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Periodic Inspections of Concrete-Armored Coastal Structures

by Robert R. Bottin, Jr.

PURPOSE: This Coastal and Hydraulic Engineering Technical Note (CHETN) provides information on the long-term structural performance of selected concrete-armored navigation structures to their environment. Inspections of coastal structures at Ofu Harbor, American Samoa; Nawiliwili, Laupahoehoe, and Kahului Harbors, HI; and Manasquan Inlet, NJ, are discussed herein. The response of stone-armored coastal structures to their environment was presented in ERDC/CHL CHETN-III-65.

OVERVIEW: In the "Periodic Inspections" work unit of the Monitoring Completed Navigation Projects (MCNP) Program, selected coastal navigation structures are periodically monitored to gain an understanding of their long-term structural response. Periodic data sets are evaluated to improve knowledge in design, construction, and maintenance of both existing and proposed coastal navigation projects, and will help avoid repeating past designs that have failed and/or resulted in high maintenance costs. Low-cost remote sensing tools and techniques, with limited ground truthing surveys, are the primary inspection tools used in the periodic monitoring efforts. Most periodic inspections consist of capturing above-water conditions of the structures at periodic intervals using high-resolution aerial photography. Structural changes (primary armor unit movement) are quantified through photogrammetric techniques. When a coastal structure is photographed at low tide, an accurate permanent record of all visible armor units is obtained. Through the use of stereoscopic, photogrammetric instruments in conjunction with stereo-pair photographs, details of structure geometry can be defined at a point in time. By direct comparison of photographs taken at different times, as well as the photogrammetric data resolved from each set of photographs, geometric changes (i.e., armor unit movement and/or breakage) on the structure can be defined as a function of time. Thus, periodic inspection data can be analyzed to determine if structure changes are occurring that indicate possible failure modes and the need to monitor the structure(s) more closely. Underwater stone and toe armor below the water surface are not evaluated.

Normally, base conditions are established and documented in the initial effort, and the site is re-inspected periodically to obtain long-term structural performance data. Also, periodic monitoring usually includes detailed broken armor unit surveys. Base level conditions were initially established for the Ofu, Nawiliwili, Laupahoehoe, and Kahului breakwaters and the Manasquan Inlet jetties. These structures also have been revisited through the "Periodic Inspections" work unit of the MCNP Program. Monitoring included limited ground surveys for control and a photogrammetric survey of the above-water armor layers. Precise positions of selected, targeted armor units were analyzed, as well as comparisons of armor unit centroid data and/or rotation angles. Orthophotos of the structures were also developed. In addition, databases of broken armor units above water were established. Results of the inspections are summarized herein. Other concrete-armored coastal structures where base level conditions have been established include the Crescent City Harbor, CA, breakwater, Humboldt Bay, CA, jetties, and Cleveland Harbor, OH, east breakwater.

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OFU HARBOR BREAKWATER, AMERICA SAMOA: The island of Ofu is one of a group of seven islands in American Samoa located in the South Pacific Ocean. Ofu Harbor is situated on a reef platform off the northwest coast of the island. The harbor was originally constructed in 1975, but sustained severe damage over the years by tropical storms, hurricanes, and typhoons. Construction of the current harbor configuration was completed in 1994. It is protected by a 185.93-m- (610-ft-) long breakwater. Base conditions were established for the breakwater in 1996 (Bottin and Boc 1997) under the "Periodic Inspections" work unit of the MCNP Program. The structure was revisited in 2002 (Bottin and Meyers 2003) to determine if changes had occurred.

