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RESEARCH PROGRAM

The REMR Bulletin

News from the Repair, Evaluation, Maintenance, and Rehabilitation Research Program

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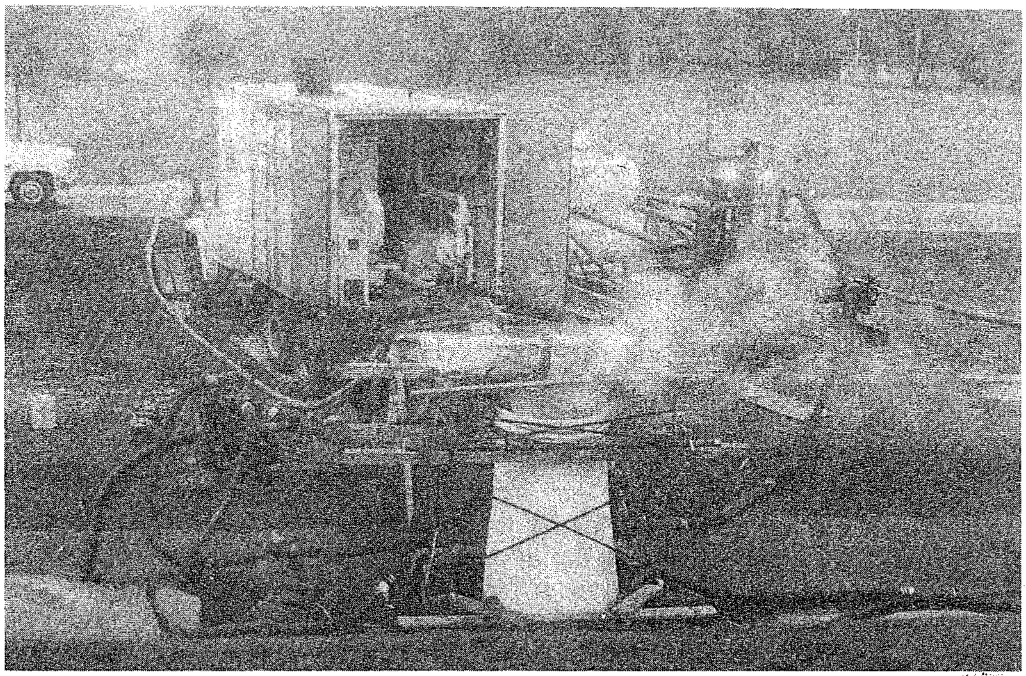


Water heated to 180°F is pumped into the liner to cure resin at Enid Lake, Mississippi

Culvert Repair at Enid Lake, Mississippi

by
Elke Briuer
US Army Engineer Waterways Experiment Station

Until recent years, repairing in-ground pipes meant dealing with heavy equipment, adversely affecting the environment, and generally disrupting the use of the area where the pipes were located.

In a Corps of Engineers' project at Enid Lake, Mississippi, a traditional approach would have resulted in the cutting of about 40 mature trees, closing an access road to a recreational area, and having to resod major portions of the dam. To avoid these and other costly problems, project officers at the Vicksburg District contracted for in situ repair of 37 surface-water-drainage culverts made from corrugated metal and concrete. These culverts had deteriorated during 30 to 40 years of use.

The solicitation specifications requested culvert cleaning and inspection. Also specified was culvert renovation to be performed by providing structural liners within the existing culverts. A contract was awarded and work began in September 1989.

Elke Briuer, Information Technology Laboratory, is assigned as a technology transfer specialist to the REMR Research Program at US Army Engineer Waterways Experiment Station. She received her B.A. degree from the University of Maryland. She attended the Defense Information School officers' and editors' course and the Army Advanced Public Affairs Course at the University of South Carolina's Graduate School of Journalism.

During the cleaning and inspection phase, culverts were measured to determine the length needed for the liners. The liners were then custom made at the factory.

The material for the liners was a polyester felt, with a polyurethane coating, vacuum impregnated with a thermal-setting polyester resin catalyzed with two organic peroxide curing agents, styrene, and other additives. When cured, the molecular alignment at right angles gives the structural liner its strength.

The felt serves as the carrier for the resin. It is manufactured from 1.5 mm to 6 mm thick. Thicker liners combine several layers; i.e., a 3-mm-thick felt inside of a 6-mm-coated liner creates a 9-mm-thick liner. The two liners are heat-tacked to assure proper placement. All liners go through several computerized quality control checks. If the product is for pressure application, the liner must pass through a dye bath to detect pin holes in the polyurethane coating, which are then patched.

For the Enid Lake project, the resin was factory installed, and the folded, impregnated liners were stored on ice in a refrigeration truck. Refrigeration keeps the liners in usable condition for up to seven days. The resin is normally applied to the liners at the plant. Very large and very long liners, however, can become too heavy to truck. In that case, as has been done at Pine Flat Dam, Calif., liners can be resin impregnated on site.

