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Increasing efficiency in a sandbagging operation

by
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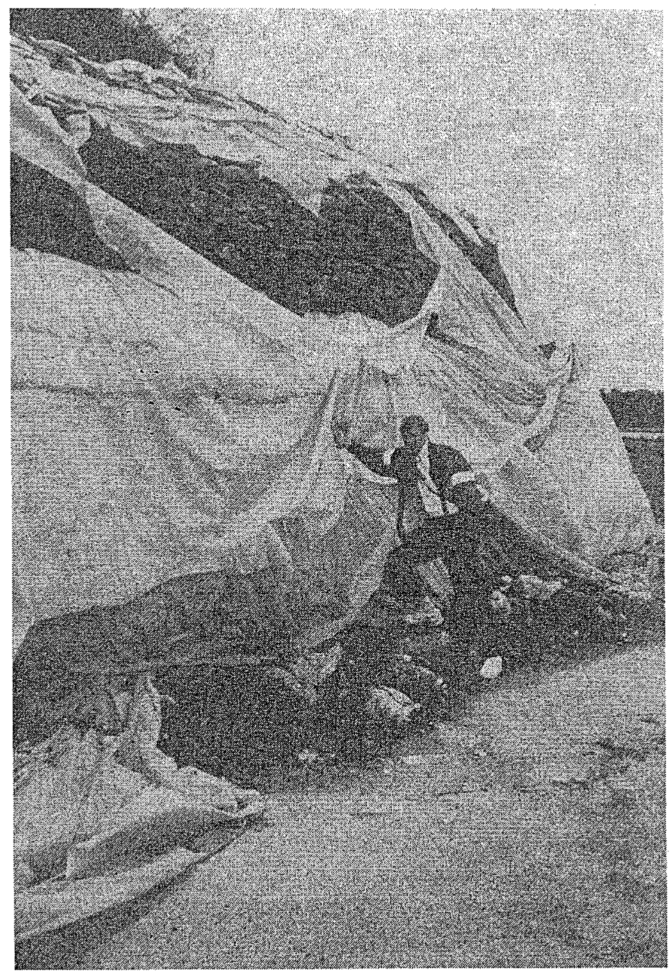
The magnitude of the devastation caused by the Flood of '93 in the Upper Mississippi and Missouri River Valley could be truly appreciated only by those who fought the Flood on the front lines. While technological breakthroughs exist in a wide variety of fields, the art of flood fighting has changed little over the past century. During the Flood, several innovative expedient flood fighting methods were tried. These included water-filled barriers, New Jersey highway barricades, and geotextile-lined earth-filled Concertainers®. However, the lowly sandbag again proved to be the most effective and versatile of all flood fighting tools.

In the past, sandbags were exclusively made of burlap, but in recent times geosynthetic bags have become more popular. Regardless of the type of sandbags used, they all share a common denominator—labor intensity. Anyone who has ever filled sandbags, even for a short time, knows what backbreaking work it takes to build even a small fortification, much less a massive structure such as one built in Ste. Genevieve, MO (see lead photo). During the Flood, over 37 million sandbags were distributed by the Corps of Engineers. These were enough bags to build a sandbag levee 2-1/2 ft high all the way from St. Louis to Kansas City. In most cases, each one of these bags was filled and placed by hand—a tremendous amount of physical labor.

As part of a fact-finding mission to the Midwest, an effort was made to identify better ways to fight floods. The conclusion was that sandbagging is going to remain the flood-fighting tool of choice for some time to come. However, several methods can be used to reduce the labor and



Massive Ste. Genevieve sandbag wall

increase the productivity of a sandbagging operation. The efficiency of sandbagging can be increased simply by avoiding some of the common mistakes and misunderstandings about the process. Many people erroneously think that sandbagging is a mindless endeavor; "just fill the bags and stack them up"; yet nothing could be further from the truth. In many instances, certain problems surfaced repeatedly across the Midwest:

- Bags were overfilled, making them too heavy to handle and too difficult to get a good seal on the levee.

- Bags were tied closed, causing one end of the bag to bunch up and not allowing as good a seal on the stack as bags with the end simply folded over.
- Bags were often stacked too steeply and could easily topple.
- Little training on placement methods was available, resulting in improper stacking.
- Many bags were transported in large dump trucks, making their loading and unloading unduly physically exhausting.

Labor can be decreased, and efficiency increased, by following these simple "rules-of-thumb" for a proper sandbagging operation:

- Sandbags should be filled only 1/2 to 2/3 full, weighing about 30 lb.
- Bag closure should be folded, not tied.
- Bags should be properly stacked (Figure 1).
- When convenient, pick-up trucks, low boys, or front-end loaders should be used, as opposed to dump trucks, for hauling bags to reduce fatigue in loading and unloading (lifting).
- The bagging operation should be staged away from the distress site to avoid traffic congestion in the emergency zone.
- Training sessions should be provided for new volunteers.

One of the most difficult jobs in sandbagging is the actual filling of the bags. Most operations used two people to fill the bags, one to hold the bag and the other to shovel in sand. Some groups cut down a standard orange highway cone and used it as a funnel to fill bags. Others made a "filling table" from 2x4's and plywood with several highway cones set in the table top. This allowed several bags to be filled simultaneously. At one operation in Jefferson City, MO, the hopper on a road sanding dump truck was modified to fill sandbags. This allowed some degree of metering of the amount of sand placed in each bag.

