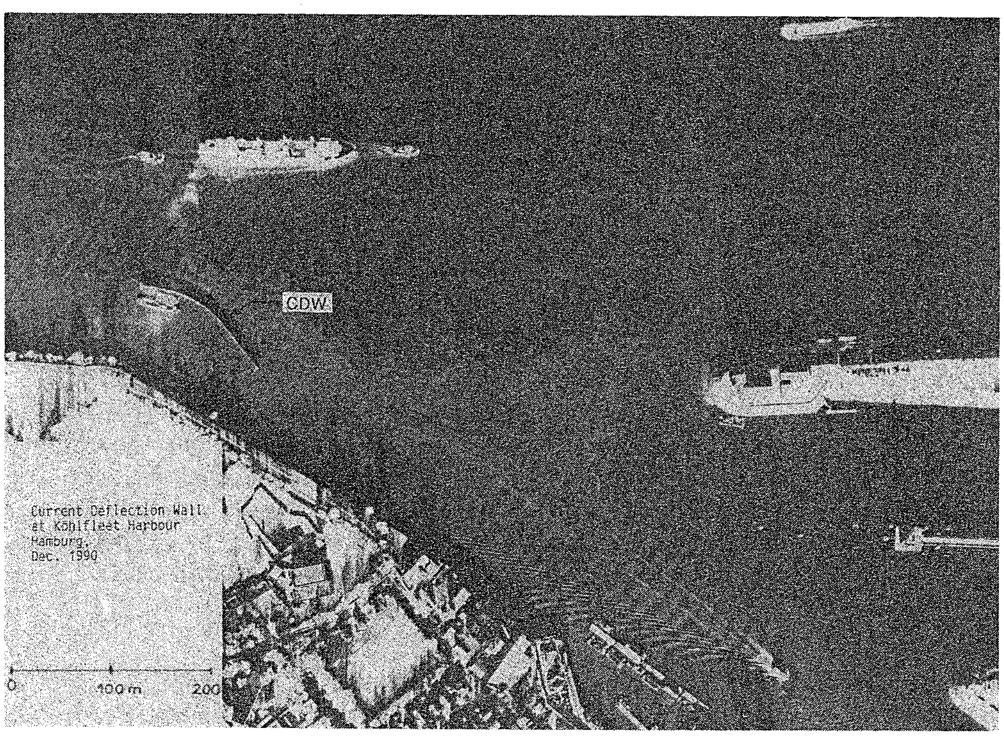
U.S. Army Engineer Waterways Experiment Station

When an eddy current forms in a channel branch, harbor entrance, or other flow bifurcation, several conditions may result that interfere with navigation. One of these is channel shoaling. Dredging is not always a cost-effective solution to the problem, especially for small, but nonetheless nonnavigable shoals. In addition, dredging presents environmental concerns because of resuspension and disposal of sediment. A new method developed in Germany uses an innovative low training structure, the current deflector wall (CDW), to eliminate these eddy currents. The use of the CDW can lower shoaling rates and extend dredging intervals.

A CDW is a fixed vertical-walled training structure with a curved deflector wall that extends through the full depth of water. A rounded vertical-walled addition to the existing upstream entrance corner will usually be required to complement the CDW. This spur wall is considered a part of the overall CDW structure (Figure 1).



Aerial view of current deflector wall prototype in Kohlfleet Harbor, Port of Hamburg, Germany.

The current deflector structure modifies flow patterns, breaking down or preventing the formation of eddies. It captures flow entering the branch channel and directs it parallel with the direction of the branch channel (Figure 2). Vortex currents can be prevented at a channel branch if a smooth transition is provided for the incoming flow velocity

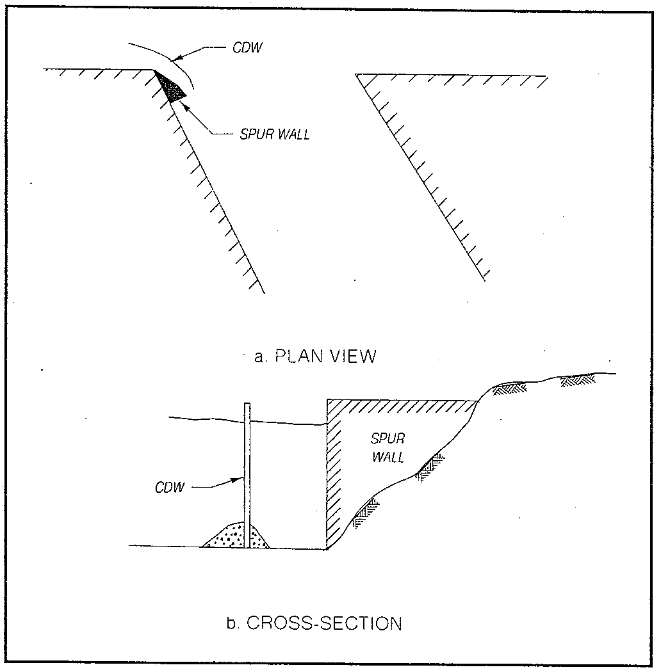


Figure 1. Plan and cross-sectional CDW schematics.