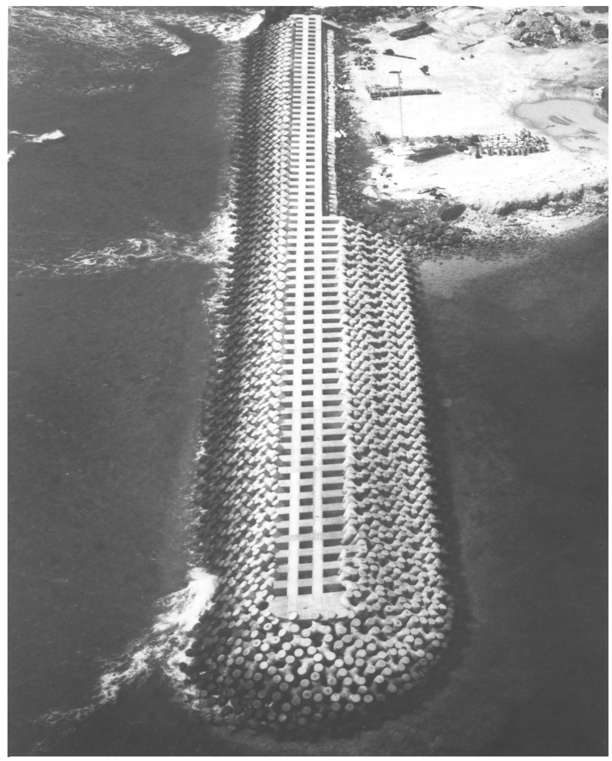
Figure 1. Ofu Harbor breakwater

The breakwater (Figure 1) is armored with a single layer of uniformly-placed 4,082.33-kg (4.5-ton) concrete tribar units. It has a concrete rib cap system on the crest to stabilize and buttress tribars at the upper sea- and harbor-side slopes. The structure has a crest elevation (el) of +4.57 m (+15 ft), and side slopes of 1V:1.5H. Due to the nonavailability of local stone, the structure was built utilizing a unique concrete design for the underlayer units. Basically the design entailed using various sized concrete units for breakwater construction as opposed to stone. Most of the underlayer consisted of 1,632.93-kg (1.8-ton) concrete units approximately 1.22 × 1.22 × 0.61-m (4 × 4 × 2 ft) with 5.08-cm (16-in.) holes in their centers and 22.86-cm (9-in.) semicircular holes on each side. When placed on the breakwater slope, the underlayer units, with the holes, resemble a slice of Swiss cheese and have been labeled Swiss cheese blocks. In addition, both 2,267.96-kg (2.5-ton) and 510.29-kg (1,125-lb) concrete units were formed by pumping high-strength, fine aggregate concrete into geotextile bags. The 2,267.96-kg (2.5-ton) units were used as a rib cap underlayer and placed along the harbor side of the structure near its origin. The 510.29-kg (1,125-lb) units were used as an underlayer for the tribars around the breakwater head since the Swiss cheese blocks could not be placed in this area due to the tight radius.

During the initial photogrammetric survey of October 1996, selected tribars were targeted (three targets each) and precise positions of these units were obtained as well as centroid data and orientations of the targeted armor units. A walking survey of the structure revealed no broken armor units, however, one sea-side tribar was slightly separated from the rib cap. In addition, it was noted that some of the Swiss cheese block underlayer units along the slope had slightly separated in a vertical direction. The maximum separation was about 20.32 cm (8 in.) The geotextile bags had deteriorated and some spalling along the edges of the 510.29-kg (1,125-lb) high-strength concrete underlayer units was also noted around the head of the structure. In general, the breakwater appeared to be in excellent condition.