INSTALLATION

At Enid Dam, most of the old drain pipes were buried within the embankment and parallel to the slope of the dam. Many started at the top with an 18-in. diam changing to 15-in. diam within 6 ft from the drop inlet. The liners were precut to change size at the approximate location of the narrowing pipe, favoring the transition to take place at the top of the 15-in. pipe. "Although small voids don't affect performance after curing, we prefer to fill all voids and put up with the wrinkles," said Steve A. Hastings, contractor operations manager for the Enid Lake project. In case of elbow pipes, cinch rings were factory-installed at the predetermined distance. When the tube was inverted, special care was taken to feed the tube with the rings in the right direction. A string to the top allowed the crew to tighten the cinch at the location of the elbow during liner inversion.

To line the pipes within the face of the dam, a direct stop-and-go water-pressure system was used. Once half of the liner was inverted, installers kept control of the inversion speed with a rope attached to the end of the liner. PVC piping was inserted at the bottom of the culverts and sealed with a piece of wood held in place by a truck. This barrier kept the end of the liner from bursting with head pressure created by the slope. Horizontally oriented culverts required a vertical attachment that allowed for water-pressure build-up (Fig. 1).

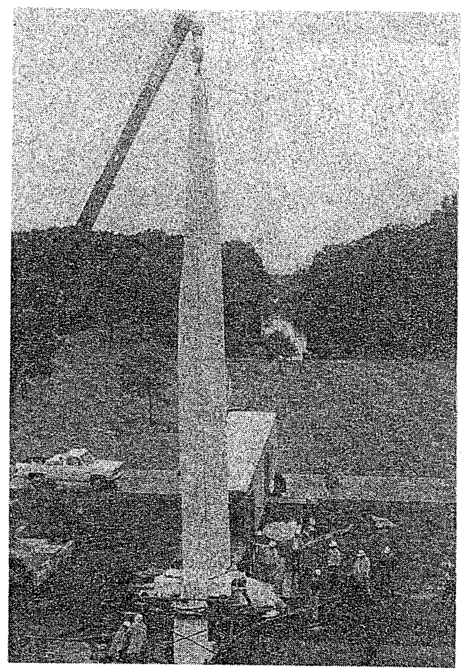


Figure 1. Installation of 46-in.-diam structural liner in horizontally oriented culvert

Once the liner was in place, hot water was pumped into the culvert to cure the resin. Water temperature for thermal setting of the resin must be 180°F. Curing time at Enid Dam was approximately 8 hours per pipe up to 18-in. diam, with 4 hours at temperature. The larger pipes (up to 48-in. diam) had to be kept at 180°F for at least two days.

A probe inserted between the felt and the old pipe monitored the temperature during the curing process. The probe showed what was going on outside of the liner and inside of the pipe. Some of the components in the resin, among them cobalt, are in themselves heat-generating. This heat promotes setting. "We watch the temperature gauge closely for a heat surge generated by the chemical processes. When the temperature peaks and then slowly goes back down to the water's temperature, the resin has set," said Hastings. The water was kept at 180°F beyond the surge time to make sure cold pockets were cured. This precaution was especially important for the larger pipes, and those of corrugated metal.

A plastic, fiberglass-reinforced tube was used to preline the asphalt-coated, corrugated metal pipes, preventing contamination of the polyester by phenolic compounds (Fig. 2). The preliner was air installed and kept inflated with blown air during the placement of the structural liner (Fig. 3). The preliner served as an isolating laminate separating the two compounds until the polyester had cured.

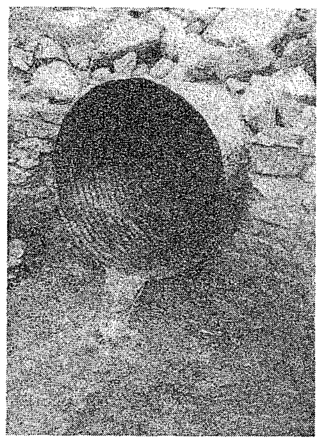


Figure 2. Corrugated metal culvert after cleaning, showing patchy tar coating

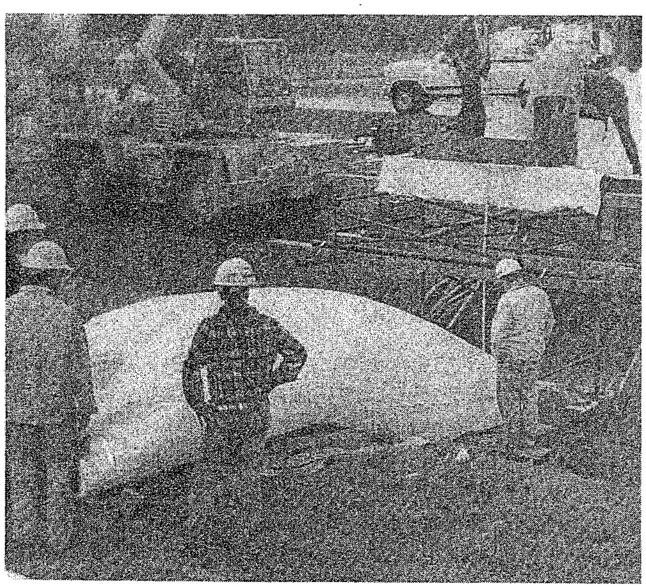


Figure 3. Air-inflated preliner is positioned in pipe while crew works on truck platform to ready liner for placement