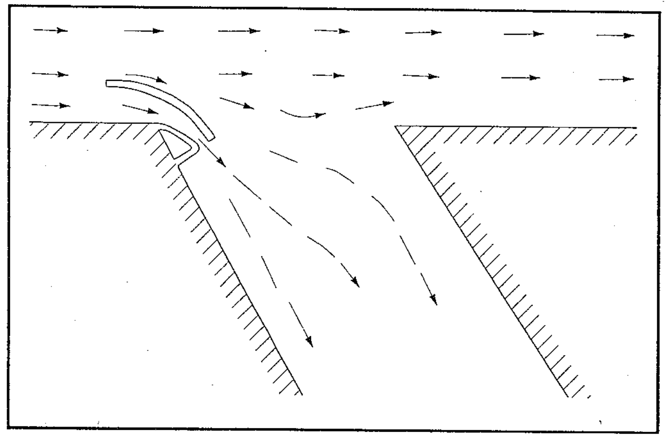


Figure 2. CDW operating principle.

vectors as they encounter depth gradients. This is the function of the CDW. Where local velocity and depth gradients change at a channel branch, the CDW can create a smooth transition that eliminates the majority of eddy turbulence.

The current deflection concept was developed in Europe for application in the Port of Hamburg, Germany.[1] Research to identify measures to reduce shoaling was prompted by the excessive costs of dredging. The Port is located along the Elbe River, about 62 miles from the North Sea (Figure 3). It is close to the nodal point of the estuarine system where riverine sediments approach from the east and ocean sediments from the west. The fine sediment deposition rate is high, with the mean annual dredging approaching 2.35 million cubic yards per year. In addition, this material is contaminated and must be deposited in a restricted land disposal site in the State of Hamburg. The excessive dredging and disposal costs have long been a problem for the Port.

Kohlfleet Harbor, one of several major harbors in the Port of Hamburg, was selected for the prototype CDW. Extensive studies of the sedimentation patterns and processes in this harbor had been made in the early 1980's. These identified a large, counterclockwise rotating eddy in the entrance, where 85 percent of the shoaling was focused.

The Franzius Institute in Hannover, Germany, constructed a scaled hydraulic model of the harbor to evaluate methods to reduce the sedimentation. The physical model studies determined that a CDW could reduce Kohlfleet Harbor entrance channel shoaling by 30 to 50 percent.

Based on the physical model studies, a prototype CDW was constructed at Kohlfleet Harbor during August-November 1990. The structure is 492 ft long, with 89-ft pilings driven 33 ft into the entrance bottom to provide the foundation for the structure. Flanged steel uprights and sliding prefabricated wooden panel sections constitute the wall itself, which extends 3.3 ft above mean high tide. The sidewalls had been built vertically along the entrance channel, a pre-existing condition that simplified the CDW spur wall design and construction.

This CDW was built with a 2-year design life so that the operating principle could be demonstrated and verified before a permanent structure was constructed. 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

1 The CDW design is protected under U.S. Patent Number 4,884,917 dated 5 December 1989. Designs for U.S. applications can be obtained through Ravensrodd Consultants, Limited, 6 Queens Drive, Taunton, Somerset, TA1 4XW, England.

