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of Engineers

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RESEARCH PROGRAM

REPAIR, EVALUATION, MAINTENANCE, AND
REHABILITATION RESEARCH PROGRAM

PROCEEDINGS OF REMR WORKSHOP ON REPAIR AND MAINTENANCE OF SHALLOW-DRAFT TRAINING STRUCTURES

24-25 February 1987

Compiled by

David L. Derrick

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

April 1991
Final Report

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Washington, DC 20314-1000

Under Work Unit 32324

The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Use of end dumping to repair Dike 332.5(L) by US Army Engineer District, Little Rock.

CENTER — Dike 332.5(L) being repaired, Arkansas River, US Army Engineer District, Little Rock.

BOTTOM — Dike 333.6(L), repairs completed, US Army Engineer District, Little Rock.

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13. ABSTRACT *(Maximum 200 words)*

Presented are the Proceedings of the Workshop on Repair and Maintenance of Shallow-Draft Training Structures. The repair of riverine shallow-draft training structures has been and will continue to be a significant maintenance cost within the US Army Corps of Engineers. The main purpose of the workshop was to gather together the working-level river engineers involved in dike repair and provide a forum in which to exchange experi- ence, methodology, and problems faced by each Corps District. A secondary purpose was to enable the people involved in this REMR work unit to gather information and establish contacts within the Districts to accomplish the stated goals of the work unit.

These proceedings provide a summary of the following: the presentations by the Districts, the discussion periods, and the summarization and conclusions. The discussion periods focused on unusual repair techniques used and future research needs in the field of dike repair.

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11. SUPPLEMENTARY NOTES (Continued).

A videotape containing the presentations of each District is available. The discussion periods were not filmed. To obtain a copy of the videotape, please contact:

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PREFACE

The Proceedings of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program Workshop, "Repair and Maintenance of Shallow-Draft Training Structures," conducted 24-25 February 1987, were prepared for the Headquarters, US Army Corps of Engineers (USACE), by the US Army Engineer Waterways Experiment Station (WES). The proceedings provide a record of the presentations given by the participating Corps Districts, plus two discussion periods entitled "Repair Techniques" and "What Research is Needed in the Field of Dike Repair?", and the summarization and conclusions.

The meeting was organized by WES under the direction of Mr. Robert F. Athow, Estuarine Engineering Branch, Estuaries Division, Hydraulics Laboratory, WES, REMR Work Unit Monitor; Mr. William F. McCleese, REMR Program Manager, WES; and Mr. Glenn Drummond, USACE Technical Monitor. Acknowledgements are extended to the following: Mr. David L. Derrick, Workshop Coordinator, Mr. David M. Maggio, videotape director and key gaffer, each of the speakers who gave a presentation during the first day of the workshop, and all attendees who joined in the discussions, making the workshop a success. The proceedings were recorded and compiled by Mr. Derrick, and reviewed by Mr. Maggio and Ms. Karen Anderson-Smith, all of the Potamology Group, Waterways Division, Hydraulics Laboratory.

Authorized by Headquarters, USACE, the workshop was funded by the REMR research program under Work Unit No. 32324, "Repair Techniques at Navigation Training Structures." Mr. Jesse A. Pfeiffer, Jr., was the REMR Coordinator at the Directorate of Research and Development; Mr. James E. Crews and Dr. Tony C. Liu served as the REMR Overview Committee. Mr. Glenn A. Pickering, Chief, Hydraulic Structures Division, was the Problem Area Leader.

A videotape containing the presentations of each District is available. The discussion periods were not filmed. To obtain a copy of the videotape, please contact:

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The Commander and Director of WES during preparation of these proceedings was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres
miles	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

PROCEEDINGS OF REMR WORKSHOP ON REPAIR AND MAINTENANCE OF SHALLOW-DRAFT TRAINING STRUCTURES

24-25 February 1987

PART I: INTRODUCTION

1. The Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Workshop on Repair and Maintenance of Shallow-Draft Training Structures was held at the main headquarters building, US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, on 24-25 February 1987. The workshop was sponsored under the REMR work unit, "Repair Techniques at Navigation Training Structures." Mr. Robert F. Athow of the WES Hydraulics Laboratory is the principal investigator for this work unit.

2. The purpose of the workshop was to provide the US Army Corps of Engineers Districts and Divisions engaged in dike repair with a forum for knowledgeable staff members to present their experience and current work practices in the area of shallow-draft training structure repair, evaluation, maintenance, and rehabilitation within the riverine environment. Also the future research needs of the Districts were explored. A total of 35 persons, representing 11 Districts, 2 Divisions, and WES, attended. The attendees and their organizations and telephone numbers are listed on page 5 of this report. All Districts engaged in shallow-draft training structure repair were well represented.

3. Most of the first day of the workshop was devoted to presentations by representatives of the participating Districts relating their experience, problems, and the current practices related to dike repair. The remainder of the workshop included discussion periods, a tour of five WES physical models, and summary and conclusions. A copy of the agenda is shown on page 7 of this report.

ATTENDEES

REMR Workshop on Dike Repair
Vicksburg, MS 24-25 February 1987

Name	Organization	Telephone Number
Dave Derrick	Waterways Experiment Station	601-634-2651
Bob Athow	Waterways Fxperiment Station	601-634-2135
Dick Sager	Waterways Experiment Station	601-634-3398
Bill McCleese	Waterways Experiment Station	601-634-2512
Mike Trawle	Waterways Experiment Station	601-634-3518
Dave Maggio	Waterways Experiment Station	601-634-3186
Dave Mueller	Waterways Experiment Station	601-634-3693
Jim Pennington	Waterways Experiment Station	601-634-3549
Herb Gernand	Waterways Experiment Station	701-237-7878
Danny Hare	Rock Island District	309-788-6361
David Borck	Rock Island District	309-788-6361
Marvin Martens	Rock Island District	309-788-6578
Ken Wrightman	St. Paul District	612-725-7592
Ken Underwood	Mobile District	205-694-4005
Maurice James	Mobile District	205-694-4008
Fred Horn	Mobile District	205-229-1043
Claude Strauser	St. Louis District	314-263-5858
Greg Bertoglio	St. Louis District	314-263-5156
T. K. Grant	Vicksburg District	601-631-5617
John Sadler	Vicksburg District	601-631-5619
James Ross	Vicksburg District	601-631-5621
Ross Jarrell	Lower Mississippi Valley Division	601-634-5819
Steve Ellis	Lower Mississippi Valley Division	601-634-5919
Tom Burke	Kansas City District	816-426-3341
Charles Wyatt	Kansas City District	816-426-2751
Joe Burton	Kansas City District	816-426-5671
Robert L. Young	Little Rock District	501-378-6946
Donald Bratton	Little Rock District	501-378-5737
Dennis Johnson	Tulsa District	918-581-2216
Bill Wilson	Tulsa District	918-581-2216
Laurie Broderick	Portland District	503-221-6443

(Continued)

ATTENDEES (Concluded)

Name	Organization	Telephone Number
Fong Grey	Portland District	503-221-6465
Al Swoboda	Missouri River Division	402-221-7327
Andy Lowery	Memphis District	901-521-3391
Steve Earl	Omaha District	402-221-4136