The August 2002 photogrammetric survey of the breakwater revealed negligible movement of the concrete armor units relative to the 1996 survey. Maximum movement of the targets established on the tribar armor units in the horizontal and vertical directions, respectively, were 0.14 m (0.45 ft) and 0.106 m (0.35 ft); and the average movements of all horizontal and vertical targets were 0.012 m (0.04 ft) and 0.021 m (0.07 ft), respectively. Maximum movements of the target armor unit centroids were 0.088 m (0.29 ft) and 0.073 m (0.24 ft) in the horizontal and vertical directions, respectively, while average movements were 0.012 m (0.04 ft) and 0.024 m (0.08 ft) in the horizontal and vertical directions. Seventy-three percent of all vertical movements and 93 percent of horizontal movements were 0.03048 m (0.1 ft) or less. Changes in rotation angles of the armor units varied from 0.0 to 4.03 deg with an average of 0.64 deg. A walking inspection of the structure in 2002 revealed no broken tribars. Fifteen sea-side tribars were slightly separated from the rib cap as opposed to one in 1996. On the entire sea side of the structure, it was noted that the Swiss cheese block underlayer units had separated along the slope between the third and fourth rows (down from the crest). Typical separations ranged from 2.54 to 10.16 cm (1 to 4 in.), and the maximum was 20.32 cm (8 in.). Some underlayer separations 2.54 to 10.16 cm (1 to 4 in.) were also noted on the harbor side of the structure. Separations between the cheese block underlayer units were more widespread as opposed to the 1996 inspection. The 510.29-kg (1,125-lb) high-strength concrete underlayer units around the head of the structure looked the same as the previous inspection. Even though slight movement in the breakwater's underlayer armor units had occurred, the breakwater appeared to be in excellent condition. It has not been subjected, however, to a major tropical storm, typhoon, or hurricane since its construction.

NAWILIWILI HARBOR BREAKWATER, KAUAI, HI: Nawiliwili Harbor is located on the southeast coast of the island of Kauai. It is protected by a 624.84-m- (2,050-ft-) long breakwater. Constructed in 1922, the breakwater has had a long history of repair. The most recent rehabilitation occurred in 1987. Base conditions were established in 1995 for the outer 259.08 m (850 ft) of the breakwater (Bottin and Boc 1996) under the "Periodic Inspections" work unit of the MCNP Program. The structure was revisited in 2001 (Bottin and Meyers 2002a).

Originally constructed with stone armor, the outer portion of the breakwater was later armored with several sizes of dolos and tribar concrete armor units 9,979.03- and 20,865.25-kg- (11- and 23-ton) dolos, and 5,896.70- and 16,147.89-kg (6.5- and 17.8-ton) tribars). It includes a concrete rib cap that provides buttressing for the armor and access along its alignment. The structure has a crest el of +4.88 m (+16 ft). Side slopes along the sea-side slope and the trunk (Figure 2) are 1V:2H, and slopes on the harbor side of the breakwater are 1V:1.5H. In general, the sea-side

Figure 2. Trunk of Nawiliwili breakwater

slope and head were armored with 16,147.89-kg (17.8-ton) tribars. Subsequent repairs involved 9,979.03-kg (11-ton) dolos along the sea-side trunk and 20,865.25-kg (23-ton) dolos around the head of the structure. The 5,896.70-kg (6.5-ton) tribars were used to repair a portion of the harbor-side slope.

During the initial photogrammetric survey of September 1995, selected armor units 16,147.89-kg (17.8-ton) tribars and 9,979.03- and 20,865.25-kg (11- and 23-ton) dolosse) were targeted (three targets each) and precise positions of these units were obtained as well as centroid data and orientations of the targeted armor units. The initial broken armor unit survey of the Nawiliwili Harbor breakwater revealed a total of 70 broken or cracked armor units above the waterline. Of the 70 broken or cracked armor units, 39 were 9,979.03-kg (11-ton) dolos, 19 were 16,147.89-kg (17.8-ton) tribars, 8 were 20,865.25-kg (23-ton) dolosse, and 4 were 16,147.89-kg (6.5-ton) tribars. Considering the types of breaks, 54 percent of the 9,979.03-kg (11-ton) dolosse and 63 percent of the 20,865.25-kg (23-ton) dolosse were determined to be mid-shank breaks. Of all the dolos breaks recorded, 77 percent were straight and 23 percent were angled. Of the 19 broken 16,147.89-kg (17.8-ton) tribars, 74 percent consisted of one leg broken off through the center of the unit. The four broken 6.5-ton tribars on the harbor-side of the breakwater appeared to have been placed in that condition. They seemed to have been fitted on the crest adjacent to the rib cap. It was noted during the inspection, that due to excessive wave action, broken/cracked armor units along the sea-side water's edge may have been missed in the previous inspection, since that portion of the structure was inaccessible by foot.