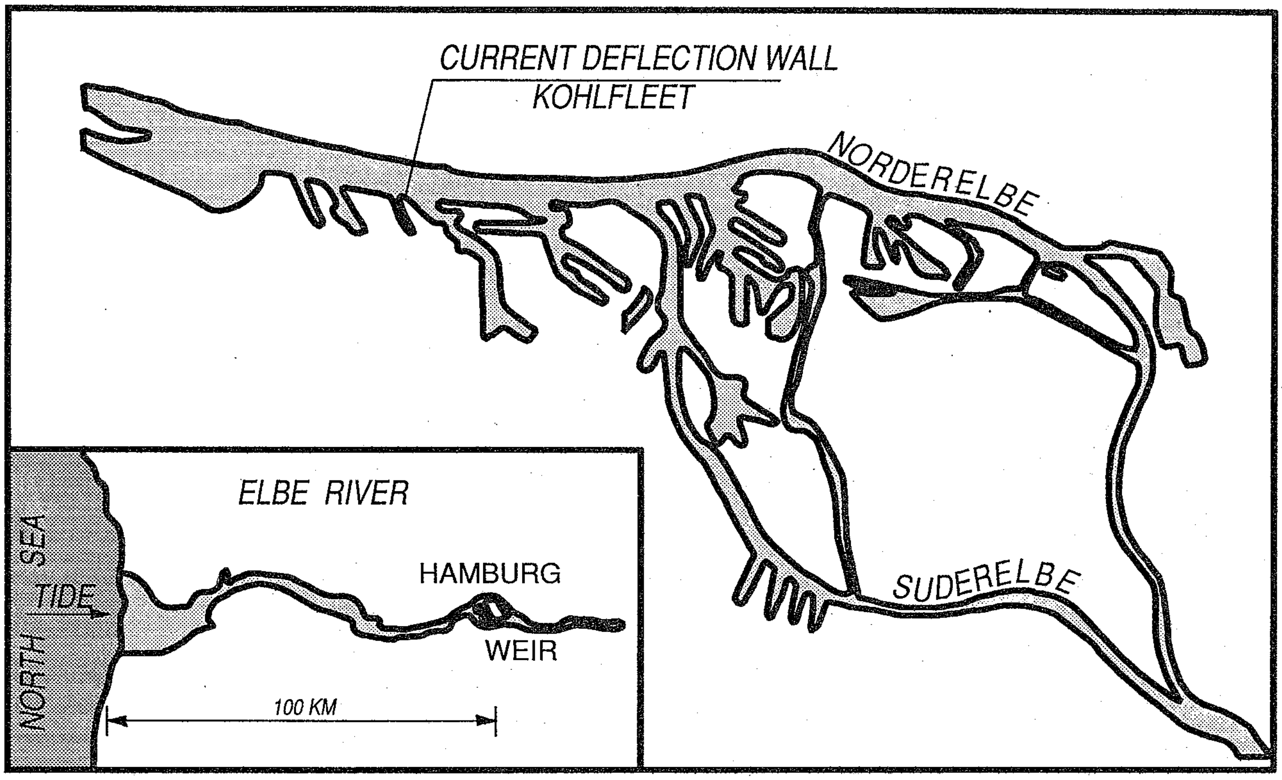


Figure 3. Port of Hamburg area showing Kohlfleet Harbor and CDW location.

damage, and some require replacement following winter icing conditions. The permanent panels will be fabricated from steel sheathing welded to the existing uprights.

Current pattern studies were repeated at the Kohlfleet Harbor entrance immediately following CDW construction. The same type of field exercise that had identified the eddy was repeated to evaluate the success of the CDW in eliminating the eddy. This exercise involved releasing radar reflectors attached to variable depth drogues. This procedure outlined the surface and middepth current patterns. Postconstruction reflectors were placed in the Elbe River, along the CDW 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. Navigation through the harbor entrance was also improved, even though the width of the harbor had been reduced slightly by the construction. Pre- and post-CDW circulation patterns at Kohlfleet Harbor are illustrated in Figure 4.

The Kohlfleet CDW design and construction cost $1.65 million (U.S. dollars). However, the cost of dredging contaminated sediments at Kohlfleet would have been approximately $7.8 million. Other locations will probably require longer intervals before a positive return is realized. Dredging costs per unit volume vary significantly among U.S. maintenance projects, but analysis indicates that the CDW can result in a positive economic return within a few years. Long-term savings could be substantial.

Prototype evaluation has demonstrated that the CDW is a viable maintenance reduction measure for eddy-generated shoaling. The prototype CDW in Kohlfleet Harbor is still functional, and the Hamburg Port authorities plan to convert it into a permanent structure. Because the CDW has resulted in a significant reduction in material deposition, other harbors are being considered for CDW application following this latest design, both in Germany and the United States.