After several culverts were completed, a three-man crew moved in to finish the outlets. The now rigid liner was cut with a diamond saw to the angle of the original culvert, and the trimmed edges of the structural liners were sealed. Following this procedure, areas of the liner exposed to direct sunlight received a coat of UV-blocking paint (Fig. 4).

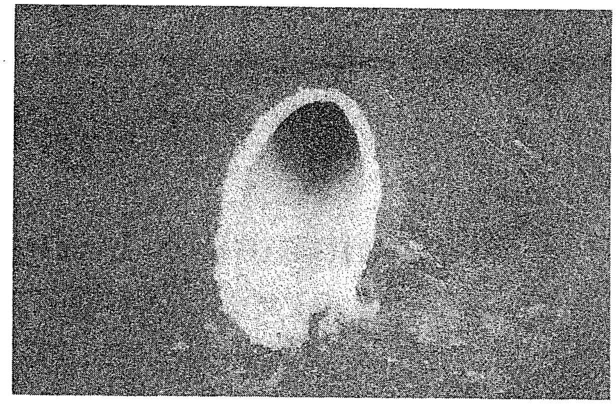


Figure 4. Finished culvert outlet on bottom of downstream face of Enid Dam

According to Hastings, this repair system can be applied to gravity culverts, high pressure sewers, utility ducts or any underground conduit except potable water pipes. Presently, the process is not licensed by the EPA for potable water pipe repair. There are no limits imposed by materials of the old pipes. Occasionally, for example for pressure mains, an epoxy may be used in place of the polyester. This does, however, add considerably to the cost. The smallest size pipe suitable for the in-situ process is one with a 6-in. diam. Hastings said that projects using this type of repair have involved pipes up to 108-in. diam.

SUMMARY

At Enid Dam, culverts ranged from 12 in. to 48 in. in diameter. Although the structural liners slightly reduce the original diameter of a pipe, the Q-factor is lowered and the capacity of the culverts will not be reduced.

With one of the Enid Dam culverts located well below the ground-water level, replacement by cut-and-fill would have included dewatering the excavated area. With the in-situ rehabilitation no muddy water had to be discharged, an environmentally positive aspect of the repair. Normally, weather conditions have no significant impact on installation, since most of the work is underground. However, rainfall affects repair efforts of pipes that drain rainwater. During the Enid Lake project, rain from Hurricane Hugo resulted in several installation delays.

This repair system is indicated whenever high site-restoration costs are involved or when it is important not to disrupt the regular use of an area. At Enid Dam, it would have been very costly to restore the grass cover on the downstream face of the dam. Additionally, the collocated recreation areas would have been closed to the public during late summer and fall. Instead, only a water pump, several trucks, and the work crews served as indicators that a major refurbishment was going on in the area.

More information about the Enid Lake project is available from Mr. Luther Newton, Vicksburg District, (601) 631-5612.

Continuous Deformation Surveillance of Large Structures Possible with New Monitoring System