All of these methods still fall short of an optimal sandbag filling machine. What is needed is an automatic sandbag filling device. Though not used during the Flood, just such a machine has recently come to the attention of the Corps and is commercially available. The Automated Sandbag Filling Attachment (ASFA) produced by TRAK International, Inc., can significantly reduce the labor involved in filling sandbags. It has been reported that the ASFA is capable of filling up to 500 bags/hour, requiring only two people and a conventional piece of heavy equipment.

Two models of the ASFA device are on the market. The Type I ASFA is a complete bucket replacement for skid-steer loaders, small emplacement excavators, forklifts, or front-end loaders. The Type II ASFA is designed to be fitted in the multipurpose 4-in-1 bucket typically available on several models of front-end loaders. Capacities range from 0.75 to 3 cu yd. The hydraulic auger/vibrator subsystem of the ASFA is designed to be quickly connected to the existing hydraulic systems of heavy equipment. Prices for these units range from $4,500 to $6,100.

In 1993, the Department of the Air Force Material Command Management and Equipment Program evaluated the ASFA at Eglin Air Force Base, FL. They found the unit performed as the manufacturer claimed, filling bags in 5 to 8 sec. In addition, the attachment was found to have some unique safety features, such as rounded corners, guards, and safety stands.

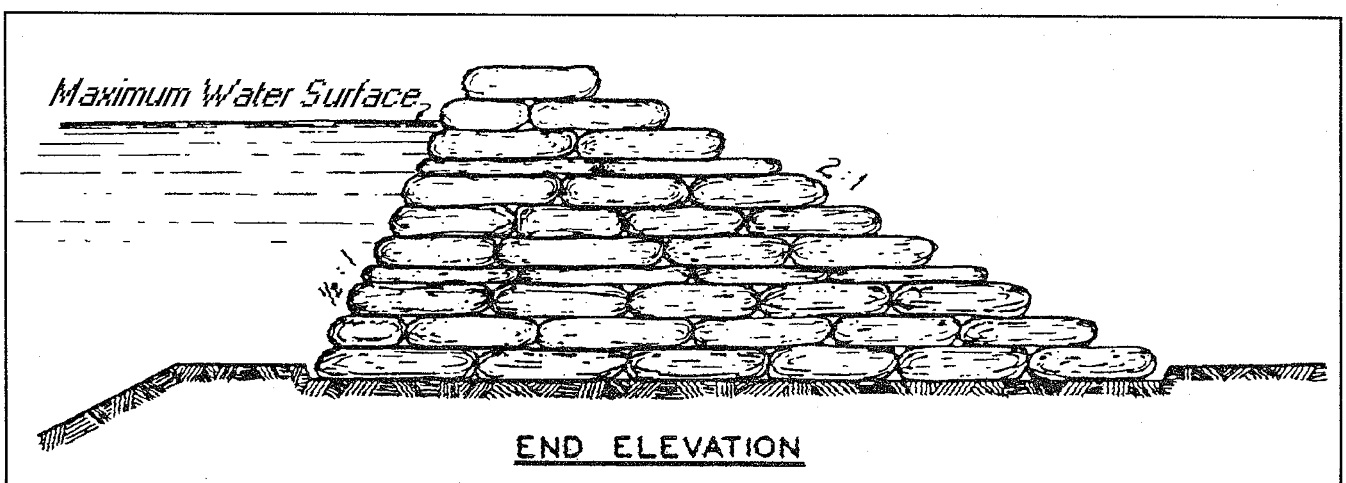
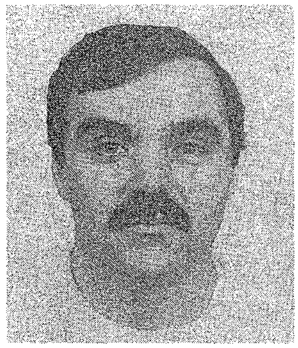


Figure 1. Properly stacked sandbags

No existing machines have been found that will reduce the labor involved in lifting and stacking the bags. But future developments in sandbagging equipment technology may evolve such that, when the next great flood happens, we may truly have the ability to expediently hold back rising floodwaters using sandbags.

For more information about the ASFA, contact TRAK International, Inc., at (414) 284-5571. For additional information about other levee control techniques, contact George Turk at (601) 634-2332 or Dr. Paul Hadala at (601) 634-3475.



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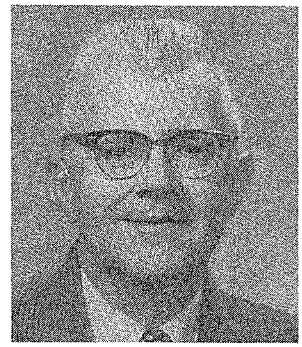

Paul F. Hadala is a supervisory civil engineer and the Assistant Director of the Geotechnical Laboratory, WES. He holds a B.S. degree in civil engineering from Union College, an M.S. degree in soil mechanics from Harvard, and a Ph.D. in civil engineering from the University of Illinois. He is a registered Professional Engineer. Hadala has done research in horizontal construction, nuclear and conventional weapons effects, offroad mobility of military vehicles, and combat engineering simulation. He is the former director of the Soil Mechanics Information Analysis Center (SMIAC), WES, and presently supervises the directors of both the SMIAC and the Airfield Pavement and Mobility Information Analysis Center, WES.

REMR technical reports now available

The following REMR technical reports may be obtained by writing Director, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-SC-A/Lee Byrne, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199 or by calling (601) 634-2587.

