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Coastal and Hydraulics Laboratory

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Monitoring Completed Navigation Projects Program

Periodic Inspections of Hilo, Kahului, Laupahoehoe, and Nawiliwili Breakwaters, Hawaii

Armor Unit Monitoring for Period 2001-2005

Glenn B. Myrick, Jeffrey A. Melby, Elizabeth C. Burg, and Kristi L. Acuff

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Final report

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Abstract: As part of the Monitoring Completed Navigation Projects (MCNP) program "Periodic Inspections" work unit, five breakwaters from the Hawaiian Islands were inspected. The Hilo, Kahului east and west, Laupahoehoe, and Nawiliwili breakwaters were examined by walking inspection in the summer of 2005. Broken, cracked, and shifted concrete armor units and stones were recorded, and overall performance of the structure was noted. Photographs were taken and detailed notes recorded at each damage site. Observations and assessments are included for each of the five breakwaters inspected.

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Preface

The studies reported herein were conducted as part of the Monitoring Completed Navigation Projects (MCNP) program under MCNP work unit IM-7, "Periodic Inspections". Overall program management of the MCNP is provided by Headquarters, U.S. Army Corps of Engineers (HQUSACE). The Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), is responsible for technical and data management, and support for HQUSACE review and technology transfer. The Principle Investigator for this study was Dr. Jeffrey A Melby, CHL.

This report presents results of inspections of Hilo, Kahului, Laupahoehoe, and Nawiliwili breakwaters, HI. These structures (except for Hilo) have been previously monitored under the MCNP program. The information contained in this report was obtained by walking inspections of the structures conducted by Dr. Melby and Glenn B. Myrick, CHL, Kristi L. Acuff (formerly of CHL), and Daniel T. Meyers, U.S. Army Engineer District, Honolulu (CEPOH).

The work was conducted during the period July through September 2005 under the general supervision of Thomas W. Richardson, former Director, CHL, and Dr. William D. Martin, former Deputy Director, CHL; and under the direct supervision of Jose E. Sanchez, former Chief, Harbors, Entrances, and Structures Branch (HES), CHL. This report was prepared by Dr. Melby, Myrick, and Elizabeth Burg (formerly of CHL), with contributions from Acuff.

At the time of publication of this report, Dr. Martin was Director, CHL, and Sanchez was Deputy Director, CHL. Dr. Rose M. Kress was Chief, Navigation Division, CHL; and Dr. Jackie S. Pettway was Chief, HES, CHL. The HQUSACE program monitor for the MCNP Program was James E. Walker, Chief, Navigation Branch, HQ. W. Jeff Lillycrop, CHL, was the ERDC Technical Director for Navigation. MCNP program manager was Dr. Lyndell Z. Hales, Hydraulic Engineer, Technical Programs Office, CHL. COL Kevin J. Wilson was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

Unit Conversion Factors

A sponsor requirement for this study was the use of English Customary units of measurement. Most measurements and calculations were done in SI units and then converted to English Customary. The following table can be used to convert back to SI units.

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic yards	0.7645549	cubic meters
degrees (angles)	0.01745329	radians
feet	30.48	centimeters
feet	0.3048	meters
inches	2.54	centimeters
miles	1.609347	kilometers
tons (2,000 Pounds, mass)	0.9071847	tonnes (metric)

1 Introduction

Monitoring Completed Navigation Projects (MCNP) program

The Monitoring Completed Navigation Projects (MCNP) program evolved from the Monitoring Completed Coastal Projects (MCCP) program. The MCCP was originally established in 1978 to help determine whether completed coastal structures were performing as designed, and to survey their effectiveness against physical environmental factors over time. The goal was to help engineers increase knowledge of how structures perform. The knowledge gained would be used to design and construct more effective structures with cost-savings to the Corps of Engineers (COE) Operations and Maintenance (O&M) budget.