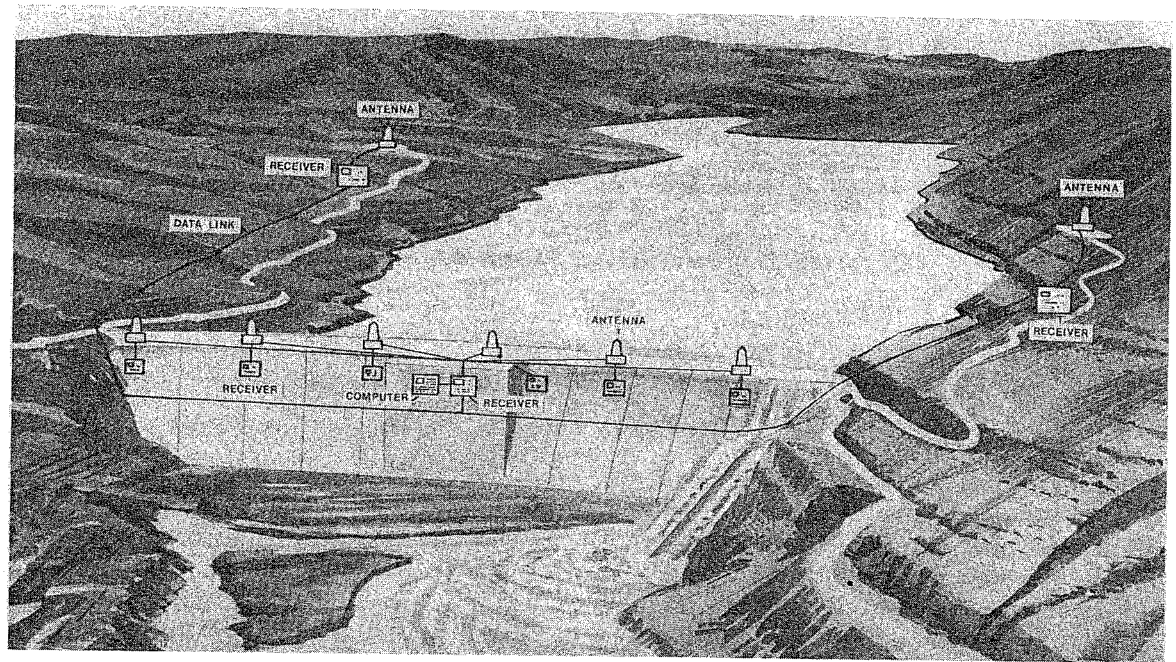
by
Carl A. Lanigan
US Army Engineer Topographic Laboratories, Fort Belvoir, Virginia

Researchers at the US Army Engineer Topographic Laboratories have developed an automated monitoring system which can detect structural deformation continuously without operator assistance. This system, known as the Continuous Deformation Monitoring System, or CDMS, was developed under the Repair, Evaluation, Maintenance, and Rehabilitation Research Program.

The CDMS uses the Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) surveying technology to perform high precision surveys of structures. The NAVSTAR GPS surveying technique is an accepted method for producing geodetic quality surveys. By tracking four or more NAVSTAR satellites, a three-dimensional baseline determination can be made between two or more GPS satellite receivers. Current post-processing software can determine the position of surveyed monuments in the subcentimetre range.

The CDMS can have a maximum of ten GPS satellite receivers in a survey network; the minimum is three. A GPS antenna will be set over each monitoring point. A minimum of two antenna stations has to be placed over reference survey monuments that will not move throughout the project life. These two stations will be used as reference points against which all other points will be judged for movement. A network of two personal computers (located at the project site) remotely operates the GPS surveying equipment. The CDMS can survey points on a structure at a minimum of one hour intervals, depending on the amount of satellite coverage available. Once a given survey is completed, the raw positioning data is downloaded to the computer network by either RS 232 cable, fiber optic cable, or telephone modem link. The two 386 based computers will process the raw survey data and report any apparent movement (in three dimensions) of the monitoring points. The length of time required to report apparent deformation is approximately equal to the duration of the survey. Therefore, if the structure is being monitored in one hour intervals, a displacement value will be displayed about an hour after the last survey. During data processing the CDMS satellite receivers will be conducting another survey. This cycle will operate continuously without user assistance.

The final product of all CDMS processing is vector representations of apparent movement and a continuous record of the movement over time. These results can be displayed on a computer monitor or drawn on a plotter. An engineer with a personal computer can link into the remote monitoring site via telephone modem and observe deformation behavior of the structure. The CDMS archives all monitoring data and stores it on cassette tapes, allowing past deformation events to



Model of monitoring system for large structures using Global Positioning System (GPS)

be viewed either at the project site or, for example, at a district office. The CDMS has the ability to be used at more than one monitoring site. The survey network of each project site is permanently stored in the computer network, thus allowing a single CDMS to operate at various structures during different times of the year.

The CDMS has undergone performance and reliability testing at Fort Belvoir for a three-month period. The system was subjected to a series of simulated deformations in order to determine its measurement precision. Preliminary testing results gave measurement precision in the millimetre range.

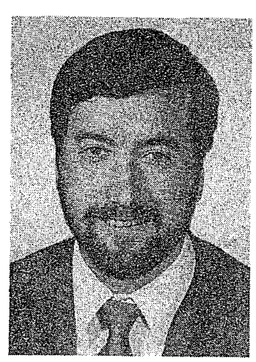
The system was installed on Dworshak Dam, Idaho, in the Walla Walla District. The CDMS operated continuously during a three-month period, taking measurements of the structure each day. A demonstration of the system was given to members of the US Army Corps of Engineers who are involved in instrumentation, and surveying and mapping. Other attendees included personnel from the Bureau of Reclamation, Tennessee Valley Authority, US Bureau of Mines, National Geodetic Survey, and private industry.