The September 2001 photogrammetric survey indicated negligible movement of the concrete armor units on the breakwater relative to the 1995 survey. Maximum movement of the targets established on the concrete armor units in the horizontal and vertical directions, respectively, was 0.1280 m (0.42 ft) and 0.1381 m (0.45 ft); and the average movement of all horizontal and vertical targets was 0.0304 m (0.1 ft) and 0.0457 m (0.15 ft). Maximum movements of the targeted armor unit centroids were 0.1036 m (0.34 ft) and 0.1127 m (0.37 ft) in the horizontal and vertical directions, respectively, while average movements were 0.0274 m (0.09 ft) and 0.0426 m (0.14 ft) in the horizontal and vertical directions. Changes in the rotation angles of the armor units varied from 0.0 to 10.2 deg with an average of 0.8 deg. A broken armor unit survey conducted during August 2001 revealed 77 broken or cracked armor units above the waterline (versus 70 in 1995). Additional broken units identified since the last survey included five 9,979.03-kg (11-ton) dolosse and two 16,147.89-kg (17.8-ton) tribars. However, as stated previously, high wave action during the 1995 walking inspection prevented a close examination of armor units on the sea-side water's edge. Of the seven additional broken units identified in 2001, six were located along the water's edge and may have been overlooked in 1995 due to the excessive wave action. Therefore, it appears that minimal armor unit breakage occurred between 1995 and 2001. Overall, the structure appeared to be in good condition.

KAHULUI HARBOR BREAKWATER, MAUI, HI: Kahului Harbor is located on the north shore of the island of Maui. It is protected by two breakwaters. The breakwaters are rich in construction, repair, and rehabilitation history. In 1931 the east and west breakwaters were extended to their current lengths of 843.07 and 705.61 m (2,766 and 2,315 ft), respectively. The most recent rehabilitation occurred in 1984. Base conditions were established in 1993 for the outer portions of the breakwaters (Markle and Boc 1994) under the "Periodic Inspections" work unit of the MCNP Program. The structure was revisited in 2001 (Bottin and Meyers 2002b).

Originally constructed with stone armor, the outer portions of the breakwaters were later armored with various configurations of dolosse, tribar, and tetrapod concrete armor units. Included were 6-, 20- and 30-ton dolos, 6.5-, 9-, 11-, 19-, 35- and 50-ton tribars, and 33-ton tetrapods. Concrete rib caps also have been installed to provide buttressing for the armor and access along the structure alignments. The breakwaters have crest elevations of about +4.87 m (+16 ft). Typically, side slopes along the sea sides and the breakwater heads are 1V:3H, and slopes on the harbor side of the structures are 1V:2H. The heads of both the east and west breakwaters (Figure 3) comprise 27,215.54-kg (30-ton) dolosse, 45,359.24-kg (50-ton) tribars, and 29,937.1-kg (33-ton) tetrapods. The sea-side slope of the east breakwater contains 5,443.10- and 18,143.69-kg (6- and 20-ton) dolosse and 31,751.47-kg (35-ton) tribars, and the sea-side slope of the west breakwater contains 18,143.69-kg (20-ton) dolosse as well as 9,979.03-, 17,236.57-, and 31,751.47-kg (11-, 19- and 35-ton) tribars. The 8,164.66-kg (9-ton) tribars were used to repair a portion of the harbor-side slope of the east breakwater and the 5,896.70-kg (6.5-ton) tribars were placed in an area on the harbor-side slope of the west structure.

Figure 3. Head of Kahului west breakwater

During the initial photogrammetric survey of August 1993, selected armor units (5,443.10- and 27,215.54-kg (6- and 30-ton) dolos and 5,896.70-, 8,164.66-, 9,979.03-, and 31,751.47-kg (6.5-, 9-, 11-, and 35-ton) tribars) were targeted (three targets each) and precise positions of these units were obtained. Centroid data positions and orientations of the targeted armor units relative to the x, y, and z axes were obtained as well. Documentation of broken/cracked armor units by foot was not conducted as part of the periodic inspection in 1993.