AGENDA

REMR Workshop on Repair and Maintenance of
Shallow-Draft Training Structures

Main Conference Room, Headquarters Building, WES

24 February	Presentation	Speaker
8:30	Registration at Main Conference Room	
9:00	Welcome	Dick Sager, WES
9:10	Opening Remarks: REMR General Status	Bill McCleese, REMR, Program Manager
9:20	REMR Repair Techniques Work Unit Overview	Bob Athow, WES
	Presentations from the Districts	
9:30	IOMT Work Unit Review	Mike Trawle, WES
9:45-1:45	Current Repair and Maintenance Practices	Laurie Broderick, Portland District
10:00		Claude Strauser, St. Louis District
10:15		Danny Hare, Rock Island District
10:30	BREAK	
10:45		Tom Burke, Kansas City District
11:00		Andy Lowery, Memphis District
11:15		Robert Young, Little Rock District
11:30		Dennis Johnson, Tulsa District
11:45		Steve Earl, Omaha District
12:15	LUNCH	
1:15		T. K. Grant, Vicksburg District

(Continued)

AGENDA (Concluded)

24 February	Presentation	Speaker
1:30		Ken Wrightman, St. Paul District
1:45	Effects of Notched Dikes on Fish Habitat	Jim Pennington, WES
2:00	BREAK	
2:15	Discussion: Repair Techniques	
4:00	ADJOURN for the Day	

AGENDA - DAY 2

25 February	Presentation	Speaker
8:30	Tour of WES Models Lock & Dam 3, Red River Estuarine Training Structure Groins and Dikes Research Model Dogtooth Bend Reach, Mississippi River Greenville Bridge Reach, Mississippi	David L. Derrick, WES
10:10	BREAK	
10:30	Discussion: What Research is Needed in the Field of Dike Repair?	
12:15	LUNCH	
1:15	Summary and Conclusions	Bob Athow, WES
2:15	ADJOURN	

PART II: MINUTES OF THE WORKSHOP

4. Mr. Richard A. Sager, Assistant Chief of the WES Hydraulics Laboratory, welcomed the participants and opened the workshop with a brief history and description of WES and the types of work its laboratories carry out. Mr. Sager also touched on the subject of the importance of workshops, saying they were invaluable in procuring information used to accomplish research at WES.

5. Mr. William F. McCleese, WES, REMR Research Program Manager, summarized the general status of the REMR program. The overall objective is to identify and develop effective and affordable technology to maintain, and where possible, extend the service life of Corps civil works projects. REMR is a civil works research program. It was approved as a 6-year, $35-million effort, which is now at its midpoint and is scheduled to end in Fiscal Year (FY) 1989. REMR is divided into seven problem areas: hydraulics, geotechnical, environmental, coastal, concrete and steel structures, electrical and mechanical systems, and operations management. The Hydraulics Problem Area has eight work units. The work unit sponsoring this workshop is titled "Repair Techniques at Navigation Training Structures." Products of the REMR effort will include technical reports, workshops, video reports, training courses, REMR notebooks, and video training films. After the REMR program is finished, the REMR Bulletin, REMR notebooks, and updating of established data bases will continue. Two other services will be provided: short-term support of field personnel in the use of REMR products, and new research, which will be conducted on problems not addressed by the original REMR program.

6. Mr. Robert F. Athow, Project Engineer, Estuaries Division, Hydraulics Laboratory, gave an overview of the REMR Repair Techniques Work Unit.

Presentations

IOMT Work Unit Review

7. Mr. Michael J. Trawle, Chief, Math Modeling Group, Waterways Division, Hydraulics Laboratory, spoke on the "Estuarine Channel Maintenance by Training Structures" work unit, which is part of the Improvement of Operations and Maintenance Techniques (IOMT) program. Through a series of Vu-Graphs, Mr. Trawle showed how the work unit covers deep-draft estuarine structures but

is mainly concerned with structure site selection, not maintenance. In selecting the correct site for a structure, Mr. Trawle is attempting to reduce shoaling in estuary navigation channels and basins. The first task was to inventory all estuarine structures, of which there are over 800.* This inventory includes a brief description and location map of each structure. Structures were then classified into four categories: constricting dikes, aligning dikes, barrier dikes, and within-estuary jetties. Examples were given of each. Constricting dikes are lateral spur dikes used to narrow a deep-draft navigation channel. Aligning dikes are longitudinal dikes, some of which are several miles in length, designed to streamline flow in the main channel and improve the channel's sediment transport capability. Estuarine jetties are used to protect harbor entrances. Barrier dikes are long dikes perpendicular to the shoreline used to protect deep-draft navigation channels by blocking crossflow currents that would normally deposit sediment in the shipping channel. This work unit also looked at successful and unsuccessful applications of these four types of estuarine structures in different prototype situations.

8. Some laboratory tests with an arrangement of spur dikes in a small flume have been completed. A study using a large flume is now underway looking at basic constricting dike design. Variables that will be studied include dike length, spacing, alignment, and permeability. Data sets from these studies will be used in high-resolution computational grids in numerical models.

9. The numerical modeling portion of this IOMT program consists of the following:

a. A comparison of several different numerical models to data obtained from the small flume studies for verification purposes.

b. Modeling the Columbia River Estuary using the TABS system.

c. A study of permeable spur dikes on Puget Island in the Columbia River.

Reports available from this program include the aforementioned inventory of structures; a report by Baker, Iannelli, and Manhardt of the University of Tennessee on applications of finite element algorithms to estuarine training

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* Walter E. Pankow and Michael J. Trawle. 1988 (Aug). "Inventory of Training Structures in Estuaries," Technical Report HL-88-20, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

structure analysis*; and a paper on the TABS-2 numerical modeling applications on estuarine training structure effects on navigation channel performance.**

Current Repair and
Maintenance Practices

10. Portland District. Ms. Laurie Broderick, Portland District, noted that there are three dikes on the Cowlitz River in a shallow-draft environment, but most of the 236 dikes are on the deep-draft portion of the Columbia River. The navigation channel on the Columbia River has a minimum depth of 40 ft† and a width of 600 ft from the mouth to mile 101. Several turning basins are wider than 600 ft. Permeable timber pile dikes are located from mile 136 to mile 4. Some of these dikes are exceptionally long, up to 5,000 ft, and some are very short. All pile dikes are designed for tidal action. A design criterion that is of critical importance is fish passage. Portland District has to worry about the downstream migration of fish fingerlings and the upstream migration of adult fish, which is one of the reasons the dikes are permeable. When the fish travel along the shoreline, they can pass through these structures. When these structures are repaired, the District has to keep permeability in mind. The District has everything from dikes in deep water, up to 50 ft, to dikes that are buried by sediment. These dikes consist of two rows of timber piles 2.5 ft on center with spreaders between the two rows and dolphins used to tie together the stream end. In the tidal area, the situation is slightly different. There the dikes consist of three rows of piles with spreaders and whalers in between. The extra bracing is used to counteract the strong tidal flows. These dikes are designed to be completely wetted during a tidal cycle. The spreaders are built at whatever height is easiest to work on during the construction season. Stone is placed on the riverbed around some of the piles for scour protection, with a heavier concentration of stone toward the channel end. Maintenance costs range from $1 to $30 per linear foot depending on location, tide, depth of water, and

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* A. J. Baker, G. S. Iannelli, and P. D. Manhardt. 1988 (Sep). "A Taylor Weak Statement Finite Element CFD Algorithm," Technical Report Comco TR 88-25.0, Computational Mechanics Corp., Knoxville, TN.