Alexander, A. M. (1993). "Impacts as a Source of Acoustic Pulse-Echo Energy for Nondestructive Testing of Concrete Structures," Technical Report REMR-CS-40, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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STREMR: Model for evaluation of near-field turbulent flow conditions

by
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Introduction

A tool to evaluate the velocity field corresponding to turbulent flow in open channels has been developed at the Hydraulics Laboratory, Waterways Experiment Station (WES), under REMR Work Units 32319, "Predictive Techniques for Approach Flow to Spillways and Other Structures," and 32656, "Dissemination and Improvement of STREMR Model." This tool, a numerical model called STREMR, has the unique capability of determining the influence of turbulence, channel resistance, and flow curvature on the development of the depth-averaged velocity field over short channel reaches. The model has proven useful in studies concerning the hydraulic performance of river bendways, diversion tunnels, pump stations, training structures, bank protection works, outlet works, and navigation channels. It is suitable for routine use by field engineers with a background in fluid mechanics, and it can be applied on most IBM-compatible personal computers.

The successful operation, design, or maintenance of river engineering works often requires an understanding of the velocity field for a variety of flow conditions. The traditional approach to designing river engineering works involves the application of past experience, empirical relationships, engineering judgment, field data collection, and physical and laboratory models. In recent years, numerical models have been used with increasing frequency as a tool to complement the design process, but the value of these models to the decision-making process depends on the selection of model parameters left up to the discretion of the modeler. For instance, most depth-averaged models require the user to select empirical coefficients for turbulent momentum exchange. STREMR eliminates much of this empirical guesswork by incorporating a k-ε turbulence model and a three-dimensional (3-D) secondary flow correction.

Numerical flow model

STREMR is a general-purpose numerical model that simulates two-dimensional (2-D) laterally or vertically averaged flow in an arbitrarily defined channel. The STREMR model has been developed for near-field flow simulations where turbulence and channel curvature are important factors in determining the velocity field. The turbulence characteristics of the flow are often important when considering the interaction of hydraulic structures and the flow in a channel. Under these conditions, the model can estimate the location and magnitude of high-velocity regions and the extent of recirculation zones. In natural bendways or curved channels, STREMR accounts for the effects of secondary flow, which is responsible for the acceleration of the flow along the outside of channel bends. The primary input to the model involves the specification of inflow, outflow, and no-flow boundaries, as well as the bathymetry and Manning's coefficient for bottom friction. The STREMR model is limited to gently varying bathymetry and Froude numbers less than 0.7.

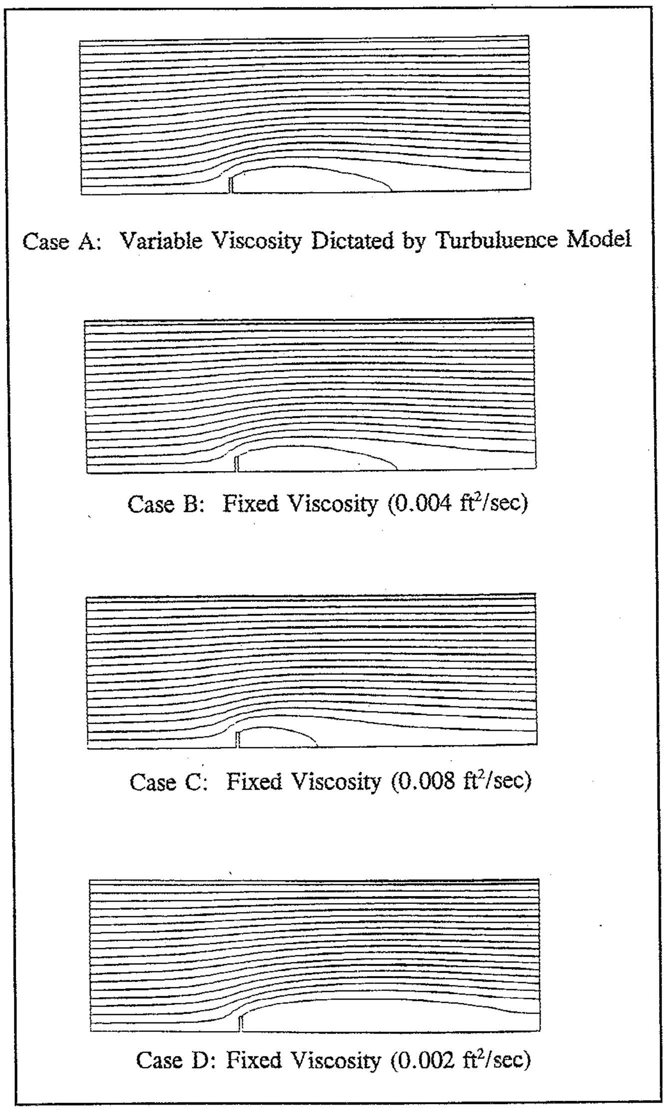
Turbulence

The features that distinguish the STREMR model from other 2-D numerical models supported by the Corps of Engineers are the corrections for turbulence and flow curvature. In hydraulics, the flows of practical importance are almost always turbulent. Turbulence is characterized by small-scale fluid motion that is random, unsteady, and 3-D. In many instances, it is the turbulent exchange of momentum that is responsible for the distribution of flow in channels where resolution of near-field flow properties is of interest. The STREMR model determines where and how much turbulence is generated, transported, and dissipated in a flow field without requiring any user-supplied empirical coefficients. The level of turbulence is used to calculate the local eddy viscosity throughout the flow field, which is then used in the determination of the velocity field, as described by Bernard (1991).