The August 2001 photogrammetric survey indicated close agreement between positions of the concrete armor units relative to the 1993 survey for most of the targets. For the east breakwater, maximum movements of the targets established on the concrete armor units in the horizontal and vertical directions, respectively, were 0.94 m (3.1 ft) and 1.52 m (5.0 ft); however this level of difference occurred for only one target for the horizontal and one target in the vertical position. Both these targets were on units situated around the seaward head of the structure. The average movements of all horizontal and vertical targets on the east breakwater were 0.15 and 0.16 m (0.51 and 0.54 ft), respectively. Maximum movements of the targeted armor unit centroids on the east breakwater were 0.54 and 0.67 m (1.8 and 2.2 ft) in the horizontal and vertical directions, respectively, while average movements were 0.12 and 0.17 m (0.39 ft and 0.57 ft) in the horizontal and vertical directions. For the east breakwater, changes in the rotation angle of the armor units varied from 0.03 to 24.57 deg with an average of 3.09 deg. For the west breakwater, maximum movements of the targets in the horizontal and vertical directions were 0.13 and 0.11 m (3.8 and 1.9 ft), respectively; however, this level of difference occurred on only one armor unit. The average movements of all horizontal and vertical targets, respectively, were 0.11 and 0.06 m (0.42 and

0.36 ft). Maximum horizontal and vertical centroid movements, respectively, for the west breakwater were 0.64 and 0.18 m (2.1 and 0.6 ft), while average movements were 0.11 and 0.06 m (0.37 and 0.21 ft) in the horizontal and vertical directions. Changes in rotation angles varied from 0.0 to 17.32 deg for the west breakwater with an average of 2.02 deg. Even though some units had moved 0.91 to 1.5 m (3 to 5 ft) on the breakwaters, visual observations indicated they had not broken and continued to be functional. A broken armor unit survey conducted during August 2001 revealed 29 broken or cracked armor units above the waterline on the east breakwater and 58 on the west structure. Of the 29 broken units on the east breakwater, 19 were 5,443.10-kg (6-ton) dolosse, two were 8,164.66-kg (9-ton) tribars, four were 27,215.54-kg (30-ton) dolos, and four were 31,751.47-kg (35-ton) tribars. Of the 58 broken units on the west breakwater, four were 5,896.70-kg (6.5-ton) tribars, one was a 9,979.03-kg (11-ton) tribar, 16 were 17,236.51-kg (19-ton) tribars, 18 were 18,143.64-kg (20-ton) dolos, 11 were 27,215.54-kg (30-ton) dolos, five were 29,937.1-kg (33-ton) tetrapods, and three were 31,751.47-kg (35-ton) tribars. Concentrations of broken armor units were identified on various areas of the breakwaters. Considering the types of breaks for the 52 broken dolosse on both structures, 75 percent had shank-fluke breaks, 16 percent had fluke-shank breaks, 9 percent had mid-shank breaks. Of the dolos breaks recorded, 78 percent were straight and 22 percent were angled. Considering the types of breaks for the 35 tribars and tetrapods on the breakwaters, 89 percent included units with breaks through the center sections where one or more legs had separated, and 11 percent had just portions of a leg broken off the unit. These data establish a base from which to evaluate future breakage in subsequent surveys. Even though some breakage has occurred, the structures appeared to be in good condition overall.

LAUPAHOEHOE POINT BOAT-LAUNCHING FACILITY BREAKWATER, HI: Laupahoehoe Point is located on the northeast coast of the island of Hawaii. A park and boat launching facility is situated in the area. To protect the boat launch, a 60.96-m- (200-ft-) long breakwater was constructed in 1988. Base conditions for the breakwater were established in 1992 (Markle and Boc 1994) under the "Periodic Inspections" work unit of the MCNP Program. The structure was revisited in 2001 (Bottin and Meyers 2002b).