Applications of the CDMS technology include monitoring:

- Earth and concrete structures
- Structures under distress
- Slope stability
- New hydraulic structures undergoing initial pool rise
- Older structures

Presently, the approximate cost of the CDMS is $50,000 for auxiliary equipment and installation, plus the number of GPS receivers desired. Trimble Navigation receivers are required for operation and cost about $30,000 apiece. The current trend in hardware prices indicates that these costs should drop by half over the next few years. The CDMS software is available to all Corps activities without charge.

The point of contact at USACE is Carl Lanigan, Precise Survey Branch, Fort Belvoir, VA 22060-5546, telephone number (202) 355-2752.



Carl A. Lanigan is a civil engineer, working as a CDMS project engineer at the Topographic Developments Laboratory, Surveying Division, Precise Survey Branch, of the US Army Engineer Topographic Laboratories at Fort Belvoir, Virginia. He received his B.S. degree in civil engineering from the Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

A Practical Application of a Low-Berm Revetment

by
Heidi Pfeiffer
US Army Engineer District, Chicago, Illinois
and
John P. Ahrens
US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Waves impinging on a vertical seawall over a period of time can have several adverse effects. Runup and overtopping can result in flooding, in ice buildup on structures and pavements, and in erosion of soils behind the seawall. Downrush can erode material at the base of the wall. Wave impact can actually compromise the structural integrity of a seawall.

Innovative shore protection structures have resulted from a link between research laboratory and practicing field office. Thoughtful and creative research activities can be the first step toward economical adaptations of standard, accepted shore-protection structures to site-specific, unusual projects. Benefits can be multiple, both for the practicing field office and the local sponsor, as they work with the research scientist. One example of such cooperation is the development of the low-berm revetment combined with a seawall.

BACKGROUND

Revetments are a common form of shore protection that can have several useful functions when protecting a vertical seawall. A riprap revetment will dissipate wave energy considerably better than the vertical wall, thereby reducing the wave reflection and the potential for scour in front of the structure. The mass of the revetment can be used to buttress the wall, insuring its stability.

One structure that has been used to protect seawalls from wave action is the high-crest revetment. This structure is usually configured of layers of various sized stone that dissipate the wave energy primarily through roughness, permeability, and structure height (Fig. 1). An alternative structure for wave dissipation is the low-berm revetment seawall. This structure's greater horizontal length dissipates incident wave energy through increased turbulence and the combination of a wave-absorbing stone structure with a wave-deflecting wall.

Laboratory tests have shown that in some cases a seawall-revetment system is more effective if the berm of the revetment is placed at the design waterline. Tests of a standard riprap revetment against a seawall indicate that the revetment reduces the overtopping by about 50 percent as compared to the same seawall not fronted by the revetment (Ahrens 1988). In laboratory tests, a seawall fronted by a low-berm revetment reduced overtopping about 25 percent more than a standard riprap revetment fronting the seawall.

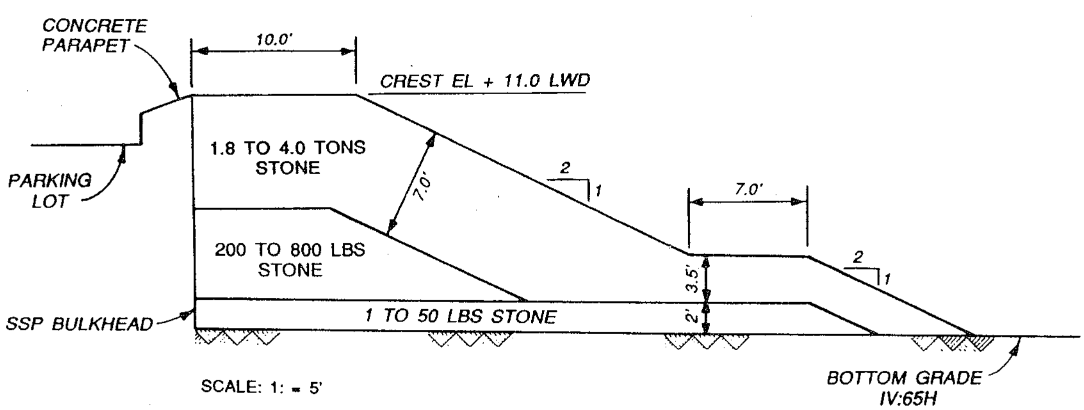


Figure 1. Typical cross section of a high-crest revetment

PRACTICAL APPLICATION

One project that shows an application of this research is located along Lake Michigan in Chicago, Illinois. The majority of the Chicago shoreline has been fully developed with seawalls commonly used for protection. However, storm waves during high-lake-level occurrences can cause excessive wave overtopping and damage of seawalls along the Chicago lakefront. This was the case at Temple Emanuel, which is protected by a concrete, vertical seawall with top elevation at +11 Low Water Datum (LWD) and toe elevation at -5 LWD. A small parking lot separates the seawall from the temple.