Typical design considerations for a dike field involve the location, length, spacing, and orientation of the dike in the channel. The selection of these design features will depend upon the resultant flow field. To illustrate the influence of turbulent momentum exchange on flow field properties, a simple case study of flow past a spur dike is considered. A straight channel approach with a constant depth (D) and width (W) was simulated for a spur dike. The spur dike was perpendicular to the channel with a length of W/10. The imposed boundary conditions consisted of a uniform upstream velocity of 1 ft/sec and negligible bottom and side-wall resistance.

This flow was simulated with (Case A) and without (Cases B, C, D) the turbulence model. For Cases B, C, and D, a constant eddy viscosity of 0.004, 0.008, and 0.002 ft^2/sec was used, respectively. The streamlines (particle paths) for all four simulations are shown in Figure 1. For thin dikes in shallow smooth channels, a separation length of about 1.2W has been reported (Rajaratnam and Nwachukwu 1983). As the flow approaches the dike, it accelerates around and separates off the dike tip. Considerable turbulence is generated at the tip of the dike, affecting the recirculation behind the dike. The length of the separation bubble for Case A was 1.1W, which is slightly shorter than the observed length. The flow field for Case B using a constant eddy viscosity was quite close to that in Case A, with about the same reattachment length. However, if the viscosity is increased or decreased by a factor of 2, the flow field is considerably different, as shown in Cases C and D. The reattachment length varies from 0.5W for Case C to more than 2.0W for Case D.

This simple study illustrates the importance of the imposed eddy viscosity on the resultant flow field. Simulations using a constant eddy viscosity can yield flow fields quite similar to the variable eddy-viscosity solution determined from the turbulence model. However, the question remains, whether a field engineer (or anyone else) can reliably guess the appropriate eddy viscosity for a wide range of flow conditions involving single or multiple dikes of various lengths.



Case A: Variable Viscosity Dictated by Turbuluence Model

Case B: Fixed Viscosity (0.004 ft^2/sec)

Case C: Fixed Viscosity (0.008 ft^2/sec)

Case D: Fixed Viscosity (0.002 ft^2/sec)

Figure 1. Flow past a dike (streamlines)

Curved channels

A second feature which uniquely defines the capabilities of the STREMR model is the influence of flow curvature on the depth-averaged flow field. In a natural curved channel, centrifugal forces generate a secondary flow perpendicular to the direction of the main flow. This secondary flow results in a helical particle trajectory, causing higher velocities to migrate to the outside of the bend. This phenomenon also causes the channel thalweg to form on the outside of a channel bend and a point bar to form on the inside of a channel bend. If no correction is added for the secondary flow, depth-averaged models may overestimate the amount of flow passing through the inside portion of a curved channel section. STREMR uses the interaction of lateral curvature, bottom friction, and depth nonuniformity in calculating the effect of secondary flow on the depth-averaged flow field. This correction allows STREMR to capture the migration of higher velocity components to the outside of channel bendways. The details of the development of the secondary flow correction for STREMR are described in Bernard and Schneider (1992).

To test the performance of STREMR in simulating the depth-averaged velocity field in a curved channel, numerical model results were compared with observations of flow conditions made in a laboratory facility. The Riprap Test Facility located at WES is a trapezoidal channel with four bends and two reversals in curvature. The plan view and channel cross section are shown in Figure 2. The inflow is from left to right, and the arrow (plan view, Figure 2) indicates an observation station and the orientation of the observer. The flow distribution throughout this complex series of bendways was observed for a flow rate of 49.5 ft^3/sec and a Manning coefficient of 0.026. These measurements were averaged over the depth and compared with numerical predictions of the flow field.

The numerical predictions of the flow with and without secondary flow correction (SFC) illustrate the improvement in predictive capability provided by the curvature correction in the STREMR model. The migration of the maximum velocity to the outside of the first 90-deg bendway is shown in Figure 3. The maximum velocity occurs near the toe of the sloped outer bank. Without the secondary flow correction, the maximum velocity tends toward the inside of the channel. Similar results were found throughout the remainder of the test channel. Without a correction for secondary flow development in curved channels, numerical models will generally underestimate the currents along the outer bank. This could have serious consequences for the design and operation of river engineering works.

Conclusion

The documentation and user's guide for the STREMR model is available in Technical Report REMR-HY-11, "STREMR: Numerical Model for Depth-Averaged Incompressible Flow" (Bernard 1993). The STREMR model and accompanying grid generation and visualization software can be obtained by contacting Dr. Bernard at (601) 634-2491.

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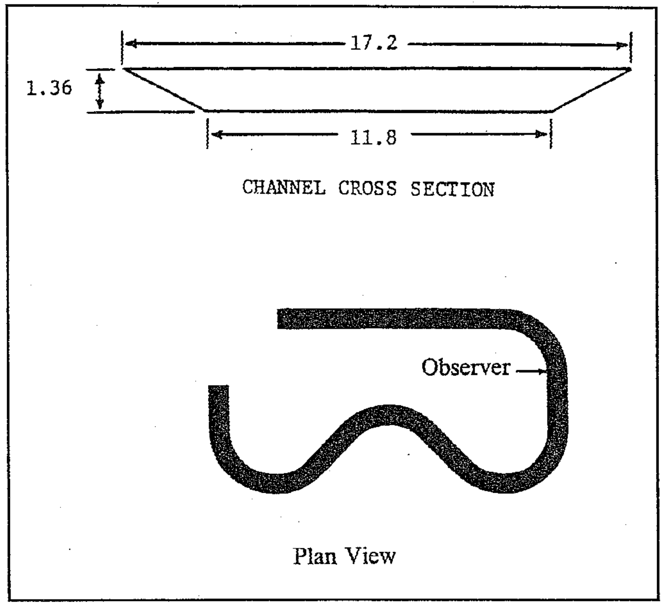