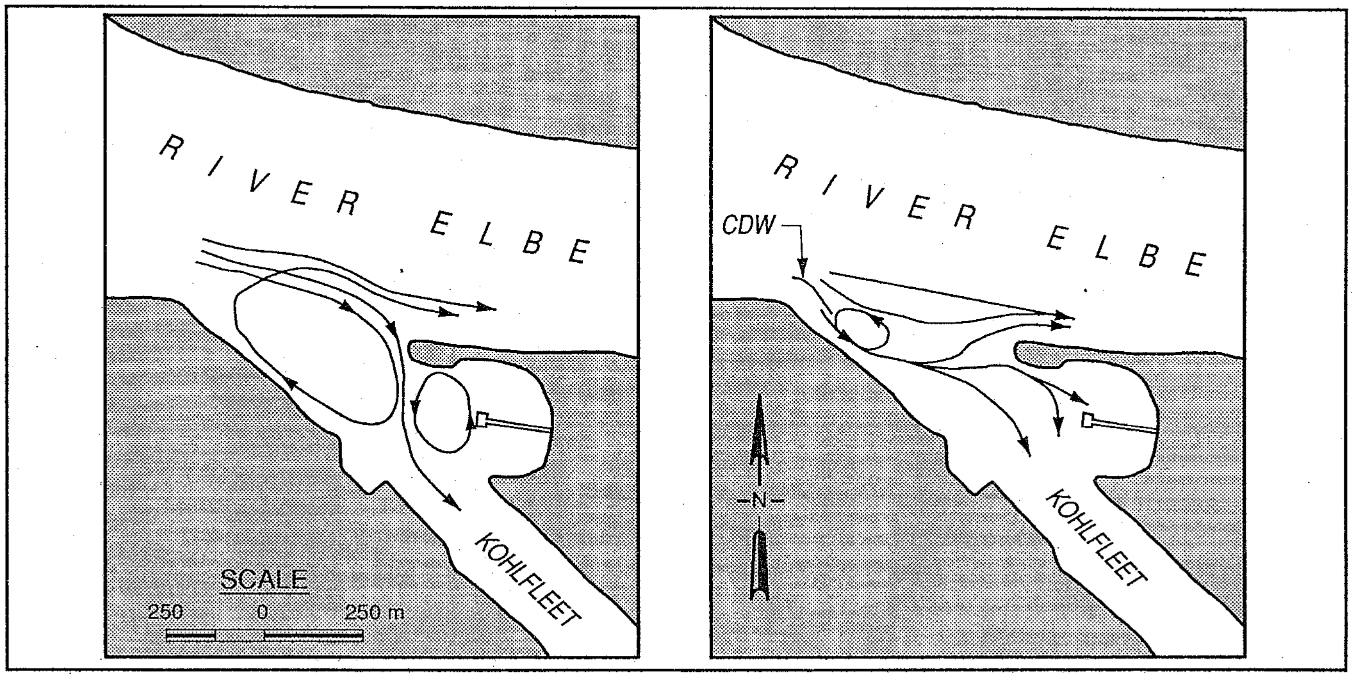


Figure 4. Pre- (left) and postcirculation (right) patterns, Kohlfleet Harbor.

When a CDW is being considered as a navigation maintenance alternative, several steps are recommended. A site investigation should be made to determine the application and feasibility of the CDW. The hydraulic processes studies should include:

- The magnitude and direction of ambient currents to verify eddy-generated shoals.
- Annual shoaling volumes and distributions.
- Site bathymetry. The CDW design must be based on local depth gradients to create a smooth velocity vector transition into the branched channel.
- Supporting information, including salinity, suspended load distribution and fluctuation, and sediment type.

Designing the CDW structure must be accomplished with the U.S. patent holder, Ravensrodd Consultants, Ltd. Modeling the site conditions with and without the CDW is necessary to refine and evaluate its application to the site. Physical modeling proved that the prototype design through numerical evaluations should not be ruled out.

For additional information, call Michael P. Alexander at (601) 634-3904.

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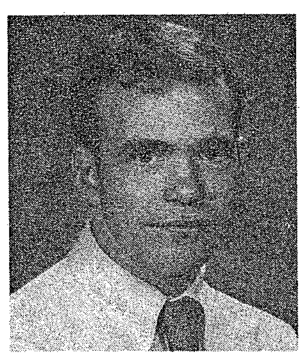

***Mike Alexander** is a research hydraulic engineer in the Hydraulics Laboratory, WES. He has worked in the areas of hydrographic surveying, dredging equipment evaluations, and flow training structure evaluations for the past 7 years. He received a B.A. degree in civil engineering through the co-operative education plan from Mississippi State University. He is a registered Professional Engineer in the State of Mississippi and a member of the Permanent International Association of Navigation Congresses.*

Coastal structure inspection in wake of Hurricane Iniki

by Jeffrey A. Melby and George F. Turk,
Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station

On 11 September 1992, the first hurricane to make landfall on a Hawaiian island since 1950 did so at approximately 2 p.m. Hurricane Iniki, a Category 4 storm, struck the coast of Kauai just west of the village of Poipu. Sustained winds in excess of 140 mph and maximum surge levels nearly 20 ft resulted in severe damage to residences, infrastructure, and agriculture on Kauai. The islands of Oahu and Lanai were also battered by severe winds and high surge levels. Local observers reported wave heights in excess of 30 ft, both on the western shores of Kauai and at Kaumalapau, Lanai.

At the request of the U.S. Army Engineer Division, Pacific Ocean (POD), engineers from the Coastal Engineering Research Center, Waterways Experiment Station (WES), together with POD engineers, conducted a damage assessment survey of coastal structures on the islands of Kauai, Lanai, and Oahu from 15 to 27 September 1992. The primary objective was to evaluate the damage due to the hurricane and assess whether and to what extent immediate repairs were necessary. A secondary objective for WES engineers was to accumulate sea state and concrete armor unit breakage data to assess concrete armor performance and verify recently developed concrete armor stress prediction methods.

A total of 11 projects were surveyed, including stone and concrete armored breakwaters and revetments, and river flood control projects. The concrete armored breakwater inspections provide an update to the concrete armor unit breakage count reported in Markle and Davidson (1984). They also provide concrete armor performance data that will be used to develop rehabilitation and maintenance guidance as part of an ongoing study being conducted under the REMR Research Program. Project locations are noted in Figure 1.

