Coastal Engineering Technical Note

Monitoring Completed Navigation Projects, Lessons Learned III

By Robert R. Bottin, Jr.

PURPOSE

To provide a summary of lessons learned and significant results for projects monitored under the Monitoring Completed Navigation Projects (MCNP) Program.

GENERAL

This Coastal Engineering Technical Note (CETN) is the third in a series summarizing lessons learned from the MCNP Program, formerly the Monitoring Completed Coastal Projects (MCCP) Program. It covers four comprehensively monitored projects for which reports have been completed: Yaquina Bay North Jetty, OR (Hughes et al. 1995); Siuslaw River Jetty Spurs, OR (Pollock et al. 1995); Burns Harbor, IN (McGehee et al. 1997); and St. Paul Harbor, AK (Bottin and Eisses 1997). The CETN also includes six projects monitored under the Periodic Inspections work unit of the MCNP Program: Kahului Harbor and Laupahoehoe Boat-Launching Facility breakwaters, HI (Markle and Boc 1994); Crescent City Harbor breakwater, CA (Markle, Melby, and Kendall 1995); Cleveland Harbor east breakwater, OH (Bottin, Marcus, and Mohr 1995); Manasquan Inlet jetties, NJ (Bottin and Gebert 1995); Burns Harbor north breakwater, IN (Bottin and Matthews 1996); and Nawiliwili Harbor breakwater, HI (Bottin and Boc 1996).

The elements of the comprehensively monitored projects included the collection of waves, wave-induced currents, bathymetry data, wave runup, underwater structure profiles, geophysical surveys, ground and photogrammetric survey data, and/or surveys of armor unit quality. Elements of the projects monitored under the Periodic Inspections work unit involved predominantly photogrammetric surveys of structures, with limited ground truthing surveys and armor unit quality surveys.

COMPREHENSIVELY MONITORED PROJECTS

Yaquina Bay North Jetty, Oregon

Yaquina Bay North Jetty, located on the central Oregon coast, was monitored during the period October 1988-September 1994 to determine the mechanisms responsible for damages occurring on the jetty. Lessons learned and conclusions are summarized below:

a. Wave height data occurring over the 6-year duration of the monitoring period aided in providing wave statistics characterizing the site. The jetty was exposed to wave heights up to about 8 m (26.2 ft). Even when reproducing the most severe wave conditions in a fixed-bed

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physical model of the site, jetty damage was not reproduced. It was concluded that structure damage was the result of more than just severe wave attack.

b. A geophysical survey provided detailed bathymetry, maps of seafloor features, charts depicting depth of bedrock and sediment thickness, and geological profiles. A sandy bottom in the vicinity of the damaged area of the jetty was discovered, which had the potential to scour during storm events. This finding prompted a moveable-bed modeling effort to determine if scour would lead to armor layer instability.

c. Analysis of side-scan sonar images, collected as part of the geophysical survey, was instrumental in determining the underwater configuration of the jetty toe and its relationship to the Yaquina Reef and surrounding sandy bottom. SEABAT track lines provided sufficient data to detail the jetty's underwater configuration. Armor stone displacement and migration downslope have resulted in underwater slopes of 1V:4H to 1V:10H along the damaged area.

d. Data obtained from photogrammetric analysis of the north jetty included contour maps of the structure, jetty cross sections, and contours showing changes from one flight to the next. These data were used to estimate volumetric changes due to armor stone loss in and around the damaged areas and to plot individual armor stone movement. Gradual deterioration indicated that armor displacement is continually occurring during severe storm conditions and most likely is not associated with liquefaction of the jetty foundation.

e. Through a "semi-quantitative" physical model which featured a moveable-bed section, it was determined that waves alone did not cause armor instability. Oblique, approaching waves modified by seaward flowing currents along the jetty, and the hard-bottom reef at the structure tip caused waves to break directly onto the structure, resulting in extensive damage and ultimately eroding the jetty to below the still-water level. Damage to the model test section was believed to be a legitimate representation of what occurred in the prototype.

f. Currents acquired in the prototype with an Acoustic Doppler Current Profiler in the vicinity of the north jetty indicated that, even in very mild wave conditions, the jetty redirects longshore-flowing currents to produce moderate seaward flowing currents adjacent to the structure. This finding lends credence to the wave/current damage hypothesis.