Figure 2. Riprap test facility

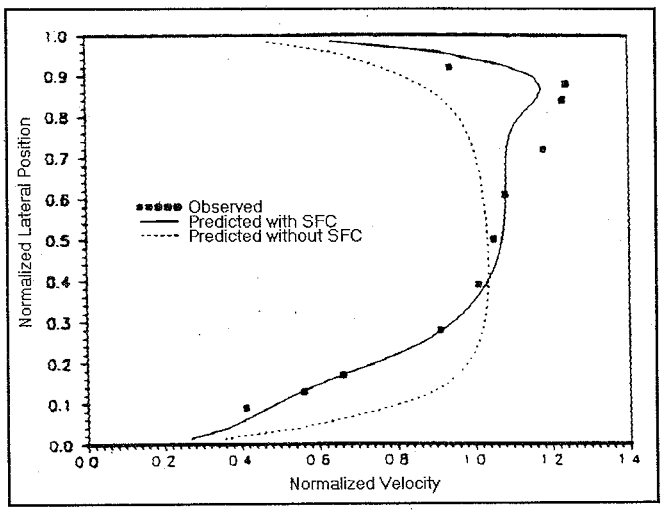

Figure 3. Observed and predicted normalized velocity distribution downstream of a 90-deg bendway

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Surveys of concrete armored coastal structures

by
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Concrete armor units (CAUs) are used to protect coastal structures from erosion when stone is not economically available. These structures include breakwaters, jetties, groins, and revetments. CAUs come in a variety of shapes (Figure 1) and can be placed quasi-randomly or uniformly and range in mass from 1 to 50 tons. CAU shapes commonly used in the past by the Corps of Engineers include the dolos, tribar, and tetrapod.

CAU shapes generally can be grouped according to how the shape resists movement. Blocky shapes resist movement primarily through self weight and surface friction, whereas slender shapes have additional movement resistance through the interlocking of slender appendages. Historically, slender armor units, such as the dolos, tribar, and tetrapod, have had a high degree of breakage because impact loads, induced by unit movement, produce high stresses in relatively weak slender central sections. Reinforcing bars and fiber reinforcement have been used in many Corps CAUs but have provided little apparent performance improvement. Under the REMR work unit "Breakwater Concrete Armor Units for Repair," the Coastal Engineering Research Center (CERC), Waterways Experiment Station, has been tasked with improving the hydraulic stability and structural capacity of existing armor shapes and ultimately with the development of optimal armor unit shapes that are more stable and stronger than existing units.

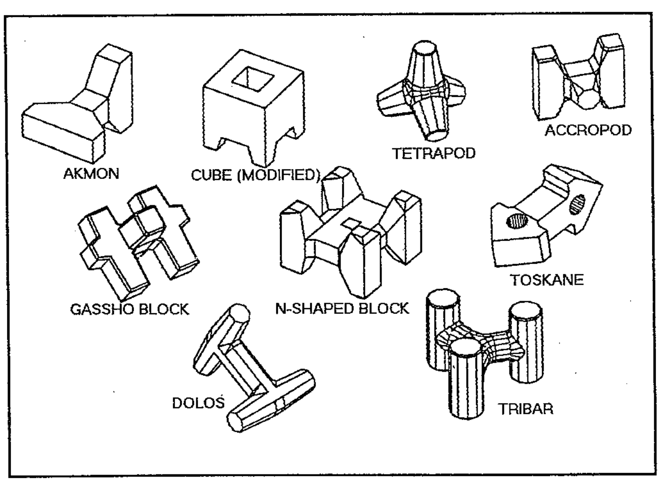

Figure 1. Various concrete armor unit shapes

In 1992 and 1993, personnel from CERC and Corps Districts conducted detailed performance and breakage surveys of several U.S. concrete armored structures, as listed in Table 1. The surveys consisted of above-water field inspections with the types and locations of armor breakage documented and logged on previously made aerial photographs. The survey results have already been used to assist in the improvement of design methods for dolosse and in the development of an improved armor unit shape called the CORE-LOC. Further analysis of the survey results will be used to document long-term performance of concrete armor, continue verification and expansion of recently developed armor design guidance, and refine guidance on concrete armor construction practices. The survey data have been examined and are discussed in this article (a) to provide insight into CAU failure mode and causal relationships; (b) to evaluate gross structural elements in order to identify critical areas of the breakwaters; and (c) to compare breakage counts to a previous survey conducted at several sites in 1983, with an intent to establish trends for use in design of rehabilitations and evaluation for repair.

Survey findings

Seven structures have been surveyed to date (Table 1). Dolos, tribar, and tetrapod CAUs were inspected. Both reinforced and unreinforced dolosse and tribars were the primary armor shapes in service on the surveyed structures. Dolos sizes on surveyed structures ranged from 2 to 42 tons, and tribar sizes ranged from 6 to 50 tons. Surveys of the remaining Corps concrete armored structures are planned.