Kauai

The entire island of Kauai was devastated by Iniki. The farthest project from the hurricane eye surveyed on Kauai was the Kekaha Beach Highway Erosion Protection Project, consisting of a mile-long revetment completed in 1979. This structure survived the hurricane intact, although it was overtopped by massive amounts of sand. At the end of the stone revetment, the shoreline highway was completely inundated with sand. Proceeding around the island counterclockwise toward the path of the hurricane eye, the Kikiaola Small Boat Harbor adjoining recreation area was inundated with beach sand. The stone-armored breakwater, built in the early 1980s, survived what appears to be significant overtopping with only a few displaced stones (Figure 2). Inspection of the Waimea River Flood Control revealed no damage at this structure. Farther east, the Hanapepe River Flood Control Project, including a 2,200-ft-long levee and 182-ft-long flood wall constructed on the east bank in

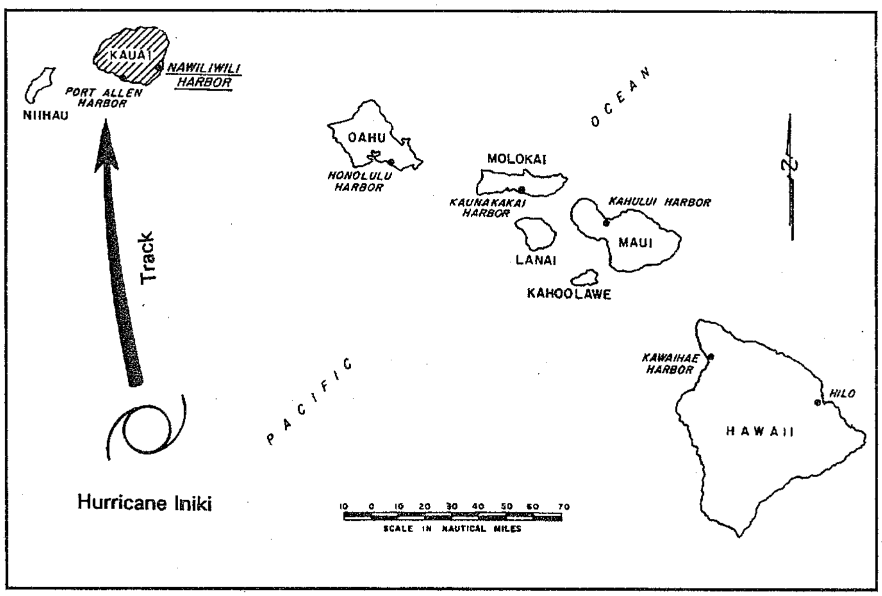

Figure 1. Location map showing track of Hurricane Iniki.

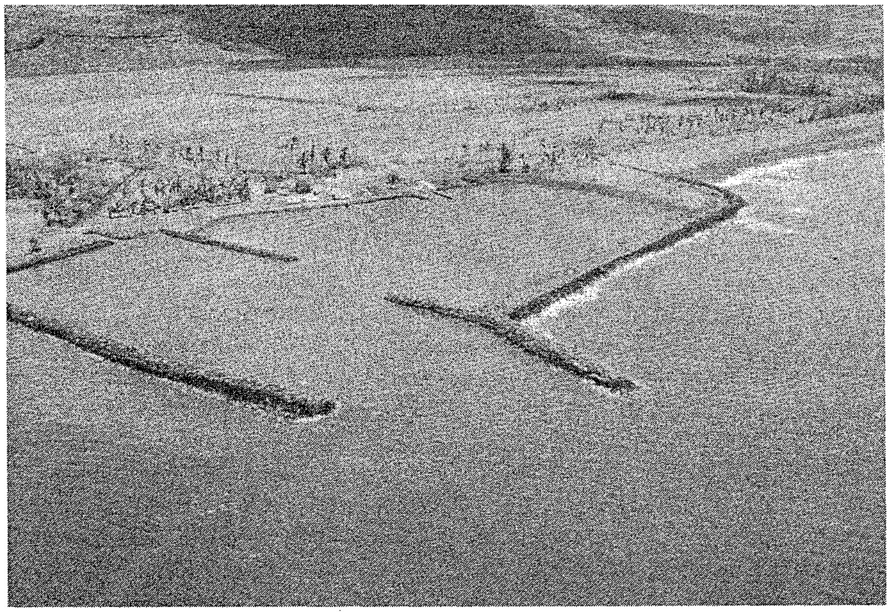

Figure 2. Kikiaola Small Boat Harbor breakwater sustained minor damage.

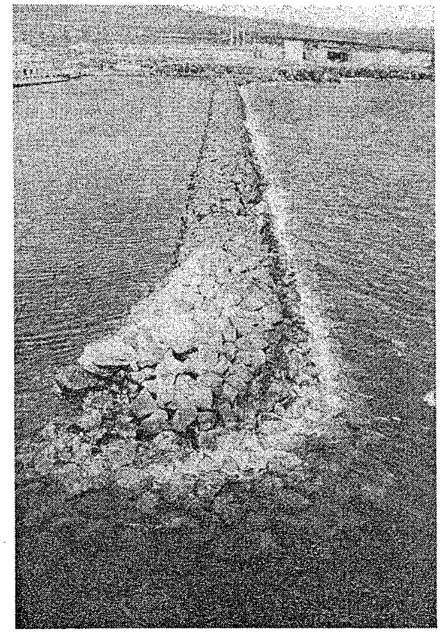

Figure 3. Port Allen breakwater sustained damage to both head and trunk.