** R. F. Athow, D. R. Richards, and M. J. Trawle. 1987. "Numerical Modeling of Estuarine Training Structure Effects on Navigation Channel Performance," Coastal Zone 87 Conference, American Society of Civil Engineers, May 1987, Seattle, WA.

† A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

accessibility of the dike. Between 1979 and 1985, $400,000 was spent on dike repair. Most dikes on the Columbia River are close to 50 years old and are approaching their design life.

11. The question the District is faced with is, are all dikes needed, or just some, and which are they? These questions were addressed by "The Lower Columbia River Maintenance Improvement Review," a plan of action designed by the District to guide dredging and pile dike repair. A value engineering team was formed to evaluate every pile dike on the river. All pile dikes in the Lower Columbia Project are constructed of timber piling. Dikes were built on the Columbia River for one of two reasons: (a) to provide a place to put dredged material, in essence, to protect the islands of dredged material, or (b) to improve the deep-water channel hydraulics, i.e., to reduce shoaling and to widen the channel to improve navigation. Most dikes were built in systems with a dike length of 2,000 ft and spaced 2,000 ft apart. Data, including year constructed, year of last maintenance, original construction length, current length, current condition, photographs of each dike, cost of repair per unit foot, depth at the channel end of the dike, and dredging frequencies in the area of the pile dike, were assembled and printed on Mylar sheets. This was done for every dike on the river. A group consisting of the value engineering team, dredging consultants, and riverboat pilots will meet to review the assembled data and choose which dikes are important. This team will divide the river into four reaches, "prioritize" the dike systems within each reach, and prioritize the dikes within each dike system. Each dike will be rated, and only the highly rated dikes will be repaired.

12. Another project of the Portland District is rehabilitating old pile dikes at Cottonwood Island on the Columbia River just downstream of the confluence of the Columbia and Cowlitz Rivers. In 1980, the Cowlitz River deposited 24 million cubic yards of sediment in the Columbia River from the Mount St. Helens volcanic eruption. Instead of the normal 40-ft depth, the channel was only 14 ft deep for a distance of 7 miles. The channel was dredged to open it up and the dredged material deposited on Cottonwood Island. Rock removed from the Bonneville Lock and Dam project will be used to repair the Cottonwood Island pile dikes to a height of 10 ft below the water surface, also called zero Columbia River datum. No rock will be placed within 100 ft of shore. Both of these measures are taken to allow for fish passage.

13. The Portland District is currently studying the Westport Reach of

the Columbia River, encompassing river miles 54 to 28. This study is aimed at improving methods of in-water dredged material disposal, river training structure maintenance, and dredging.

14. St. Louis District. Mr. Claude Strauser, St. Louis District, stated that the St. Louis District has 300 miles of the Mississippi River from Hannibal, MO, to Cairo, IL, and they are a transition District; i.e., two different kinds of river engineering are practiced. Upstream of St. Louis, navigation is obtained using locks and dams; and downstream of St. Louis, dredging, dikes, and revetments are used.

15. "To repair a dike, you need to know how to build one." Using slides, Mr. Strauser explained the history of dike and revetment construction in the St. Louis District. The earliest dikes on the Mississippi River were floating whiskey kegs with a screen attached. The idea was to slow the velocity down so that sediment was deposited. The life of this type of dike was short, typically a year or less. A single row of timber piles with a wire screen on the upstream face was tried next, but this also had a short life. Two rows of piles with the second row bracing the first pile was then tried. This was more effective. In more modern times, clumps of piles connected with horizontal stringers proved successful. Lumber screens were added to encourage deposition. An average of 400,000 to 1 million tons of suspended sediment passes St. Louis every day. In the mid-1960's, stone was used to improve or repair existing pile dikes. Since then, almost all dikes have been built of stone. The material used is quarry-run Graded Stone A, with a top size of 5,000 lb. The stone is barged into place and a dragline used to place the stone. Mr. Strauser also gave a short history of revetment, starting with willow and lumber mats sunk with stone. Next was hand-placed stone revetment, then today's technique, using a dragline and casting the stone up on the bank.

16. One of the problems the St. Louis District faces that many southern Districts do not have to contend with is ice. This is a major cause of concern, and under certain conditions, can cause considerable river training structure damage. "Above St. Louis the river freezes over every winter, and below St. Louis it will or it won't," depending on weather conditions. In the pool area the shipping interests remake their tows into a push-pull configuration to keep a narrow channel open. Even on the open river the ice floes can pack together. In the winters of 1977 and 1979, over 100 miles of ice sheet completely shut down shipping on the river below St. Louis. "If the ice cover

goes out nice and easy, maintenance costs on dikes and revetments won't be too bad, on the order of several million dollars; but if it breaks up badly, maintenance costs from dike and revetment damage will be considerably more." The most damage occurs when the ice forms a hanging dam or gorge. The water level rises on the upstream side and falls downstream of the gorge, causing a large head differential. "An ice gorge can only last about 24 hr on the Mississippi River, because when the head differential gets to about 8 ft, it blows out and takes all the dikes, revetments, buildings, warehouses, wharfs, and whatever else you can think of down the river. In some places we couldn't even find where there had been any dikes or revetments. These were stone structures." Ice problems and damage are always a matter of concern.

17. Mr. Strauser stated that the St. Louis District "has never had enough maintenance money to take care of all the problems. You have to set priorities." When you "prioritize," the most important question is "What are the consequences of failure?" Can you allow the river to cause problems in a certain area? To illustrate his point, Mr. Strauser cited two examples: the Dry Bayou area and the floodwall at Cairo, IL. The river has attempted to form a cutoff at Dry Bayou during high stages. This is an expensive high-maintenance area, but the District maintains it because it is cheaper to maintain than if the river were allowed to change course. The bank line at Cairo will always be maintained; otherwise the town will be lost. In some places, dikes or revetments cannot be allowed to fail. In other areas, maintenance can be delayed, with few adverse effects.

18. Mr. Strauser outlined some keys to successful dike maintenance and repair:

- a. Good, reliable records of dike construction and repair work need to be kept.
- b. Structures need to be continuously monitored and evaluated using photographs, inspections, and surveys.
- c. The maintenance program needs to be prioritized using the consequences-of-failure question. This can be divided into two categories: the engineering consequences and political or public relations consequences of allowing something to fail.
- d. The final decision in many instances boils down to using engineering judgment. Variables cannot be put into an equation and an answer cranked out.

19. Rock Island District. Mr. Danny Hare, Rock Island District, stated that all dikes in his District are submerged. Dredging frequency and quantity

dredged are the only indicators used to determine if a dike field needs repair. A typical field consists of 8 to 20 dikes. Past dredging costs for each section of the river are determined and a 5-year plan of action is implemented. This allows a long lead time for surveys and budgeting and adds flexibility to their plans. The dikes are surveyed, compared to as-built drawings, and built back to original specifications.