Unit failure

One component of the study was to assess armor unit failure modes by cataloging all in situ broken armor units.

a. **Dolos failures.** The failure modes for broken dolosse were categorized as either flexure or torsion dominated. Distinction of the failure mode was made based on the character of the exposed failure surface, with torsion-dominated failure surfaces being at 45 deg to the longitudinal member axis and flexure failures being orthogonal to the member axis. Failures denoted as "flexure" included those due to bending as well as those due to shear and axial loads because it was not possible to discriminate among these failure modes on the basis of failure surface characteristics. Armor strain measurements in physical-model studies will be used to further separate the fraction of flexural shear and axial-dominated failures. Figure 2 shows the percentage of the total failures that were either torsion or flexure dominated. As can be seen from this graph, flexure was the dominant failure mode. Breakage was observed throughout the dolos shape but occurred predominantly in the shank at the shank-fluke interface (Figure 3). Figure 4 shows a typical example of a shank failure that was considered torsion dominated, and Figure 5 shows a flexure-dominated shank failure. Figure 6 shows a typical fluke that failed due to flexural shear.

b. **Tribar failure.** Tribars tend to fail at their central node. The slender spars typically failed in flexure (Figure 7). Also noted were failures of the cylindrical sponson. Both failure modes are most likely due to unit-to-unit impacts.

Table 1
CAU Breakage Survey Results

Structure Identifier	CAU Type, Size, Location, Date Identifier[1]	No. of Units Placed	No. of Units Broken		Percent of Units Failed	
			1992 or 1993	1984	1992 or 1993	1984
Cleveland[2]	DO-2-CL-80	29,700	782	487	2.6	1.6
Cleveland[2]	DO-4-CL-87	250	7	N/A[3]	2.8	N/A
Crescent City[2]	DO-42-CC-86	760	12	N/A	1.6	N/A
Humboldt N[2]	DO-42-HN-72	1,292	8	11	0.6	0.9
Humboldt N[2]	DO-43-HN-72	967	8	11	0.8	1.1
Humboldt S[2]	DO-42-HS-72	1,090	9	6	0.8	0.6
Humboldt S[2]	DO-43-HS-72	1,445	9	6	0.6	0.4
Kahului E	TP-33-KE-56	200	N/A	4	N/A	2.0
Kahului E	TB-35-KE-66	827	2	6	0.2	0.7
Kahului E	TB-50-KE-66	43	0	0	0.0	0.0
Kahului E	DO-20-KE-77	164	0	2	0.0	1.2
Kahului E	DO-30-KE-77	610	0	1	0.0	0.2
Kahului E	DO-06-KE-77	455	9	6	2.0	1.3
Kahului E	TB-09-KE-84	755	0	0	0.0	0.0
Kahului W	TP-33-KW-56	400	N/A	9	N/A	2.3
Kahului W	TB-50-KW-66	173	1	0	0.6	0.0
Kahului W	TB-35-KW-66	181	0	2	0.0	1.1
Kahului W	TB-19-KW-69	260	6	15	2.3	5.8
Kahului W	TB-19-KW-73	80	0	0	0.0	0.0
Kahului W	TB-35-KW-73	25	0	2	0.0	8.0
Kahului W	DO-20-KW-77	291	13	18	4.5	6.2
Kahului W	DO-30-KW-77	257	8	3	3.1	1.2
Kahului W	TB-25-KW-84	10	0	0	0.0	0.0
Kahului W	TB-11-KW-84	N/A	0	0	N/A	N/A
Kahului W	TB-06-KW-84	540	0	0	0.0	0.0
Nawiliwili	TB-18-NI-59	598	16	0	2.7	0.0
Nawiliwili	DO-11-NI-77	485	40	0	8.2	0.0
Waianae	DO-02-WE-79	6,633	222	170	3.3	2.6

[1] Type = DO for dolos, TB for tribar, and TP for tetrapod; size = armor size in tons; date = year placed. Cleveland 1987 rehabilitation number of units is approximate.
[2] Survey was completed in 1993; otherwise, surveys were completed in 1992.
[3] N/A = not available.

c. **Spalling.** Two types of spalling were observed. Unstable units that were obviously rocking under wave loading showed signs of spalling due to repeated impact. Spalling was observed both on tribars and dolosse. Reinforcement-induced corrosion spalling was in evidence in both CAU types. The steel reinforcing bars had corroded and expanded, causing sections of the overlying concrete to spall. Figure 8 shows spalling on a dolos and the resulting increase in exposed reinforcing bars.