1959 and a 4,465-ft-long levee constructed on the opposite bank in 1963, showed no evidence of significant damage. Some of the unprotected bank upstream of the project had minor erosion. A debris line on the river bank about 1 mile upstream showed the high water mark to be approximately 9 ft.

The 1,126-ft-long Port Allen breakwater, constructed on the south side of the island in 1935, suffered extensive damage. Large gaps appeared in the extraordinarily well-constructed keyed-and-fitted stone armor (Figure 3). Many 8- to 12-ton stones were totally displaced. The displacement appeared to be the result of excess internal pressure, evidenced by localized seaside and backside "blowouts" and backside toe stone displacement. While this breakwater was still functional, it was noted that immediate repairs were necessary to maintain the structural integrity. This breakwater had no repair history until severely damaged by Hurricane Iwa in 1982. The breakwater was repaired in 1984 but was shortened by 74 ft.

At the Nawiliwili Harbor, eyewitness accounts put the wave height at 30 ft outside the harbor and 8 ft inside. The 2,150-ft-long Nawiliwili breakwater was intact with no breaches and no evidence of gross armor movement (Figure 4). Originally constructed in 1926, this structure has been repaired several times with 598 18-ton reinforced tribars placed in 1959 and 934 11-ton lightly reinforced dolosse placed over the tribars in 1977. Recently, 6.5-ton tribars were placed on the harbor side of the breakwater. A detailed inspection of the breakwater revealed seven newly broken dolosse and six newly broken tribars (Figure 5). The total count for broken units observed above the still-water level:

- 11-ton dolosse — 40 out of 934 units broken
- 17.8-ton tribars — 16 out of 598 units broken

Figure 4. Nawiliwili Harbor breakwater.

- 6.5-ton tribars — 1 break

There were many signs of concrete armor unit movement. Almost uniformly distributed across the face of the breakwater were fresh spall marks where units had rubbed against

Figure 5. Freshly broken tribar on Nawiliwili breakwater.

units. One dolos was completely displaced, with the fluke resting atop the ribbed concrete cap.

A 150-ft-long groin and a 100-ft-long revetment at the Kapaa Beach Erosion Control Project, built in 1976, were fully intact. Some scouring and erosion had occurred on the backside of the revetment, but not enough to jeopardize its integrity.

Lanai

On the island of Lanai, inspection of the Kaumalapau Breakwater was conducted at the request of the State of Hawaii. Approximately 180 ft of the original 270-ft-long rubble-mound structure had been destroyed by estimated 30-ft waves on a surge of approximately 15 ft (Figure 6). This is one of the few breakwaters observed that does not have a fronting reef. The shelf slope is very steep here allowing deepwater waves to the breakwater. The inspection revealed a wide scatter of breakwater remnants, consisting of stone, a few dolosse, and concrete and metal refuse, strewn into the mouth of Kaumalapau Harbor.

Also inspected were a breakwater and revetment protecting the small boat harbor at Manele. The well-constructed keyed-and-fitted stone armored stub breakwater, built in 1965, is 430 ft long. A similarly constructed revetment was recently completed. A storm surge in the 6- to 7-ft range was reported, and most of the beaches fronting the nearby resort were severely impacted with most of the beach sand being moved inland approximately 100 yd. The structures were not damaged by the hurricane.

Oahu

The Waianae breakwater, completed in 1979 to a length of 1,690 ft on the south side of Oahu, sustained minor damage from Iniki. The harbormaster reported waves nearly 20 ft breaking in depth-limited waters seaward of the breakwater head. The design wave for this structure was 11.8 ft in 16 ft of water. Severe overtopping of the structure was observed during the hurricane. Inspection of the structure revealed 10 of the originally placed 6,633 2-ton dolosse freshly broken. Local estimates of the static storm surge ranged from 3 to 6 ft along the southern coast of Oahu. There was no evidence

Figure 6. Breakwater destroyed by hurricane at Kaumalapau, Lanai.

of crown stone displacement or backside instabilities. A total of 222 dolosse armor units of the original 6,633 are now broken. This compares with a 1984 count of 170 units, of which 47 were original construction breaks left on the breakwater.

Summary and Conclusions

Although Hurricane Iniki damage was extensive, the Corps structures sustained relatively minor damage. This can be primarily attributed to excellent construction techniques. The keyed-and-fitted stone breakwaters are exceptionally stable. But it is difficult to achieve new structure stability when repairing keyed-and-fitted structures because of limited stone selection. This is supported by the fact that the Port Allen breakwater has sustained progressively more damage with each hurricane.