20. Once a year the Committee to Assess Regulated Structures (CARS) meets to review the 5-year plan. This committee consists of planning, engineering, operations, and environmental personnel. The amount of repair work for the year and which specific dikes need repair are determined in this meeting. Usually 60,000 to 80,000 tons of rock are placed each year by hired labor. Planning so far ahead builds in a certain amount of flexibility. This year some areas scheduled for repair are being skipped because of environmental concern for the Fat Pocketbook Clam, an endangered species, but this skipping around has caused few problems.

21. The Rock Island and St. Paul Districts face "absolutely monumental environmental problems" in maintaining the navigation channel. Emergent river training structures are prohibited and guidelines on depositing dredged material are very strict. Mr. Hare feels that restrictions are greater for his District than on the lower river. Mr. Steve Ellis, Lower Mississippi Valley Division (LMVD), asked if dikes are surveyed annually. Mr. Hare replied that the only time dikes are surveyed is when they are in the repair plan areas. Many of the dikes shown on the navigation charts were built between 1900 and 1920 to maintain a 6-ft channel and are no longer in existence.

22. Kansas City District. Mr. Thomas Burke, Kansas City District, through a series of slides, gave a tour of the Missouri River. The river, which starts in Montana and empties into the Mississippi River near St. Louis, is approximately 1,900 miles long. The bank stabilization and navigation project encompasses the lower 734 miles of the river, from Sioux City, IA, to the mouth. The Kansas City District oversees the lower 500 miles of the project. Above Sioux City are six mainstream dams and reservoirs. Within the navigation portion of the project there are no locks or dams; the channel is maintained and constricted using dikes. Minimum size of the navigation channel is 9 ft deep by 300 ft wide. The flow varies from 60,000 to 100,000 cfs at Rulo, NE, and stage varies from 5 to 10 ft annually. Many different types of control structures are used, including L-head dikes, revetments, chute

closure dikes, bankheads, convex dikes, concave dikes, crossing control structures, kicker structures, and low-elevation underwater sills. The first control structures were timber pile dikes and willow mattress revetment. Stone has been used for all structures since the 1950's. The Missouri River Project was completed in 1980. Since then, occasionally a new structure has been built, but the bulk of the work is maintenance of existing structures.

23. Damage to structures is caused by ice bridging, floods, and to a lesser extent, propwash from towboats. Mr. Burke showed an example of floodwaters destroying the toe-fill revetment and breaching a levee. With large-scale damage such as this, a stone-fill structure would be built to stop riverflow and encourage deposition in the blowout area.

24. Presented here, in no particular order, are considerations used for structure repair:

a. Integrity of the project.

b. Adequacy of navigation channel.

c. Presence of serious bank erosion.

d. Integrity of individual structures.

e. Integrity of structure system.

f. Environmental consequences.

g. Extent of damage.

h. Location of the structure.

i. Type of structure.

j. Available funding.

In some cases these considerations would be weighed equally; in other cases, some considerations would carry more weight than others.

25. Specific criteria for structure repair are as follows:

a. Serious bank erosion.

b. Inadequate navigation channel.

c. Structure degraded more than 2 ft in height.

d. Damaged area more than 100 ft long.

The rock used to repair the structures is usually quarried very close to the river and does not have to be transported more than 30 miles to the repair site. Quarry-run stone with a maximum size of 2,000 lb is used for all dike repair. Fines smaller than 1/2 in. cannot exceed 5 percent. Cost in place varies from $8 to $10 per ton. Mr. Burke then opened his presentation to questions.

26. In response to a question about dredging, Mr. Burke replied that a lot of dredging was carried out from the 1940's to the 1960's where bends were realigned and in areas where shoaling occurred in the main channel. In the last 8 to 10 years, as the project was virtually complete, very little dredging has been performed. Mr. Burke feels that during a prolonged drought, dredging would again be needed to clear shoals.

27. A question was asked as to who performs dike maintenance. According to Mr. Burke, the majority of repair work is done by contract, but jobs that are hard to estimate or that require complex specifications are done by hired labor. Hired labor jobs cannot exceed 10,000 tons of rock per year.

28. Mr. Athow wanted to know if Kansas City District had experimented with environmental cuts in their training structures. Mr. Burke explained that they had, with success. A notch 50 ft wide by 5 ft deep is cut into a dike or, in the case of a degraded dike, this area is simply not built back to grade. The bottom of the notch is usually 2 ft below construction reference plane (CRP). Approximately 1,200 dikes have been notched. The notch allows flow through the dike, which keeps the area downstream of the dike from filling in. This serves two purposes:

a. It keeps the bank from infringing on the flood-carrying capacity of the river.

b. It increases water surface area for wildlife habitation.

29. Mr. Ellis asked if the notches have decreased dike performance or increased maintenance costs. Mr. Burke replied that the District has not noticed any increase in maintenance costs. Dike performance has not been affected. The notches are designed to work at low and midbank flows. Most dikes are from 300 to 600 ft long, with the notch located 50 to 100 ft from the bank. Even if the notch causes some bank erosion, dike failure at this point is unlikely as most of the dikes extend hundreds of feet into the bank. Mr. Burke ended his presentation by handing out some pamphlets containing terminology and definitions used on the Missouri River.

30. Memphis District. Mr. Andy Lowery, Memphis District, presented a series of slides that showed dikes, typical dike damage, and methods used to repair damaged dikes. Work by the Memphis District, which oversees 355 miles of the Mississippi River, is authorized and funded by the Mississippi River and Tributaries Act of 1928. Dikes were originally timber pile, and construction methods were similar to methods outlined by Mr. Strauser of the St. Louis

District. All dikes built after 1963 have been constructed of quarry-run stone with an upper size limit of 5,000 lb. Dikes of various lengths and heights are built for several purposes. Dike types include trail, closure, transverse, and aligning dikes. Transverse dikes are the most common, built in systems at an angle of 90 deg to the current.

31. Causes of dike damage include the following:

a. River currents.

b. Floods or extended periods of high water.

c. Some ice damage but usually not a major problem.

d. Towboats hitting the dikes.

e. Drift and debris.

Aerial photographs are taken each year to spot dike damage. Towboat captains also report damaged dikes. The Navigation Section regularly patrols the river to check on the condition of dikes and revetments. The bulk of dike inspection is carried out on the low-water inspection tour. A small boat is used to observe and inspect each dike for damage. Any damage found is noted, the location is written down, and the damage is classified as either major or minor. A minor repair is defined as one in which the extent of damage to the dike can be visually determined and an estimate of the amount of stone needed to complete the repair can be easily made.

32. Minor repairs are handled under a stone repair contract that is let on a unit price per ton basis. This type of contract covers all minor repairs throughout the District. Simple specifications are drawn up noting location of damage and the estimated amount of stone needed to bring the dike up to original grade and section.

33. A major repair requires a survey of the dike to determine the amount of damage. Detailed plan specifications and profile drawings are produced and a repair contract for each dike is advertised. Stone cost is usually cheaper than in the minor repair contract. Sometimes the depth of the scour hole resulting from the damage precludes repairing a dike along the original alignment. In these cases the scour hole will have to be skirted.

34. All maintenance money is handled on a budgetary request. Historical records are used to estimate the amount of money needed for the coming year. Floods or other unforeseen events make this estimate difficult. If money is short during a year, the various repair projects must be "prioritized."