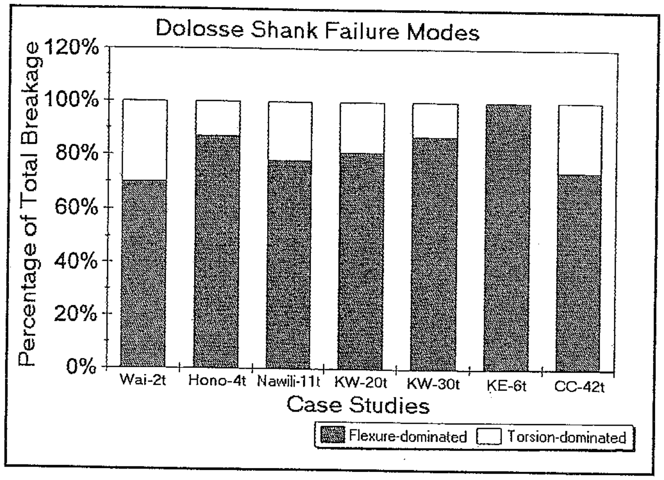

Figure 2. Dolos failure modes

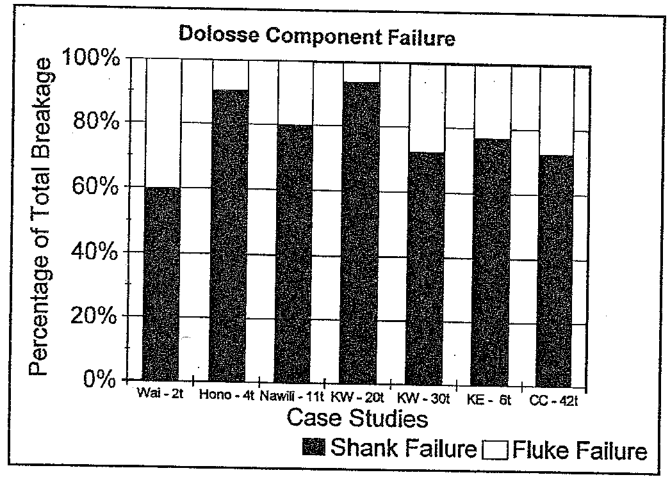

Figure 3. Dolos component failure

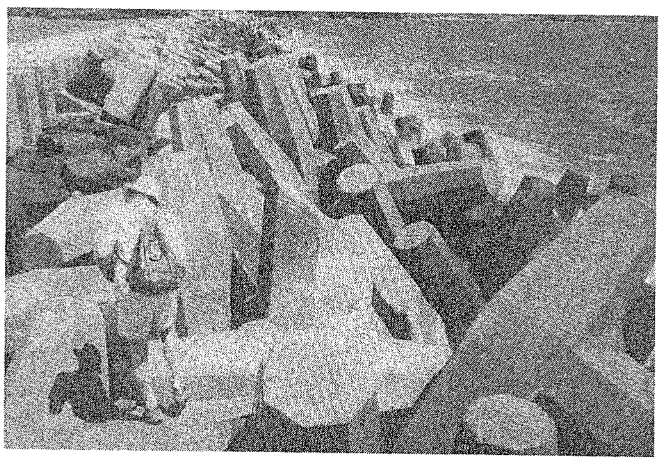

Figure 4. Typical torsion break of dolos shank

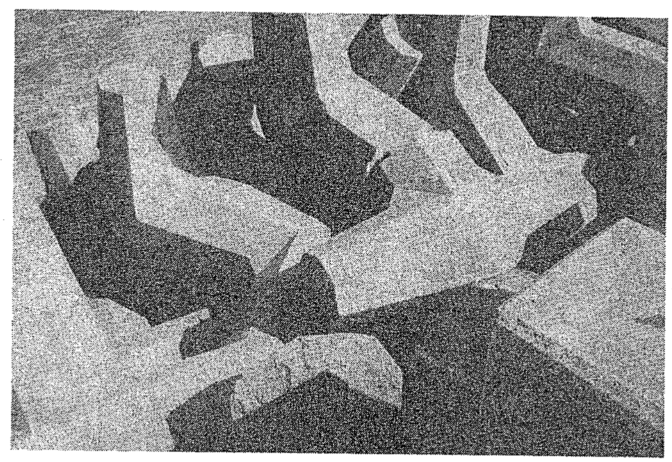

Figure 5. Typical flexure failure of dolos shank

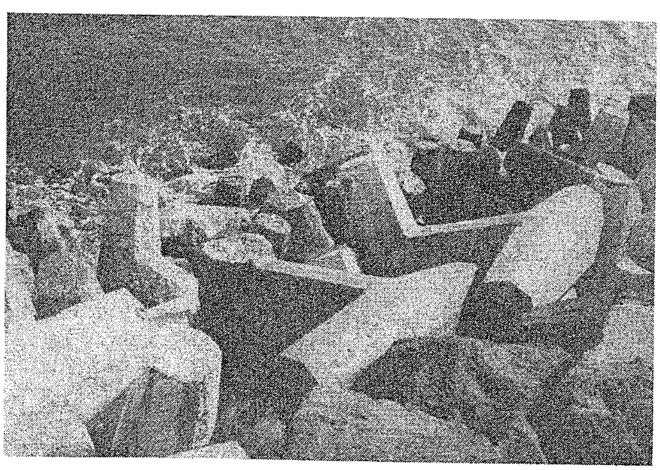

Figure 6. Dolos with fluke section sheared off

Figure 7. Tribar failure at central node

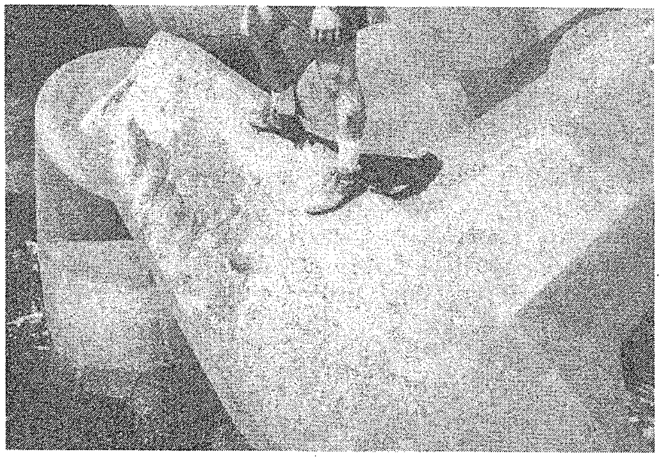

Figure 8. Corrosion of reinforcing bar causing spalling of dolos

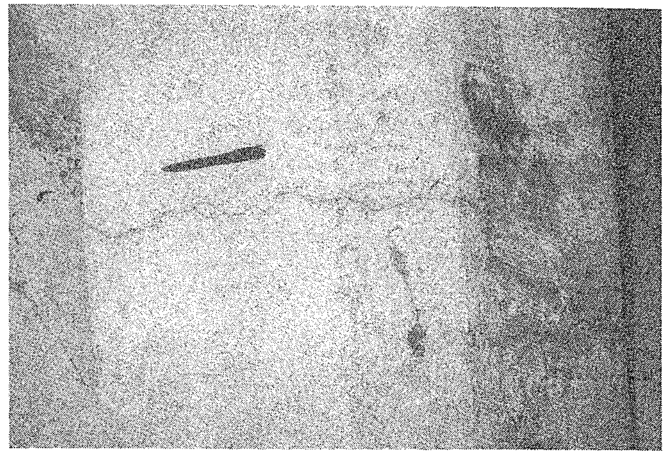

Figure 9. Crack in concrete rib cap at Kahului West

Comparison with past survey

In order to establish trends, the results of the recent surveys were compared with survey results compiled in 1984 (Markle and Davidson 1984). The comparison is presented in Table 1. The structures with significant increases in breakage are Cleveland, Nawiliwili, and Waianae. Small decreases or increases in breakage are difficult to interpret because of differing survey techniques and because, over time, broken armor pieces can move down under the still-water level and become hidden.

Conclusions

CAU breakage can be primarily attributed to several factors: lack of adequate concrete quality control, rough handling, improper placement techniques, wave-induced rocking, and static loading with severely constrained boundary conditions. For Corps structures, breakage of armor appears to be due to a broad mixture of these items, with each structure having a different combination. All of the present Corps structures were built prior to the recent development of CAU structural design guidance. Consequently, nearly all structures appear to be slightly underdesigned with respect to strength.

For main armor that is not near a transition and is constructed correctly with sufficient strength concrete, breakage appears to be primarily the result of movement. Randomly placed armor layers will always have some movement, and breakage of these noninterlocked units is acceptable as long as the surrounding interlocked armor is not affected. Stable dolos and tribar slopes will typically have between 1 and 2 percent of the units rocking during design conditions. Without significant reinforcement, these units will likely fail, but the remaining slope can remain intact. But the surveys seem to indicate that the structures may continue to loosen and renest, particularly at transitions, and armor units in these areas may continue to unlock, begin moving, and break over the lifetime of the structure.

The Humboldt jetties have very little armor breakage for their age. The conventional reinforcement in the dolosse provides approximately 20-percent increase in flexural capacity and no increase in torsional capacity over the unreinforced section. The fiber reinforcement provides approximately 10-percent increase in tensile strength. Surveyors could find no cracking at critical cross sections, so it is unlikely that the flexural reinforcement is the primary reason for the superior performance. The lack of breakage appears to be due to a combination of high concrete tensile strength and shiplap placement of the dolosse, where upslope units overlie downslope units. If strictly adhered to, this placement configuration can significantly reduce the amount of movement and therefore breakage.