Figure 4. Laupahoehoe breakwater

The breakwater (Figure 4) is armored with 30-ton dolosse and the crest is stabilized with a concrete rib cap. The crest elevation of the structure is +3.66 m (+12 ft). Side slopes along the sea side and the breakwater head vary from 1V:2H to 1V:2.5H and slopes on the harbor side of the structure vary from 1V:1.5H to 1V:2H.

During the initial photogrammetric survey of November 1992, selected armor units were targeted (three targets each) and precise positions of these units were obtained. Centroid data positions and orientations of the targeted armor units relative to the x, y, and z axes were obtained as well. No broken/cracked armor units were documented during the walking inspection.

The September 2001 photogrammetric survey indicated minimal horizontal and vertical movement of the targeted units relative to the previous survey. Maximum movements of the targets in the horizontal and vertical directions, respectively, were 0.10 m and 0.13 m (0.34 ft and 0.43 ft). The average movements of all horizontal and vertical targets, respectively were 0.03 and 0.05 m (0.1 and 0.16 ft). Maximum movements of the targeted armor unit centroids were 0.0914 and 0.085 m (0.3 and 0.28 ft) in the horizontal and vertical directions, respectively, while average movements were 0.0304 and 0.0335 m (0.1 ft and 0.11 ft) in the horizontal and vertical directions. Changes in the rotation angle of the armor units varied from 0.01 to 0.36 deg with an average of 0.1 deg. No broken or cracked armor units were observed during the walking inspection. The structure is considered to be in excellent condition.

MANASQUAN INLET JETTIES, NJ: Manasquan Inlet is located on the Atlantic Coast of New Jersey. It provides the northernmost connection between the ocean and the New Jersey Intracoastal Waterway. The inlet is stabilized by two jetties, spaced 121.92 m (400 ft) apart. A major rehabilitation of the jetties was completed in 1982. The north jetty is 374.90 m (1,230 ft) long, and the south jetty is 313.94 m (1,030 ft) in length. The project was monitored under the MCNP Program during the period June 1982 through October 1984 (Gebert and Hemsley 1991). Photogrammetric analysis of armor unit movements and broken armor unit surveys of the outer portions of the jetties were included in the initial monitoring effort. Base conditions were established in 1982 with additional surveys through 1984. The structure was revisited under the "Periodic Inspections" work unit in 1994 (Bottin and Gebert 1995) and 1998 (Bottin and Rothert 1999).

During the major rehabilitation of 1982, the outer 121.92 m (400 ft) of the north jetty (Figure 5) and 76.2 m (250 ft) of the south jetty were armored with 14,514.96-kg (16-ton) dolosse. The jetty crests were concrete caps with elevations of +4.26 m (+14 ft). Side slopes for the dolosse were 1V:2H. Additional repairs were conducted in 1997 that included the placement of 29 CORE-LOCs™ on the north jetty and 16 CORE-LOCs on the south structure. Also, some of the dolosse were repositioned to improve interlocking and allow space for the new CORE-LOCs. Several broken dolosse were removed. The CORE-LOCs used for the repairs were 17,236.51-kg (19-ton) units.