To reduce the overtopping at Temple Emanuel, the Chicago District planned to construct a riprap revetment against the wall. The revetment was also intended to address erosion at the base of the wall and suspected minor instability of the wall itself. The design criteria were as follows:

- Nearshore slope = 1V:100H
- Design deepwater wave = 17.7 ft
- Design wave period = 9.5 sec
- Significant wave height = 9.13 ft
- Storm water level = +5.1 LWD
- Toe elevation at structure = -5.0 LWD
- Depth of water at structure = 10.1 ft

Based on laboratory findings and an economic evaluation, a decision was made to construct a riprap revetment that used a low berm rather than a standard revetment profile. The design used at Temple Enamuel evolved from laboratory tests conducted to help reduce wave overtopping at Roughans Point, Massachusetts, and subsequent tests conducted under REMR. Profile and plan views of the low berm revetment-seawall constructed for the protection of Temple Emanuel are shown in Figures 2 and 3. Certain features of this design are worth noting:

- The function of the lower berm of the revetment is to disrupt incident wave action during storms and reduce the intensity of the wave impact and subsequent runup.
- The function of the upper berm is to further attenuate the resulting wave.
- The function of the exposed bulkhead-parapet is to form a substantial discontinuity to deflect the remaining wave energy.
- The increased horizontal length of the revetment, as compared to high-crest revetments, initiates wave breaking earlier and thereby increases wave energy dissipation through turbulence.

The low-berm revetment seawall system constructed at Temple Emanuel should reduce wave overtopping rates by about 60 percent over those of the initial, vertical seawall configuration and alleviate some of the secondary problems as well. Importantly, the low-berm revetment construction costs were 12 percent lower than the cost of building a standard high-crest riprap revetment. An added benefit is that the lower profile is more acceptable to the public.

CONTINUED APPLICATION

The success at Temple Emanuel is leading to other proposed application of the low-berm revetment, i.e., the Illinois Shoreline Erosion-Interim III study, which addresses approximately 28 miles of highly developed shoreline along the Chicago lakefront. The study, which is primarily concerned with erosion and instability of structures, is sited in an area dominated by 1920's and 1930's steel sheetpile and step-stone revetment structures backed by landfill. Since the majority of the study

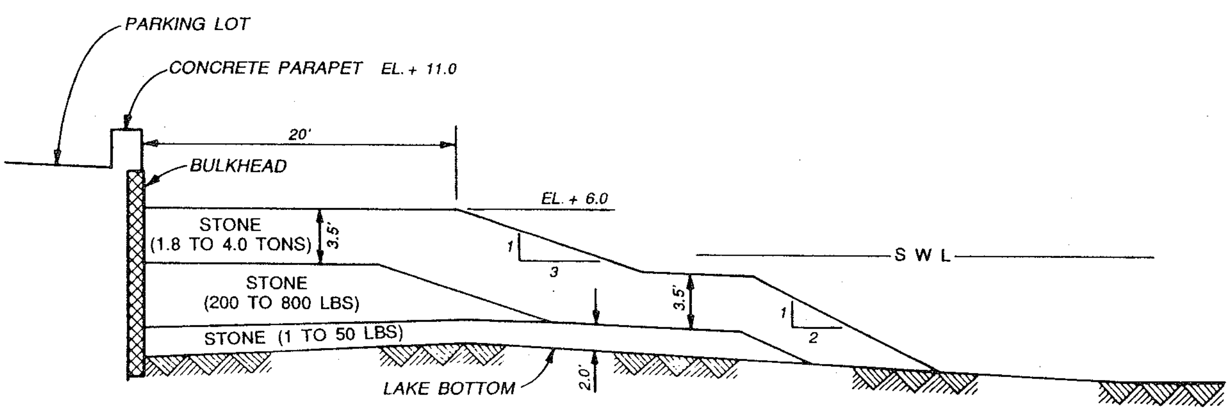


Figure 2. Low-berm revetment-seawall profile devloped for Temple Emanuel, Chicago, Ill.