35. Mr. Lowery feels that unless the stone is displaced, these structures last indefinitely.

36. Little Rock District. Mr. Robert Young, Little Rock District, stated that Little Rock District is responsible for maintaining navigation on the McClellan-Kerr Arkansas River Navigation System from Fort Smith, AR, to the Mississippi River, a distance of 386 miles. The structures used on the Arkansas River are similar to the structures used on the Missouri River as described by Mr. Burke. Some pile structures were used in the beginning, but these have since been capped out with stone. All structures built from the mid-1960's on are of stone-fill construction.

37. Resident Office personnel using reconnaissance boats check the depths of the entire channel each week. Reaches that are too shallow or too narrow are surveyed. These surveys are furnished to the Navigation Branch and River Design Unit personnel for study. The reconnaissance personnel and landowners report damaged structures and damaged bank lines. The River Design Unit or Resident Office personnel then inspect the damaged areas.

38. Design Office personnel inspect the entire channel by boat once a year. They are accompanied by personnel from the Resident Offices, Navigation Branch, Southwest Division, the Coast Guard, and others. There are usually 25 to 30 people on this trip, all looking at different things. Damaged dikes and bank problems are noted on the navigation charts. The only dikes not inspected are those submerged in the pool areas.

39. "Since the primary purpose of the structures is to maintain navigation, we do not repair low areas of the structures unless maintained navigable depths and widths have become a problem, or if the low area has the potential to become much larger." Generally if the crown elevation has degraded 1 or 2 ft without any navigation problems, nothing is done. If the crown has degraded 4 or 5 ft over a length of 25 or 50 ft or more, then stone is usually added to the structure. The District tries to ensure that all structures stay attached to the bank. Scallops downstream of the dike have been a problem in the past. The scallops can enlarge, causing the dike to be flanked. Scallops are noted and recorded on the navigation charts. Aerial photographs are used to ascertain scallop growth. If it appears the dike will be flanked, the bankhead is extended downstream past the center of the scallop. Usual practice when building a dike is to pave the bank 25 ft upstream and 75 ft downstream of the dike.

40. Mr. Young used a series of slides to show how scallops had developed at various locations. It has not been determined why scallops develop downstream of some dikes but not others. Some instances have occurred where a dikehead has been stable for years, but then a scallop will develop rapidly.

41. Also shown was a flanked dike where 300 to 400 ft of bank line was lost.

42. Tulsa District. Mr. Dennis Johnson, Tulsa District, discussed the Oklahoma portion of the McClellan-Kerr Arkansas River Navigation System. Tulsa District faces the same types of river problems as Little Rock District. Navigation in the Tulsa District starts at Fort Smith, AR, on the Arkansas River, follows this river up to the Port of Muskogee, then transfers over to the Verdigris River and follows that up to the head of navigation at Port Catoosa, near Tulsa, OK. The channel on the Verdigris River is 9 by 150 ft and the channel dimensions on the Arkansas River are 9 by 250 ft. Within this system are a series of five locks and dams with a total lift of 120 ft. Lock size is 110 by 600 ft. The two high-lift dams incorporate hydroelectric power plants with generating capacities of 110 and 60 mw of power. A feasibility study is currently underway to determine costs versus benefits for a low-head power plant on Lock and Dam 14. Shipping tonnage is approximately 3.5 million tons per year consisting mainly of coal, petroleum products, grain, and fertilizers.

43. Mr. Johnson, through a series of slides, showed two areas where high flows in 1986 had damaged dikes. The confluence of two channels below Lock and Dam 17 had had a shoaling problem for years. A trail dike was built at the confluence, which solved the problem. The high water in October 1986 destroyed the trail dike, and the shoaling problem reappeared. Currently a contract to rebuild the trail dike to original specifications is being readied.

44. The second area discussed was the confluence of the Canadian and Arkansas Rivers in the upper reaches of the Robert S. Kerr Reservoir. Long training dikes were used to guide these rivers into the reservoir instead of converging with each other and then flowing into the reservoir. After the dikes were breached during the 1986 high-water flows, navigation problems again occurred on the Arkansas River. These dikes are scheduled to be built back to original specifications.

45. Omaha District. Mr. Steve Earl, Omaha District, stated that the

Missouri River Project was completed by the Engineering and Construction Divisions in 1981. After that, the project was turned over to the Operations Division. Omaha District oversees navigation on the Missouri from Rulo, NE, to Sioux City, IA, a distance of 234 miles. The major difference between the Missouri River in the Kansas City District and in the Omaha District is the six main stem dams, four of which are among the top twenty dams in the world.

46. Willow mat revetment and snag removal were carried out by the Corps as early as 1832. In 1927 Congressional authority was granted to develop and maintain a navigation channel from Sioux City to the mouth with a 6-ft navigation channel. In 1945 authority was granted to increase the channel depth to 9 ft. Under that authority $190 million was spent on original construction in the river. The length of the Missouri River was decreased 75.3 miles (9.3 percent) between 1890 and 1960. Mr. Earl feels that the work done on the river was well planned and well thought out, resulting in basically a maintenance-free river as far as dredging is concerned. No dredging has been performed since the 1960's. Operation and maintenance costs range from $1.5 million to $2.8 million annually, the variance depending mainly on construction contracts.

47. Areas of concern at this time include the following:

- a. Chronic depth problem areas (crossings).
- b. Increased channel velocities (the reach from Gavins Point Dam to Omaha, NE).
- c. Channel bed degradation (lowering).
- d. Channel capacity to pass floods.
- e. Increased stages at flood flows.
- f. Environmental impacts (concern of the future).

Underwater sill extensions of existing dikes have helped with the environmentalists' opposition to emergent structures. These have been developed and used over the last 15 years.

48. The basic maintenance criterion used for dike repair is that when 2 ft or more of dike degradation occurs, the dike will be repaired.

49. The plan used to meet the District's goal of maintaining the authorized 9- by 300-ft navigation channel includes the following:

- a. Additional new dikes where needed.
- b. Reevaluation of target flows.
- c. Dredging (at locations when and where it will have a lasting impact).

d. Providing up-to-date channel status reports.

50. Vicksburg District. Mr. T. K. Grant, Vicksburg District, through a series of slides, showed the location of work, mission, type of work involved, types of dikes used, typical dike failures, repair evaluation, and repair work undertaken by the Vicksburg District. The District is located between the Memphis and New Orleans Districts and oversees about 300 miles of the Mississippi River. The Mississippi drains approximately 41 percent of the continental United States.

51. The mission of the Vicksburg District is as follows:

a. Plan and design Mississippi River channel improvement works.

b. Design tributary bank stabilization works.

c. Program channel improvement funds.

d. Coordinate channel improvement activities with other Districts, LMVD, and local interests.

The District's goal is to provide an adequate channel for flood control and navigation (9 by 300 ft) using revetments, dikes, and dredging. One hundred sixty-four dikes have been built in the river, and 108 more will be built by the year 2010 to complete the master plan.

52. Mr. Grant showed slides of dike failures at Greenville Bridge, Cottonwood Bar, and Ajax Bar.

53. A low-water inspection tour is carried out each year to inspect dikes and revetments. Survey boats are also used to inspect dikes and to survey dikes to determine depth of failure on damaged dikes.