The two concrete armored breakwaters, Nawiliwili and Waianae, are aging. The concrete armor rehabilitations and construction in the late 1970s show a high percentage of damage, nearing 5 percent. Recently developed stress prediction methods show that the design tensile stress corresponding to 5-percent exceedance is approximately 550 psi in the 11-ton dolosse at Nawiliwili, which is approximately equal to the concrete tensile strength (Melby 1989). This stress was determined using the concrete armor design program called CAUDAID.

A conservative redesign might incorporate fattening of the basic shape, higher strength concrete, or more reinforcement (Melby and Turk 1992). The stress prediction methods developed to date assume stable nonrocking armor units. The small dolosse at Waianae have very low predicted stable stresses but are probably rocking about on the slope, producing high impact stresses. Current investigations in the REMR Research Program are addressing incorporation of impact stresses due to armor unit movement into current stress prediction methods. Draft guidance for dolosse should be available this fall.

For additional information, contact Jeffrey Melby at (601) 634-2062 or George Turk at (601) 634-2332.

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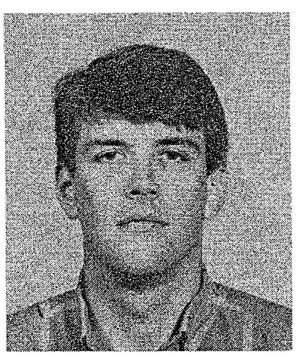

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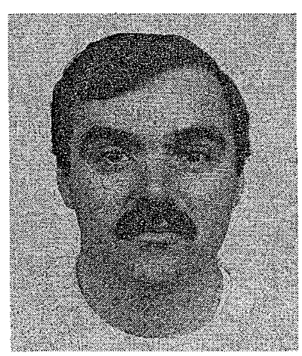

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Geomechanical modeling of concrete gravity structures: the physical model plan

by Ronald B. Meade, Consulting Engineer, Vicksburg, MS
Robert D. Bennett, Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station

Some older gravity structures fail to meet current U.S. Army Corps of Engineers criteria for sliding and overturning, yet they still perform satisfactorily. This disparity between current stability criteria and the performance record of gravity structures is being investigated under the REMR Research Program to assess the correctness of current stability analyses. The key assumptions being examined are boundary conditions, stress distribution on the failure surface, and the loads applied by compacted fill.

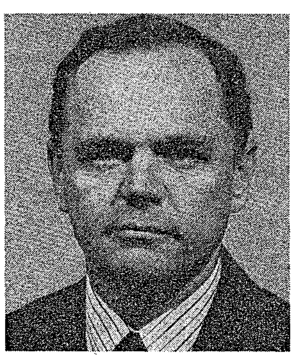
A comprehensive program of testing physical models, both full- and reduced-scale, has been prepared as the Physical Model Plan. Execution of the plan will allow refinement of stability analysis procedures.

The full-scale models, or prototypes, will be instrumented with stress gages, piezometers, and displacement gages. New locks and other structures undergoing rehabilitation are suitable prototypes for testing. An agreement has been reached between the Huntington District and Waterways Experiment Station to instrument one of the landwall lock monoliths being constructed as part of the additional lock at Winfield Lock and Dam. Although no specific projects have been designated for destructive testing at this time, it may be possible to test to failure selected monoliths at several gravity structures scheduled for removal after new locks become operational.

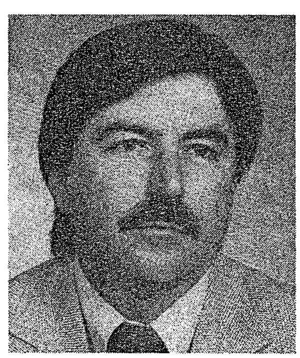
The reduced-scale models provide an inexpensive way to evaluate stability analysis procedures, with assumptions and limitations similar to those of full-scale structures. Two types of testing are in the planning stage. In one series of tests, small models will be loaded by both body forces and forces applied with devices such as jacks and free weights. In a second series of tests, the models will be subjected to body forces increased by spinning the model within a centrifuge.

The centrifuge test program will begin during the summer of 1993. A 1/20-scale model will be tested at an acceleration of 20 g's. These first tests will be used to develop and refine the instrument package and data acquisition issues for small models as well as to provide data for evaluation of the assumptions made in routine analyses.

For additional information, call Ron Meade at (601) 634-4129 or David Bennett at (601) 634-3974.



***Ron Meade** is a consulting engineer currently on contract with WES. He received B.S.C.E., M.S.C.E, and Ph.D. degrees from Purdue University. He is a registered Professional Engineer in the States of Mississippi, Virginia, and Indiana. He is a member of the American Society of Civil Engineers, the National Society of Professional Engineers, and the U.S. Committee on Large Dams.*



***Dave Bennett** has been a research civil engineer at WES for 17 years. His work has included a variety of geotechnical and waste management and disposal projects. He received B.S. and M.S. degrees in civil engineering at Mississippi State University and has done postgraduate work in geotechnical engineering at the University of Illinois at Champaign, IL. Bennett is a registered Professional Engineer in the State of Mississippi and is a member of the American Society of Civil Engineers and the Society of American Military Engineers. He is the Principal Investigator for REMR Work Unit 32648, "Geotechnical Modeling for Stability of Existing Gravity Structures."*

Annual Field Review Group meeting

The 5th REMR-II Field Review Group Meeting will be hosted by the Missouri River Division (MRD) on 28-30 July 1993 in Omaha, NE. At this time, the progress of ongoing work units will be reviewed, and R&D priorities will be addressed. In addition, technology transfer will be assisted by means of presentations on current research and availability of technical reports and videos.