Siuslaw River Jetty Spurs, Oregon

Siuslaw River Jetty Spurs, located on the central Oregon coast, were monitored during the period 1987-1990 to identify shoaling and current patterns and determine the effectiveness of the jetty spurs in reducing maintenance dredging. Lessons learned and results are presented below:

a. Bathymetric data obtained during the monitoring effort revealed that the jetty spurs effectively deflected sediment away from the entrance channel. Sediment either circulated back toward shore, where it was reintroduced into the littoral system or was carried offshore away from the jetty by a jet of water parallel to the spur.

b. Drogues, dye studies, and aerial photographs were initially used to determine current patterns in the area, but were not adequate in delineating bottom currents. An Airborne Coastal Current Measurement (ACCM) system was developed through the program to measure and establish bottom current patterns in the area. The system proved to be a very effective method for obtaining bottom currents in hostile wave environments where boat operation is dangerous or where quick mobility is necessary. Current patterns obtained correlated well with depositional patterns identified through bathymetric data obtained.

c. The Helicopter-Borne Nearshore Survey System, initially developed by Portland District, proved to be effective in measuring seabed bathymetry at Siuslaw in hazardous regions where other survey vessels cannot operate safely. Soundings were taken quickly and proved to be accurate and repeatable.

d. Current patterns and sediment depositional patterns obtained through the monitoring efforts parallel predictions and verify three-dimensional physical model laboratory experiments of spur jetties at the Siuslaw River site.

e. Navigation conditions at the jettied entrance have improved as supported by analysis of shoaling and sediment volume accumulation in the channel, and by inspection of bathymetric data. Accumulation of material has shifted offshore into deeper water as opposed to in the entrance channel. Prior to jetty improvements, navigation was limited to high tide conditions during the summer months, and fishing operations had to be moved to other harbors in the winter months. Vessels are now able to navigate the entrance year-round, barring storm events, and are not confined to periods of high tide.

f. Shoreline change north and south of the jetties is most prevalent immediately adjacent to the structures where fillets have developed. This process is more pronounced to the north. These changes were predicted reasonably well with a numerical model using a simple wave energy littoral transport equation and an equilibrium shoreline concept.

g. Overall, the jetty improvements were a success. The construction cost of the spur system was estimated to be approximately $5 million less than the original design cost estimate for jetty extensions alone, and annual maintenance dredging costs have been reduced by approximately 133,800 cu m (175,000 cu yd). Results of the monitoring provide strong support for the effectiveness of spur jetties at this site and their potential use at other sites.

Burns Harbor, Indiana

Burns Harbor, located on the southern shore of Lake Michigan, was monitored between 1985 and 1992 to determine the cause of loss of crest elevation of the breakwater and to evaluate wave conditions in the harbor. Results and lessons learned are shown below:

a. Operational problems frequently occur in the harbor. Prototype wave gauging at the site revealed an approximate 30-percent transmission coefficient for the breakwater. This is attributed to the structure's high porosity. Therefore, when incident waves exceed 3 m (10 ft), an annual occurrence, the 0.9-m (3-ft) operational criteria in the harbor is exceeded. The harbor was functioning, though not to the satisfaction of the users.

b. Analysis of design procedures used for Burns Harbor revealed that the design wave and water level were severely underestimated prior to original breakwater construction. In addition, a three-dimensional model investigation under-predicted wave heights throughout the harbor because it used an impermeable breakwater (as opposed to a porous structure). A two-dimensional model also over-predicted armor stone stability and under-predicted transmission. These model investigations were performed in the early 1960's.

c. The breakwater has experienced considerable damage over its life, but no single storm or specific event has caused loss of a section below the waterline. The loss of armor stones on the crest is assumed to be caused by high wave action. The structure has experienced waves larger than its design condition on numerous occasions. Harbor-side armor damage is assumed to be due primarily to overtopping and/or transmitted waves.

d. The crest elevation of the breakwater is 0.3 m (1.0 ft) below its design elevation on the average. There is evidence that the foundation may not have been constructed appropriately, thus causing greater settlement of the breakwater than anticipated. Excavation of clay and installation of sand were included in design of the foundation. A trench was dug and clay was placed lakeward of it. Clay deposition piles noted during the geotechnical portion of the monitoring make it obvious that some of the clay was washed back into the trench prior to construction. In addition, there is evidence that a significant portion of the sand backfill material for the trench may have been placed lakeward of the proposed structure location.

e. Alternatives for the reduction of maintenance of the breakwater are to (1) add larger stone and/or increase the angle of the slopes, (2) add a concrete cap to the structure to improve stability of the crest, or (3) place a protective structure (reef-type structure well below the water level) in front of the existing breakwater. An economic analysis was conducted to determine which alternative(s) would result in reduced overall costs. (Note: Alternative three was selected subsequent to monitoring of the site and is currently being constructed in the prototype).

St. Paul Harbor, Alaska

St. Paul Harbor, located in the Pribilof Island chain in the eastern Bering Sea, was monitored during the period July 1993-June 1996 to determine if the harbor and its structures were performing (both functionally and structurally) as predicted by model studies used for the project design. Lessons learned and conclusions are summarized as follows:

a. When working in high-energy wave environments at remote locations, extra precautions must be taken to ensure that wave data are collected. The loss of two directional wave gauges outside the harbor significantly reduced the value of some of the other data obtained. The wave data were required for correlation with other monitoring elements. Devices hard-wired to shore (to obtain real-time data) and/or other appropriate measures to improve the probability of success should be included in project budgets.