54. Untreated timber pile dikes were used up until the early 1960's. Some pile dikes are still in good shape; some are not. Stone has been used exclusively since then, usually quarry run with an upper size limit of 5,000 lb. End dumping from trucks is the preferred method of construction when building dikes on bars or in dry conditions. Floating plant is used where the water is deep enough for barges. Stone dikes have been found to be very effective and durable. High flows and floods have been the biggest cause of damage. Ice is not a problem in this District.

55. Two types of repair contracts are let, major and minor.

56. One million dollars per year is spent on major repairs. In this type of contract the repair sites and amounts of stone are specified. Stone costs between $7 and $9 per ton and is barged in from Kentucky.

57. Funding for the minor contract runs about $150,000 per year. Cost

per ton is $11 to $14. This is an open-ended contract, whereby the contractor can be directed to work anywhere on the river, depending on need.

58. Life of a dike depends on the following:

a. The river's unpredictable behavior.

b. Major floods.

c. Riverflow.

d. Dike configuration.

e. Navigation operations (minimal damage).

In reply to a question by Mr. Fred Horn, Mobile District, Mr. Grant stated that groundings on dikes rarely, if ever, happen in the Vicksburg District.

59. St. Paul District. Mr. Ken Wrightman, St. Paul District, explained that most structures in the District are submerged, similar to the structures in the Rock Island District. Of the four emergent structures within the District, two had been troublesome. Mr. Wrightman discussed these in detail. To block crosscurrents, a 650-ft trail dike was built below the Upper Saint Anthony Falls Lock and Dam on the Mississippi River. On the lock side of the dike, because of the steep side slope (1.5H to 1V) and ice action, displacement damage and benching had occurred. The riverside of the dike was constructed of derrick stone, again on a very steep slope. A typical derrick stone is approximately 3 by 3 by 7 ft. Erosion had occurred at the toe, causing the derrick stones to slide down the face of the dike. The dike is gradually deteriorating. The District would like to reshape the dike and flatten the side slopes, but removal of the large derrick stones will be costly and difficult. No firm plans for dike repair have been made.

60. Another structure with which the District has had problems is a breakwater at Lock and Dam 4. Because this structure was built in the winter, stone could not be barged in, and construction was accomplished by end dumping from trucks. Fine material was placed over the already-placed rock fill to form a roadway for the trucks. Because of wet conditions and a severe freeze, the fines were not completely removed. Wave action and higher-than-normal water levels washed the fines out of the dike, causing degradation of the dike and damaging a concrete walkway built on top of the dike. Repair plans have not been finalized.

61. Most dikes are built of stone with a maximum diameter of 36 in. and a minimum diameter of 4 in. When quarry-run stone is used, the specifications call for rock to be placed with a front-end loader with tines 4 in. apart

instead of using a dragline bucket. In deeper water, rock is placed using barges with dump gates in the bottom.

62. The navigable section of the Mississippi River under the jurisdiction of the St. Paul District extends from Minneapolis, MN, to just south of the Iowa-Minnesota State line. Thirteen locks and dams control navigation. Most submerged structures were built of stone and brush and are approximately 50 years old. They seem to have held up well. The only way to tell when there are problems is when dredging increases significantly. The Operation Section performs most dike observation. The Engineering Section, when needed, does all dike design and repair.

Effects of notched dikes on fish habitat

63. Dr. Jim Pennington is a fisheries biologist at WES who has studied several notched dike fields on the Missouri River. Mr. Burke had discussed notched dike design earlier in his presentation for the Kansas City District. Dikes placed in a river system can cause shifts in the types of habitats and in the sediment deposition patterns as the river rises and falls. The habitat quality in the pools between the dikes during low flows is quite different from the habitat quality found in the main channel. As a result, different species of fish are found in these areas, which closely resemble backwater areas of the river.

64. One indicator of habitat quality is the quantity (in pounds) of fish per acre. Some typical figures follow: Reservoirs in the southwest United States average 174 pounds of fish per acre (pfpa); borrow pits, 600 pfpa; and dike fields at low water, 215 pfpa. Dr. Pennington cited one example in the Ajax Bar dike field on the Mississippi River where 8,500 pfpa were netted.

65. Over a span of 27 years, from 1923 to 1950, some sections of the Missouri River have changed dramatically. The river is no longer a braided river but is now a narrow channelized river with a noticeable absence of backwater areas. Over 1,350 dikes have been notched in an effort to increase the backwater area. Recently the material removed when a dike is notched has been dumped a short distance downstream of the notch, forming a small reef. As the water flows through the notch, it hits the reef causing additional scour to occur.

66. A REMR study was conducted during the summer of 1986 to evaluate changes in aquatic habitat as a consequence of the notch and notch-with-reef

program. Nine dikes, three of each type, were studied in a reach of river above Omaha, NE. Water quality, sediment distribution, fish species, and current directions and velocities were studied. The only differences found were a slight increase in the number of fish with the notched-with-reef dike, and some differences in current speed and direction. A hydroacoustic fathometer was used to determine fish size. No differences in fish size were found.

67. The study did not prove that one type of dike was any better than the others. But the aquatic habitat area increased by 2 percent per structure at 0 CRP with the notched and notched-with-reef structures. At -2 ft CRP, aquatic habitat area was increased by 4 percent, and at -4 ft CRP the increase was 6 percent.

68. The notch program has been successful in reclaiming lost habitat area. Steep clay banks are also formed, which are prime habitat for caddis flies and mayflies, an important link in the food chain for fish.

69. In reply to a question by Mr. Athow, Mr. Burke stated that the selection of dikes to be notched was "almost random." Degraded dikes that needed repairs simply had a section left unrepaired. That section formed the notch. Other dikes were selected by visual observation, the "I think we ought to do a notch here" type of thinking.

Discussions

Repair techniques

70. Mr. Strauser gave a short presentation on the most cost-effective method used by the St. Louis District to repair a dike. "The most important rule to keep in mind is that you have to work with the river, not against it." The best way is to build or repair a dike in "lifts." Contractors do not like this method because they are "working in the dark" until the dike is built up high enough to break the water surface. To prevent scour at the toe of the section of the dike already completed, a 5-ft lift should be built out from this section at the end of the workday. Then, when work starts the next day, the contractor will be building on top of that lift instead of filling up a scour hole.

71. Mr. Athow asked if hand-placed stone revetment lasts longer than dragline-placed stone. Mr. Burke replied that on the Missouri River the

hand-placed stone held up better and lasted much longer but is no longer economically feasible.

72. Mr. Strauser noted that revetment damage occurs at the point of highest pressure. This is usually the middle third of the bend or the area directly across from the point bar. Repair costs for this high-pressure area are two or three times higher than repair costs for the rest of the revetment in the bendway.

73. Ms. Fong Grey, Portland District, told of a method used by Portland District called "plating." A large slab of steel is used to pound the rock smooth after the dike has been built. This has two benefits: (a) less debris is caught by the smooth stone, and (b) the surface is smooth for fish to migrate up and down the river.

74. This plating process is written into the specifications and is required by the fisheries and wildlife specialists. The plated areas appear to stay in place longer.

75. Mr. Burke stated that the Missouri Fish and Wildlife Department prefers irregular and rough surfaces on dikes and revetments on the Missouri River. This is termed "diversity of habitat." It allows a greater surface area to which zooplankton and other fish food organisms can attach. In the Kansas City District the contractor uses the dragline bucket to smooth the dikes. However, quarry-run stone contains a lot of fines; and after a few high flows the fines wash out, leaving the surface irregular.