Figure 5. Manasquan north jetty

During the initial photogrammetric survey in January 1982, 111 dolosse distributed over the two jetties were targeted to determine armor unit movement through photogrammetry. In addition, photogrammetric maps were developed and plotted on transparent drafting material. They documented the location, orientation, and elevation of about 57 percent of the armor units placed on the jetties. The remaining dolosse were underwater or beneath the top layer of dolosse and not visible in photography. A survey in September 1983 indicated that 65 percent of the targets were within 0.09 m (0.3 ft), and 91 percent were within 0.3048 m (1.0 ft), of their initial positions. The maximum vertical change was a drop of 1.28 m (4.2 ft) on a dolos at the head of the south jetty. The largest horizontal displacement was nearly 1.83 m (6.0 ft) on the channel side of the south jetty head. It was noted that storm events had occurred during the period between January 1982 and September 1983. A survey conducted in March 1984 revealed that the mean vertical displacement for all points monitored on the two jetties was 0.05 m (0.15 ft), and only 10 percent of the monitored dolosse experienced detectable horizontal movements, the largest of which was about 0.3048 m (1.0 ft) when compared with the September 1983 data. This was a relatively storm-free period. Between March and May 1984, the mean vertical displacement of all monitored dolosse was 0.14 m (0.46 ft). Approximately 3 percent moved in excess of 0.3048 m (1.0 ft) vertically, with a maximum value indicating a 0.61-m (2.0-ft) drop. The largest horizontal displacement was 2.13 m (7.0 ft) at the head of the south jetty. Altogether, about 9 percent of the monitored dolosse moved in excess of 0.61 m (2.0 ft) horizontally, with 31 percent moving up to 0.61 m (2.0 ft). About 60 percent experienced no detectable horizontal movement. During this period (March through May 1984), an intense coastal storm affected the mid-Atlantic states and exposed the jetties to what was believed their design wave heights. A walking survey in May 1984 revealed four broken dolosse on the north jetty at the head of the structure and one broken unit on the south jetty located near the head on the channel side of the structure. Despite exposure to the design storm wave event, only five of the 1,326 dolosse (0.4 percent) used in the 1982 rehabilitation had broken. Of the five broken units, only one had experienced a horizontal displacement in excess of 0.61 m (2.0 ft) from its initial location. Others had moved up to 2.13 m (7.0 ft), yet had not broken. This finding suggested that impact may be more important than movement in dolos breakage. An armor unit may experience significant impacts even with only small movements.

The May 1994 photogrammetric survey indicated that the targeted dolosse on the north and south jetties had been dynamic since the initial monitoring ended in 1984. Horizontal movement had ranged up to 2.01 m (6.6 ft) and vertical displacement (subsidence) as much as 1.62 m (5.3 ft). Dolos movement on the north jetty was slightly greater than those on the south. From 1984 to 1994 about 73 percent of the targeted units on the north jetty and 86 percent of the units on the south jetty had moved less than 0.3048 m (1 ft). Conversely, about 13 and 4 percent of the north and south jetty units, respectively, had moved distances greater than 0.91 m (3 ft). With regard to el changes between 1984 and 1994, 93 percent of the dolosse on the north jetty and 95 percent of those on the south structure had subsided. Between 1984 and 1994, the average movements of horizontal and vertical targets on the north jetty were 0.2743 m and 0.2438 m (0.9 ft and 0.8 ft), respectively; and on the south jetty the average movement was 0.1828 m (0.6 ft) both horizontally and vertically. The 1994 broken armor unit survey revealed 17 broken/cracked dolosse as opposed to five in1984. Of the broken/cracked units, nine were located on the north jetty and eight were situated on the south structure. Pieces of the armor units were separated on 10 dolosse. Four dolosse were broken and being held together by rebar, and four had only hairline cracks. Considering the types of breaks, the majority (10 units) had shank-fluke breaks. There were five mid-shank breaks and two fluke-shank breaks. There were nine angled breaks and eight straight ones. Fifteen of the 17 units were concentrated around the jetties' seaward heads. An area of concern was noted during the walking inspection at the tip of the south jetty where a broken unit had resulted in exposure of the core stone under the jetty cap. During the period October 1991 through March 1994, three major storm events (northeasters) occurred in the vicinity of Manasquan Inlet. These events probably significantly contributed to the armor unit movement and breakage at the heads of the jetties.