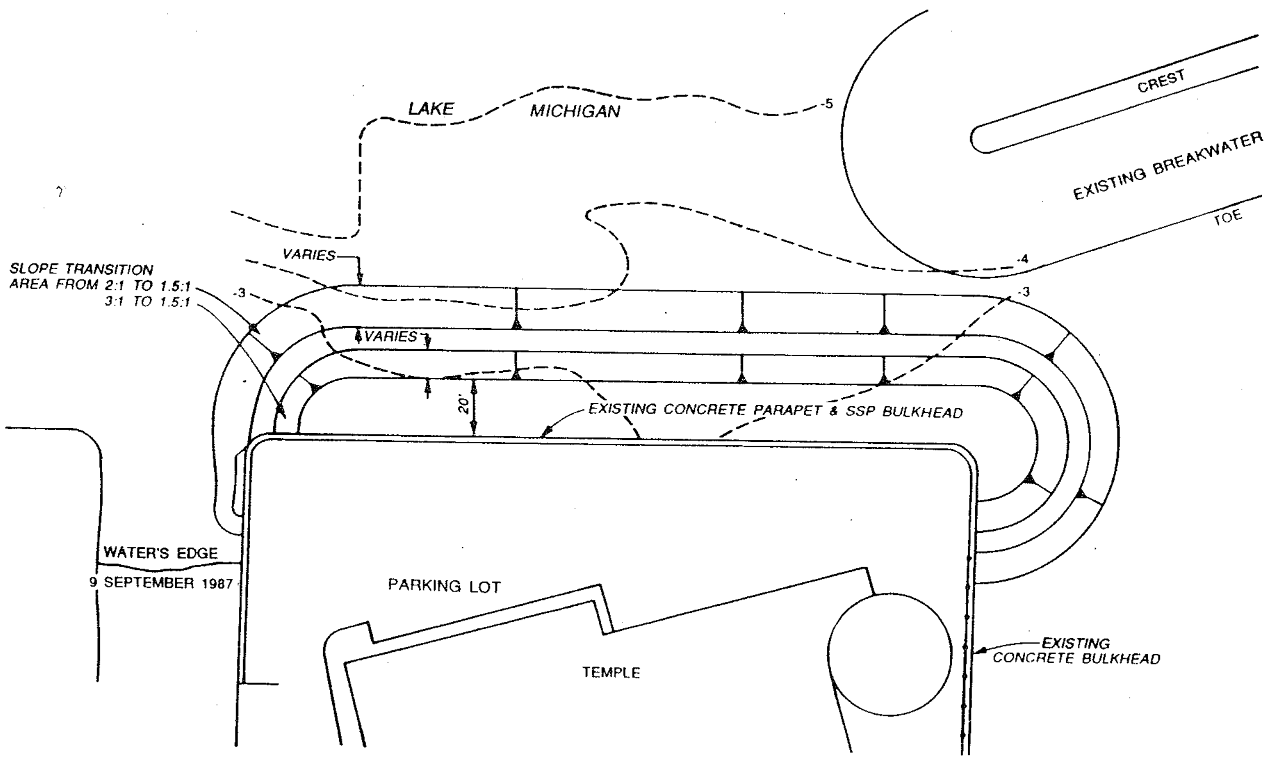


Figure 3. Plan view of Temple Emanuel low-berm revetment-seawall construction

area is highly used park land, the design criteria dictated an alternative which could enhance as well as protect the existing coastal structures. The low-berm revetment was found to be a practical application.

At this project, the shoreline areas that are in need of repair and upgrade—but which have not been severely damaged—require an alternative that is 1) compatible with the existing structure type and 2) that protects the structure and the backshore areas from erosion. In this case, it was preferable to extend a low-berm revetment from the lower portion of an existing step-stone revetment rather than to cover the entire structure with a high-crest, random placement revetment. While it was recognized that some overtopping might occur with this alternative, the following advantages were important: the low-berm structure is desirable where nearshore depths are not great and/or existing shore protection is in good shape, and the existing structure is incorporated into the design and remains functional, enhancing public access. Figure 4 illustrates a typical cross section of a low-berm revetment extending lakeward of an existing steel sheetpile stepstone revetment. One additional benefit of the low-profile revetment is the effect the flatter slopes have on the required stone size. Table 1 indicates the correlation between wave height, structure slope, stone size, and structure crest elevation for the Illinois Shoreline Erosion-Interim III study reach.

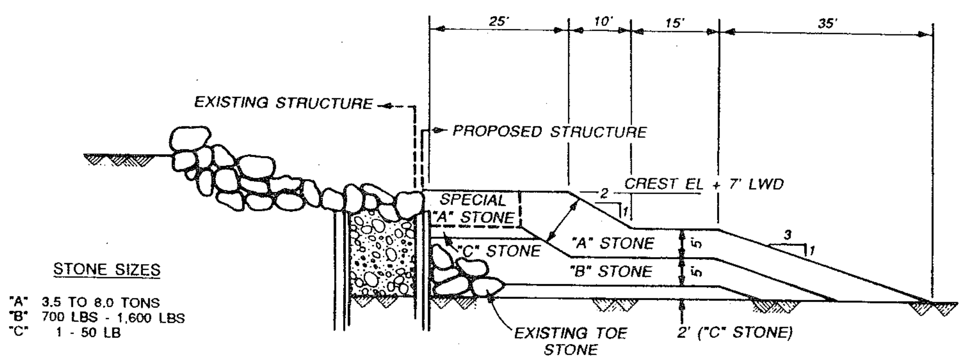


Figure 4. Typical cross-section low-berm revetment applicable to the Chicago lakefront

Table 1. Median armor stone weight (as a function of wave height and slope)

Proposed Structure Frontal Slope	"A" Stone Median Weight (tons)	Structure Crest Elev. for No Overtopping (ft, LWD)
	Incident Wave Height = 16.0 ft	
1.5H:1V	21.0	19.7
2.0H:1V	16.0	18.2
3.0H:1V	10.5	15.8
	Incident Wave Height = 13.0 ft	
1.5H:1V	11.5	17.7
2.0H:1V	9.0	16.7
3.0H:1V	6.0	14.5
	Incident Wave Height = 8.0 ft	
1.5H:1V	2.8	12.6
2.0H:1V	2.0	12.0
3.0H:1V	1.4	10.8

Obvious advantages to using smaller armor stone include cost, availability, quality control, transportation, and constructibility.