76. Mr. Athow asked about the advantages and disadvantages of the end dumping method of dike construction. Mr. Grant said that end dumping was slightly more expensive. Mr. Young felt that end dumping resulted in a more compacted structure that stays in place better and holds grade longer. The crown width is 10 to 12 ft wide, whereas a floating plant-built dike will have a crown width of only 2 to 3 ft.

77. Mr. Greg Bertoglio of the St. Louis District stated that the District is requiring the contractor to come back during low flows to "dress out" dikes that were built during high water. This increases the life of a dike with no appreciable cost increase. The length of construction on a dike building contract in the St. Louis District is 365 days, so a smart contractor can take advantage of the variations in river stages.

78. Answering a cost question from Mr. Hare, Mr. Strauser stated that quarry-run stone is about $2 per ton cheaper than graded top size 400-lb

stone, so quarry-run stone is cheaper and the fisheries people like it better. The only place graded stone is used is in recreation areas where safety is a factor. Also, to obtain a cheaper price on stone, the river in St. Louis is divided into three 100-mile-long sections with each section having a separate maintenance contract. Yearly maintenance is concentrated on about a 30-mile stretch of each 100-mile section. Since the contractor does not have to move up and down the river as often, his price is cheaper.

79. Turning to the subject of maintenance budget estimates, Mr. Strauser stated that because of the unpredictable nature of the river, an accurate budget prediction is hard to make. "The more a river engineer knows his reach of river, the better he is at it." Unless unusual events (floods, ice, extended high water) are anticipated, the budget will have to be based on the maintenance costs associated with an average annual hydrograph. "Good records need to be kept and the history of the river used to project into the future, which all boils down to judgment." Mr. Lowery said that if you budget using costs associated with an average annual hydrograph and a flood occurs, the structures needing attention will have to be prioritized.

80. Mr. Ellis remarked that during a flood on the Mississippi River, priorities are assessed throughout the Division, all available maintenance money is gathered together, and it is funneled to those areas of highest priority. If more money is needed, the Division goes to the Headquarters, US Army Corps of Engineers (USACE), for additional funds.

81. In response to a question asking if dredging records were used in determining dike repair, Mr. Lowery said that dredging records were used to prioritize which sections of the river receive maintenance attention first. The thinking here is that maintenance on dikes will immediately decrease the amount of dredging needed.

82. Mr. Strauser feels that over the life of a project, as more and more of the entire project is completed, dredging will be reduced in the long run, but in any one year or group of years, this relationship cannot be assumed to exist. There are too many other variables besides dike repair that affect dredging. Dredging, among other things, is a function of the hydrograph and the amount of material introduced into the system.

83. Mr. Burke asked Mr. Strauser if the District is short of money, do they repair a dike only halfway to the original design grade. Mr. Strauser replied that "it has been the philosophy of the river engineers in Lower

Mississippi Valley Division that if you did not have the opportunity to build all of it, you build it gradually." Many times only a part of a dike is built or repaired. "Sometimes you have to be satisfied with compromise. In some situations the river will work to your advantage if the dike is partially built and the river deposits sediment around it. The second phase of building will cost less as less rock will be needed. Of course this only works if you have the luxury of time."

84. Mr. Ross Jarrell, LMVD, noticed that most Districts were getting away from hired labor and going more toward contracting work out. His question was, "Are we losing some of our techniques in hired labor that we have learned over the years?" Mr. Strauser replied that most contractors used have done river work for a number of years and are familiar with Corps guidelines and techniques. Mr. James Ross of the Vicksburg District mentioned that one advantage of hired labor is if there is an emergency, people can attack the problem immediately instead of using valuable time to let a contract or hire a crew.

85. Mr. Athow asked, "How good are the inspectors?" Mr. Grant replied that at the present time the inspectors from the Vicksburg District are good and have years of experience, but he is worried about what will happen when they retire. Mr. Bertoglio thought that the inspectors are of critical importance. The job the inspector does will determine the amount of maintenance performed in the future. If a dike is built with substandard material and the inspector does not catch it, that dike will have a short life. Mr. Burke agreed that inspection is critical but feels that too much emphasis is placed on the "old timers" and that some of the younger people are just as capable of inspecting as those nearing retirement age. Mr. Burke does not feel that the quality of inspection will decrease in the future.

86. Mr. Horn asked, "How do the various Districts mark the ends of their dikes?" Mr. Hare stated that only every third or fourth dike is marked, usually with a buoy anchored by a 1-ton concrete block. These buoys stay in place fairly well, but under certain conditions time is spent resetting buoys. It is the responsibility of the Coast Guard to mark the channel, but trips are infrequent and the Corps helps out. Ms. Grey said that Portland District uses a cluster of piles called a dolphin to mark the end of dikes. A flashing light is mounted on top of the dolphin to aid navigation. Mr. Athow stated that the towboats go in and out of the dike fields to duck the main channel

current and save fuel. Mr. Johnson commented that because of budget restrictions the Coast Guard makes only two trips a year up and down the river to mark the channel. This causes quite a problem for the Corps. The marking clusters used by the Mobile District are sheared off frequently by floods, driftwood, or errant tows. Mr. Young told how the Little Rock District analyzed and identified the dikes that needed an end marker about a year ago. Markers consisting of a 10- by 10-ft pile of rock with a steel marker were pile driven into the dike. These rock mounds have been in less than a year and some have already settled 3 to 4 ft because of scour at the end of the dike.

87. Mr. Bill Wilson, Tulsa District, said that Tulsa District has a navigation conference with the towboat people every year. Dikes identified as troublesome are marked with an 8-in.-diam pipe set in a trapezoidal concrete base. When flows are high or drift hits the marker, they usually just roll over. The District then has to set them upright. Very few have been lost.

88. Mr. Athow asked if there were any hard and fast rules on dike repair criteria, specifically, when to repair a dike. There was little response to this question. Mr. Ellis did say that LMVD tries to bring all dikes up to design grade every year. In the recent past, reaches of river with deteriorated dikes have continued to function well for years and years; then suddenly, extensive dredging is needed and it is found that the dikes are in very poor shape and need to be repaired quickly. Of course this is more expensive. The policy now is to maintain all structures at design grade on an annual basis. Mr. Ellis also feels that the repair work that each District wants to do, but is unable to complete because of budget restrictions, needs to be documented. "As we move into the operation and maintenance era of river management, we need to get the maintenance money up where it should be, so that the Districts are not playing catchup all of the time."

89. Mr. Jarrell reported that LMVD has a T-1 report where all dredging data from the Lower Mississippi River is put in the computer and plotted out.

90. Mr. Athow reported that the Portland District takes pictures of each dike every year as a form of documentation of condition.

91. Mr. Jarrell told how LMVD wanted to increase the maintenance funding by $20 million to clear up a backlog of maintenance work. Fact sheets and photographs were assembled and presented to the Real Estate and Engineering groups in USACE. Of the $20 million they gave an additional $12 million for

FY 1987. Mr. Jarrell said the photo documentation had really helped.

92. Mr. David Derrick, WES, gave a brief outline of workshop activities for day two. The workshop was adjourned for the day.