Several Corps structures have CAU layers with more than 2-percent above-water breakage. The majority of this additional breakage appears to be due to instability at transition areas and noninterlocked or upslope-overlaid repair units. But at Waianae, the majority of the breakage was apparently due to rough handling during construction. The instability at transitions can be minimized through buttressing and careful attention to interlocking. Cap or crown transitions may require additional attention for structures that are frequently overtopped. Building repair sections, where upslope units overlie downslope units, is difficult with limited repair budgets. It may be possible to repair in inverted triangular-shaped sections, where a triangular-shaped section, with the triangle apex near the toe, is disassembled and rebuilt in a shiplap fashion. However, it should be noted that slender repair armor units placed individually on top of an existing slope will likely break.

Past breakage surveys have been primarily visual inspections above the still-water level. Underwater visual inspections are of limited or no value in low visibility coastal areas, and diving near coastal structures is often very dangerous. But new multibeam sonar technology, as being used in research under the REMR work unit "Quantitative Imaging and Inspection of Underwater Portions of Coastal Structures," is being evaluated for use in future breakage surveys. Identification of underwater breakage of armor units is critical because of the importance of the toe to the integrity of the structure and because it is probable that the percentage of broken or displaced units underwater may be as great as that abovewater.

Finally, recent research results combined with the surveys indicate that using recently developed Corps CAU strength and stability design guidance coupled with strict quality control measures during construction should significantly reduce CAU breakage on future structures.

Future developments

The collection of field data relating to concrete armor unit performance is an ongoing process. The remainder of Corps CAU-armored structures will be surveyed during 1994 and 1995, and a concrete core sample collection will begin in order to assess in situ CAU strength. The performance database on in-place concrete armor units is sparse, and any information on past projects using concrete armor units (concrete testing, unique problems during construction, etc.) would be of great value to the authors.

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

Reference

Markle, Dennis G., and Davidson, D. D. (1984). "Breakage of Concrete Armor Units; Survey of Existing Corps Structures," Miscellaneous Paper CERC-84-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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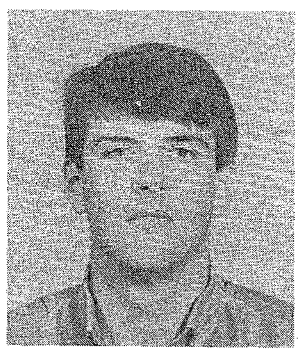

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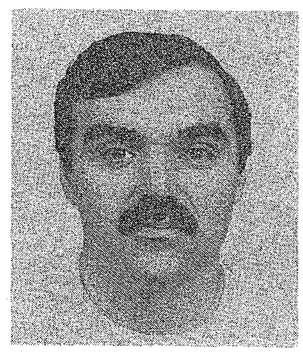

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