CONCLUSION

A low-berm revetment can be a viable approach to upgrading the performance of seawalls and revetments at a wide range of locations. In the case of Temple Emanuel, extensive laboratory tests done to evaluate the relative overtopping of a combination low-berm revetment vertical seawall compared to the standard high-crest revetment resulted in a more economical and a more acceptable shore protection structure (Fig. 5).

Maintaining the link between research laboratory and field office showed that teamwork can expand the knowledge base and that pooling

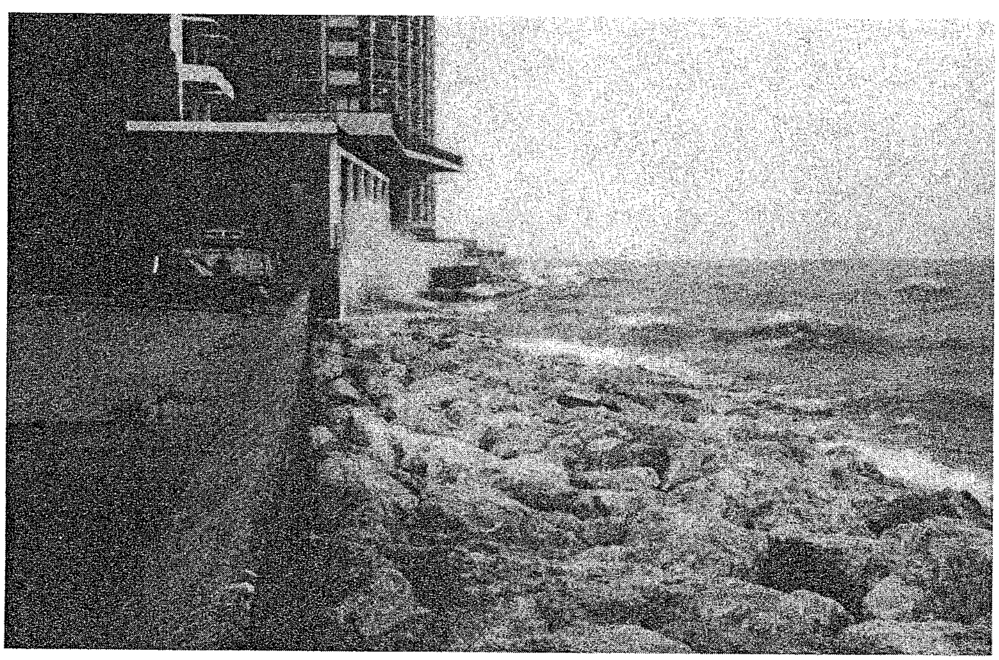
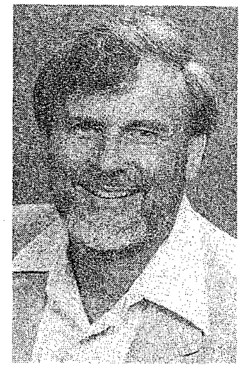


Figure 5. Effectiveness of low-berm revetment in reducing wave runup is clearly evident compared to wave action against vertical wall in background

immportant information on available techniques can result in new ways to solve practical problems.

For more information contact Heidi Pfeiffer at (312) 353-6517, or John P. Ahrens at (601) 634-2062.

Heidi Pfeiffer is a civil engineer in the Geotechnical and Coastal Branch at the US Army Engineers, Chicago District. She received her B.S. degree in civil engineering from Valparaiso University, Indiana. She currently serves as leader of the Coastal Unit for the Chicago District.



John P. Ahrens is an oceanographer working as a coastal engineer in the Wave Research Branch of the Coastal Engineering Research Center, Waterways Experiment Station. He has more than 20 years of research experience in the design of coastal stuctures. He received his B.S. in physics from Marietta College, Ohio, an M.S. in oceanography from Texas A&M University, and has a diploma in hydraulic engineering from Delft, The Netherlands.

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COVER PHOTOS:

On completed repair, structural liner extends beyond culvert and preliner is still visible

CDMS computer network

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LARRY B. FULTON
Colonel, Corps of Engineers
Commander and Director

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