The August 1998 photogrammetric survey revealed significantly less dolos movement between 1994 and1998 as detected during previous survey periods. Movement of dolos targets in the horizontal direction ranged from 0 to 0.55 m (0 to 1.8 ft), and vertical displacement ranged from 0 to 0.07 m (0 to 0.22 ft). Only three target positions on the north jetty moved over 0.15 m (0.5 ft) in the horizontal direction, and all other targets on the north structure moved 0.08 m (0.25 ft) or less. On the south jetty, all targets moved 0.06 m (0.21 ft), or less, horizontally. In the vertical direction, target movement did not exceed 0.07 m (0.22 ft) on the north jetty and 0.06 m (0.21 ft) on the south structure. Between 1994 and 1998, the average movements of the targets on the north jetty were 0.05 and 0.03 m (0.15 and 0.09 ft) in the horizontal and vertical directions, respectively. On the south jetty, the average movements of the targets in the horizontal and vertical directions, were 0.02 and 0.03 m (0.07 and 0.09 ft), respectively. During the previous surveys, the more significant movement occurred around the heads of the jetties. During this period (1997), however, the jetty heads were rehabilitated with CORE-LOCs. Some dolosse were covered and/or repositioned during this process. Therefore, no correlation in movement could be made for armor units in areas where the more significant movement had occurred previously. During the November 1998 broken armor unit survey, eight broken/cracked dolos armor units were observed. Four broken units were observed on each structure. Of the eight broken armor units observed, six were identified in the previous 1994 survey, and two were new breaks. As stated earlier, 17 broken units were observed in 1994. During the 1997 CORE-LOC rehabilitation, however, several broken dolosse were removed from the heads of the structures. Records indicate that several northeasters occurred between 1994 and 1998. During the 1998 periodic inspection, initial base data were obtained for the CORE-LOC armor units installed on the heads of the jetties. These data will establish a base from which to evaluate the effectiveness and analyze the performance of the CORE-LOCs in subsequent inspections.

ADDITIONAL INFORMATION: Questions relative to this CHETN may be addressed to Mr. Robert R. Bottin, Jr., Coastal Harbors and Structures Branch, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center at (601-634-3827), FAX (601-634-4827), or e-mail: Ray.R.Bottin@erdc.usace.army.mil. Additional information on the MCNP Program may be obtained from: *http://chl.wes.army.mil/research/navigation/mcnp_site/default.htm*.

This CHETN summarizes data obtained for concrete-armored coastal structures under the "Periodic Inspections" work unit of the MCNP Program. Detailed information relative to photogrammetric techniques, design and model studies, and case histories, etc. of the structures discussed herein may be obtained from individual references listed in the following "References" section.

REFERENCES

Bottin, Robert R., Jr., and Boc, Stanley J. (1996). "Periodic inspection of Nawiliwili Harbor breakwater, Kauai, Hawaii; Report 1: Base conditions," Technical Report CERC-96-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bottin, Robert R., Jr., and Boc, Stanley J. (1997). "Periodic inspection of Ofu Harbor breakwater, American Samoa; Report 1: Base conditions," Technical Report CHL-97-32. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bottin, Robert R., Jr., and Gebert, Jeffrey A. (1995). "Periodic inspection of jetties at Manasquan Inlet, New Jersey; Report 1: Armor unit monitoring for period 1984-1994," Technical Report CERC-95-19, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bottin, Robert R., Jr., and Meyers, Daniel T. (2002a). "Periodic inspection of Nawiliwili Harbor breakwater, Kauai, Hawaii: Armor unit monitoring for period 1995-2001," Technical Report ERDC/CHL TR-02-7, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Bottin, Robert R., Jr., and Meyers, Daniel T. (2002b). "Periodic inspections of Kahului and Laupahoehoe breakwaters, Hawaii: Armor unit monitoring for period 1992/93-2001," Technical Report ERDC/CHL TR-02-11, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Bottin, Robert R., Jr., and Meyers, Daniel T. (2003). "Periodic inspection of Ofu Harbor breakwater, American Samoa: Armor unit monitoring for period 1996-2002," Technical Report ERDC/CHL TR-03-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Bottin, Robert R., Jr., and Rothert, William F. (1999). "Periodic inspection of jetties at Manasquan Inlet, New Jersey: Armor unit monitoring for period 1994-1998," Technical Report CHL-99-16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Gebert, Jeffrey A., and Hemsley, J. Michael. (1991). "Monitoring of jetty rehabilitation at Manasquan Inlet, New Jersey," Miscellaneous Paper CERC-91-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Markle, Dennis G., and Boc, Stanley J. (1994). "Periodic inspections of Kahului and Laupahoehoe breakwaters, Hawaii; Report 1: Base conditions," Technical Report CERC-94-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.