The meeting will be open to the public as well as to Corps personnel involved in the repair, evaluation, maintenance, and rehabilitation of the Nation's infrastructure. Representatives from all Districts and Divisions are encouraged to attend. The meeting will be held at the Red Lion Hotel, 1616 Dodge Street, Omaha, NE 68102. Reservations for rooms may be made by calling (402) 346-7600. When reserving a room, refer to the U.S. Army Corps of Engineers REMR Field Review Group Meeting.

For additional information, contact Lee Byrne, CEWES-SC-A, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or call (601) 634-2587.

Changes in key personnel

William N. Rushing has been named the new REMR-II Coordinator for the Directorate of Research and Development. He replaces ***Jesse A. Pfeiffer, Jr.*** Bill has been with CERD-C since 1989 and has been active in previous REMR-II Program Reviews. Prior to assuming his duties in Washington, he was affiliated with the Aquatic Plant Control Research Program at WES. Bill may be reached at (202) 272-1841.

Special thanks are due to Jesse Pfeiffer for his outstanding leadership in getting the REMR Research Program started and for guiding its progress during the past 9 years. He has been instrumental in keeping the Program focused on identifiable goals that meet the needs of the field. He will be missed by all.

Sam Powell, Chief of the Hydraulics and Hydrology Branch, Civil Works, has replaced ***Glen Drummond*** as the REMR Technical Monitor for the Hydraulics Problem Area. Glen has retired from the Corps of Engineers. Appreciation is extended to him for his service to the REMR Research Program. Sam may be reached at (202) 272-8501.

Bob Neal, North Central Division, has recently retired from the Corps of Engineers. Bob joined the REMR Program as an Operations Member in 1987. We wish him the best in his retirement and thank him for his service to the Program. His replacement will be announced at a later date.

Recent publications

An updated version of the *Index of REMR Technology and Listing of REMR Research Publications Through March 1993* is now available. This document provides a subject index and listings of REMR technical reports, technical notes, bulletin articles, and video reports through March 1993. When requesting copies of this resource, please ask for the March 1993 edition.

Icing Problems at Corps Projects by F. Donald Haynes, Robert Haehnel, and Leonard Zabilansky, U.S. Army Cold Regions Research and Engineering Laboratory, has been printed. This report describes the problem of icing of machinery (such as dam gates, lock gates, gears, and seals) at Corps projects. It also includes the results of a survey distributed to Divisions and Districts to obtain information on icing problems and existing solutions. To receive this report, request Technical Report REMR-HY-10.

Use of a Rubble Berm for Reducing Runup, Overtopping, and Damage on a IV to 2H Slope: Experimental Model Investigation by Donald L. Ward and John P. Ahrens, Coastal Engineering Research Center, WES, is also available. In this report, laboratory tests with irregular waves to determine wave runup characteristics and armor stability of riprap revetments are discussed. Request Technical Report REMR-CO-17 for copies.

To receive these publications, contact the REMR Technology Transfer Specialist, Lee Byrne, at (601) 634-2587 or write Director, Waterways Experiment Station, ATTN: CEWES-SC-A (Lee Byrne), 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

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The REMR Bulletin is published in accordance with AR 25-30 as one of the information exchange functions of the Corps of Engineers. It is primarily intended to be a forum whereby information on repair, evaluation, maintenance, and rehabilitation work done or managed by Corps field offices can be rapidly and widely disseminated to other Corps offices, other US Government agencies, and the engineering community in general. Contribution of articles, news, reviews, notices, and other pertinent types of information are solicited from all sources and will be considered for publication so long as they are relevant to REMR activities. Special consideration will be given to reports of Corps field experience in repair and maintenance of civil works projects. In considering the application of technology described herein, the reader should note that the purpose of *The REMR Bulletin* is information exchange and not the promulgation of Corps policy; thus guidance on recommended practice in any given area should be sought through appropriate channels or in other documents. The contents of this bulletin are not to be used for advertising, or promotional purposes, nor are they to be published without proper credits. Any copyright material released to and used in *The REMR Bulletin* retains its copyright protection, and cannot be reproduced without permission of copyright holder. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. *The REMR Bulletin* will be issued on an irregular basis as dictated by the quantity and importance of information available for dissemination. Communications are welcomed and should be made by writing US Army Engineer Waterways Experiment Station, ATTN: Lee Byrne (CEWES-SC-A), 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or calling 601-634-2587.

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