What Research is Needed in the Field of Dike Repair?

93. Mr. Jarrell distributed some handouts pertaining to the budget. As Mr. Jarrell says, "you have to get your money first before you can do any work." USACE uses five budget levels. Under each level, 103 separate items are prioritized according to importance. When a District hands in a budget request for the coming year, USACE is going to review this package "by exception." In other words, if any item deviates by more than 10 percent from the previous year, USACE wants to know why. The District then has to get with the Division and write up a justification on why the budget item has deviated more than 10 percent. Most justifications are a couple of pages long and include a drawing or pictures of the work or structure in question. Mr. Jarrell feels that if the District has a good rapport with Operations and impresses upon the right people that dike and revetment maintenance is important, getting money will not be a problem.

94. The question, "What research is needed in the field of dike repair?", was posed by Mr. Derrick and each District was asked to respond.

95. Mr. Maurice James, Mobile District, felt that he had learned a great deal about dike repair in the workshop, but Mobile District has not yet engaged in actual dike repair work. Although Mr. James did not have any opinion on what research needs to be done, he could use some design guidance that would be compatible with the strict environmental guidelines that the Mobile District must work under. Mr. Horn asked about the efficiency gained by rebuilding a dike in an area not experiencing dredging problems. "Do you rebuild that deteriorated dike, and if so, how do you measure the gains resulting from rebuilding that dike?"

96. Mr. Ken Underwood, Mobile District, asked, "How do you evaluate rehabilitating an existing dike field short of a physical model study? Is there any computer method that would help?"

97. Mr. Ellis felt that from his observations most problems on the Lower Mississippi River occur in areas where there is no bank control (low banks) or there is not enough contraction. This problem needs further study.

98. Mr. Wrightman felt that numerical modeling needs to be improved to

the point where it could be used in dike field evaluation.

99. Mr. James asked, "When you lose a dike, do you reevaluate?" Several people joined in this discussion. This comes down to basic engineering judgment. If the river is being forced to do something it does not want to do and it takes out a structure or structures, then that entire reach of river needs to be evaluated and analyzed for long-term effects and costs before any repair or rehabilitation is done. The Buck Island realignment on the Mississippi River, performed by the Vicksburg District, was discussed at length.

100. Mr. Burke felt that the notched dike program is successful and does not need to be researched further. Revetment maintenance, while off the subject, is one of the biggest areas of controversy within the Missouri River Division. When revetment looks questionable, when should it be repaired? Mr. Burke also noted that their dikes are visually inspected four times a year, which he believes to be adequate.

101. Mr. Horn asked if side scan sonar would help with dike inspection. Mr. Athow replied that Portland District had tried it without success. Likewise Memphis District had tried sonar to check the condition of revetment, which was also unsuccessful. It just does not give enough information and is very much "operator dependent." Mr. Burke has tried a 16-channel multitransducer sounder to contour some of the low-elevation structures. The problem with this system is that it generates so much information that picking out the information needed is troublesome. A method to reduce the data down to a usable format has not been found.

102. Mr. Strauser felt that if a stretch of river is model tested and a workable plan is developed, it would be helpful to the District to build all dikes and revetments in that plan out of an erodible material, run an additional test, and let the model indicate areas that might be high-maintenance areas in the future. The problem is finding an erodible material to use in the model. Along these lines Mr. Derrick suggested that experts from the District involved might be able to pinpoint possible pressure points, deterioration at these points could be molded in, and tests run to ascertain what effect this deterioration would have on river navigation.

103. Ms. Grey wanted to see some research into different timber pile dike designs. Currently pile dikes are repaired back to "as-built" specifications, but Ms. Grey felt that the river regime is different from when those dikes were originally built.

104. Mr. Lowery wanted some indicators that would predict when dike maintenance will be needed.

105. Mr. Grant wanted to know why some dikes fail and others do not.

106. Mr. Hare wanted to see some research into different designs of armouring the dike root where it joins the bank.

107. Mr. Young wanted some research into more economical ways to raise or repair structures. Mr. Young also had some concerns about dike flanking and bank scour downstream of dikes.

108. Mr. Johnson wanted to see some research that would determine what the optimum side slope of a rock dike should be. Also Mr. Johnson wanted to find an inexpensive way to keep oxbow cutoffs from silting in.

PART III: SUMMARY AND CONCLUSIONS

109. Mr. Athow emphasized the following points that were brought out during the course of the workshop:

- a. Dike systems for channel control and bank stabilization are used extensively throughout the shallow-draft domain.
- b. For the last several decades a movement away from pile structures to rock dikes has occurred.
- c. Damage to dikes is usually caused by one or several of the following events:
  - (1) High flows and flood events.
  - (2) Ice (both impact and ice dam breakups).
  - (3) Propwash.
  - (4) Towboat impacts.
  - (5) Poor quality stone and/or poor construction inspection.
  - (6) Normal wear and deterioration.
  - (7) Dike geometry and design.
- d. Reliable repair records of construction, and repair histories for each dike or dike system are beneficial. This is especially important when attempting to justify future repair work.

110. Mr. Athow then listed a few items he thought should be in a dike repair criteria:

- a. The question, "What are the consequences of failure?", should be determined.
- b. Shoaling or dredging records should be analyzed; i.e., is the dike performing to its design function?
- c. What can be repaired with the dollars available?
- d. What are the consequences of deferring repairs?

Mr. Athow stated that periodic inspections of dikes and revetments have many benefits.

111. Mr. Hare noted that in the Rock Island District there are approximately 1,200 dikes, all submerged, which would be prohibitively expensive to inspect, and in this case would have few benefits. Most were built between the 1890's and 1930 and after so many years might not be working effectively. The problem is identifying the effective dike. Mr. Hare felt that dike failures need to be analyzed and the causes of failure identified.

112. Mr. Athow then listed the subjects that workshop participants felt needed additional research:

a. Evaluating the effectiveness of a dike or dike system.

b. The effectiveness of preventive maintenance.

c. Early detection of possible failure areas.

d. Evaluation of failure mechanisms.

e. Confined geometry: the special problems of developing a navigation channel that might be half the width of the available bank-to-bank width in a narrow river system.

f. A low-maintenance, effective method for marking the ends of dikes.

g. Research and formulation of revetment maintenance guidelines.

h. A physical model test procedure: for the final plan, make the dikes and revetments erodible, and run tests on this plan so that problem areas can be identified.

i. Research into timber pile dike design.

j. Dike failure: Why do dikes fail? Where does failure occur in a dike field? Why does failure occur where it does?

k. Testing to determine when a bank will erode (New Orleans District is doing some major research in this area).

l. Shoaling patterns in oxbow lakes where boat launching ramps are impacted.

m. When disposing dredged material in a dike field, can the material be piled higher than the dikes, and if so how high?

Participants felt that no further research was needed in the area of environmental notches in dikes.

113. Mr. Athow asked if the workshop was beneficial. Mr. Lowery replied that it is always a benefit to meet with your peers to discuss problems of mutual interest. Mr. Strauser agreed that the exchange of ideas with different points of view and different opinions on similar problems plus the variation of problems that different people experience and how they perceive them is always beneficial.

114. Mr. Athow thanked the participants for attending, and the workshop was adjourned.