b. Wave height data obtained inside the harbor appeared to validate the three-dimensional model study. Maximum significant wave heights measured in the lee of the breakwater were in agreement with those predicted by the physical model study.

c. The videotape analysis method used to obtain runup data along the face of the breakwater was successful, except during periods of low visibility. The technique is relatively low-cost, logistically simple, and provides accurate measurements.

d. Wave hindcast data correlated reasonably well with runup data in a qualitative sense (i.e. larger wave heights correlated with higher runup). The absolute values of the hindcast significant waves, however, appeared substantially lower than the waves experienced at the site based on runup values, overtopping observed, and local forecasts.

e. Since construction of the breakwater improvements, a scour hole has formed at the head of the main breakwater and sediment has accumulated, forming an underwater spit adjacent to the detached breakwater. Some sediment has moved into the harbor, but it has not deposited in the federal channel or mooring area. Recorded sediment patterns in the harbor are the same as predicted by the three-dimensional model investigation.

f. Armor stone degradation (breaking and/or cracking) is occurring on the main breakwater. A geologic assessment indicated about 25 percent of the original stone was geologically unacceptable, and a significant number of stones were blast-damaged. Continued degradation is predicted due to freeze-thaw and wet-dry cycles as well as large waves and sea ice action. The structure should be monitored very closely since the rate of deterioration is expected to increase. In future construction, the highest grade of geologically acceptable stone should be placed above the water line in this extremely harsh environment.

g. Photogrammetric analysis of the main breakwater proved to be an excellent tool in mapping the above-water portion of the structure and quantifying changes in elevation. Results revealed most of the breakwater is below its design elevation. Almost one third of the structure adjacent to the harbor roadway is at least 0.6 m (2 ft) below its design elevation of +11.3 m (+37 ft). Analysis also indicated essentially no change in elevation of the breakwater during the monitoring period.

h. When working at remote sites, logistical problems may be a significant factor. In most cases, equipment and supplies required are not available and must be shipped from the mainland. Delivery times are uncertain and shipping costs are significantly higher.

PERIODIC INSPECTION PROJECTS

Selected coastal structures are periodically monitored to gain an understanding of their long-term structural responses to their environments. Relatively low-cost remote sensing tools and techniques, with limited ground truthing surveys, are the primary inspection tools used in the monitoring efforts. Photogrammetric analysis has proved to be an excellent tool in obtaining very precise positions of above-water armor units on the structures monitored. Base conditions have been established for Kahului Harbor, Nawiliwili Harbor, and Laupahoehoe Boat-Launching Facility breakwaters, HI; Cleveland Harbor east breakwater, OH; and Burns Harbor north breakwater, IN. Future periodic monitoring will be compared to base conditions at each project to determine their long-term responses. Crescent City Harbor breakwater, CA, and Manasquan Inlet jetties, NJ, have been revisited with monitoring data collected over a period of time. Lessons learned and significant results for the latter two projects are presented below:

Monitoring data for the period 1989-1993 were analyzed for the Crescent City Harbor breakwater. Very accurate data on the movement of armor units above the waterline were obtained. Low-altitude helicopter surveys significantly improved data accuracy and photo image resolution when compared to higher altitude, fixed-wing surveys. Very little significant movement occurred in the dolos field during monitoring; thus, no patterns of movement could be established. Strain gauges positioned inside instrumented dolosse revealed that static stress loads in some of the units were reaching levels that left little residual strength for pulsating wave loads and impact loads. It was determined that the most significant structural design parameter for large dolosse is static stress. Forty-seven broken dolosse were identified on the structure, but breakage appeared to have subsided in 1993, and was not considered a major concern. However, with the question of rising dolos static stresses, close inspections are recommended following major storm events.

Monitoring data for the period 1984-1994 were analyzed for the Manasquan Inlet jetties. Results of the monitoring effort, through photogrammetric analysis, indicate that dolosse on both jetties have been dynamic since their placement. Horizontal movement has ranged up to 2 m (6.6 ft), and vertical displacement (subsidence) as much as 1.6 m (5.3 ft). Most movements in both directions, however, have been less than 0.3 m (1.0 ft). Horizontal movement for the majority of the dolosse has been relatively uniform (the entire unit moved in the same direction as opposed to rotating). Vertical motions revealed that most dolosse have subsided slightly. The downslope portions of the armor units, in general, tended to subside more than the up-slope portions. Photogrammetric maps also revealed missing dolosse at the waterline along the head of the north jetty on its channel side. Seventeen broken armor units were identified in 1994 as opposed to five in 1984. The only area of concern was at the head of the south jetty, where a broken dolos resulted in exposure of core stone under the jetty cap. To maintain the design cross-section stability of the structure, additional armor units are required in the void along the inside head of the north jetty, and at the tip of the south jetty where core stone is exposed. Otherwise, the jetties appear to be in good structural condition. (Note: Repairs of the jetty voids with CORE-LOC^{TM} armor units are scheduled during the late summer/early fall 1997 time frame).

ADDITIONAL INFORMATION

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