Funding constraints necessitated the need to select representative sites to monitor in lieu of monitoring all Corps coastal structures. A COE Coastal Program Field Review Group (FRG) presented recommendations to Headquarters, United States Army Corps of Engineers (HQUSACE) Directorate of Research and Development (DRD). The resolution was that the COE should:

1. Prioritize candidate locations based on the need to understand site-specific physical interactions, and ability to apply this knowledge on a regional basis.
2. Thoroughly monitor selected coastal structures from construction completion for a finite amount of time, usually 3-5 years.
3. Evaluate the constructed design performance after exposure to physical elements.
4. Apply knowledge gained from monitoring and analysis to new research and technologies targeting site-specific conditions.
5. Include structures undergoing extensive rehabilitations due to failure or poor performance to the monitoring candidate list.
6. Fund the program through the COE Operation and Maintenance (O&M) budget.

Monitoring such environmental factors as wave, current, and sediment effects on coastal structures could help validate site-specific designs. Alternatively, if the design proved ineffective for its physical conditions, the monitoring and analysis could provide data for future research, design, and construction efforts.

In addition, the selection process would provide an array of site-specific conditions which could theoretically be applied to other sites with similar variables. Optimally, a small number of structures would provide enough information to be applied regionally.

Districts nominated candidates for inclusion in the program to a panel of CHL engineers and scientists who reviewed and ranked each project. The highest ranking project proposals were presented to the FRG to create a prioritized list. Final selections were made by HQUSACE based on the priority listing, national priorities, and available funds.

Inland navigation projects were added to the MCCP in the late 1990s and, thus, the program was reclassified as the Monitoring Completed Navigation Projects (MCNP) program.

With the criteria for the program established, the Engineer Regulation 1110-2-8151 (Headquarters, U.S. Army Corps of Engineers (HQUSACE) 1997)) formalized the program and governs the MCNP efforts.

Today, the MCNP monitoring efforts involve a variety of associated research topics such as Great Lakes armor stone deterioration, lock and dam wall armor deterioration, specific concrete armor unit stability, and periodic inspections (the subject of this report).

Objective of Periodic Inspections work unit

The current objective of the Periodic Inspections work unit in the MCNP program is to periodically inspect selected coastal navigation structures to monitor the long-term performance of structures affected primarily by wave action and weathering. Originally intended to monitor coastal structures intensely for relatively short, finite time periods, it was determined that more valuable information could be obtained by inspecting and surveying sites at much less frequent intervals over longer periods of time. To accomplish this, a structure is selected for monitoring under the Periodic Inspections work unit, a baseline condition is recorded, and the structure is revisited periodically. The data collected during inspection of the selected structures can be used to analyze progressive deterioration, ascertain and measure causes of structure damage, and determine if the structures are performing to design standards.

Study scope

The information in this report was obtained by conducting walking inspections of breakwaters located at Hilo Harbor, Island of Hawaii, HI; Kahului Harbor, Island of Maui, HI; Laupahoehoe Point Boat-Launching Facility, Island of Hawaii, HI; and Nawiliwili Harbor, Island of Kauai, HI. The approximate locations of the sites visited are shown in Figure 1. The walking inspections and assessments of the structures at these sites did not generally include the use of sophisticated instrumentation. However, baseline terrestrial and Light Detection and Ranging (LIDAR) multibeam sonar instrumentation were used to obtain bathymetric and topographic baseline data for the Hilo breakwater. Previous surveys of the Kahului, Laupahoehoe, and Nawiliwili structures included photogrammetric topographic surveys to track armor unit movements.

The present walking surveys were intended to supply supplemental interim condition data between topographic surveys to provide a more continuous record of structure performance. Data from previous inspections were used to identify locations of broken, cracked, or displaced armor units during the walking survey, and new damage was carefully recorded. Settlement along the structures and voids in the armor layer were also noted, and photographs of the structures were obtained. Hilo Harbor breakwater baseline conditions were completed in 2005 and reported for the first time herein, at Laupahoehoe in 1992 (Markle and Boc 1994), in 1993 for Kahului, and in 1995 for Nawiliwili (Bottin and Boc 1996). These breakwaters were nominated for periodic monitoring by The U.S. Army Engineer District, Honolulu (POH) (hereafter, the Honolulu District). Additional monitoring of these locations, excluding Hilo, was conducted during the period August – October 2001 (Bottin and Meyers 2002a, b).

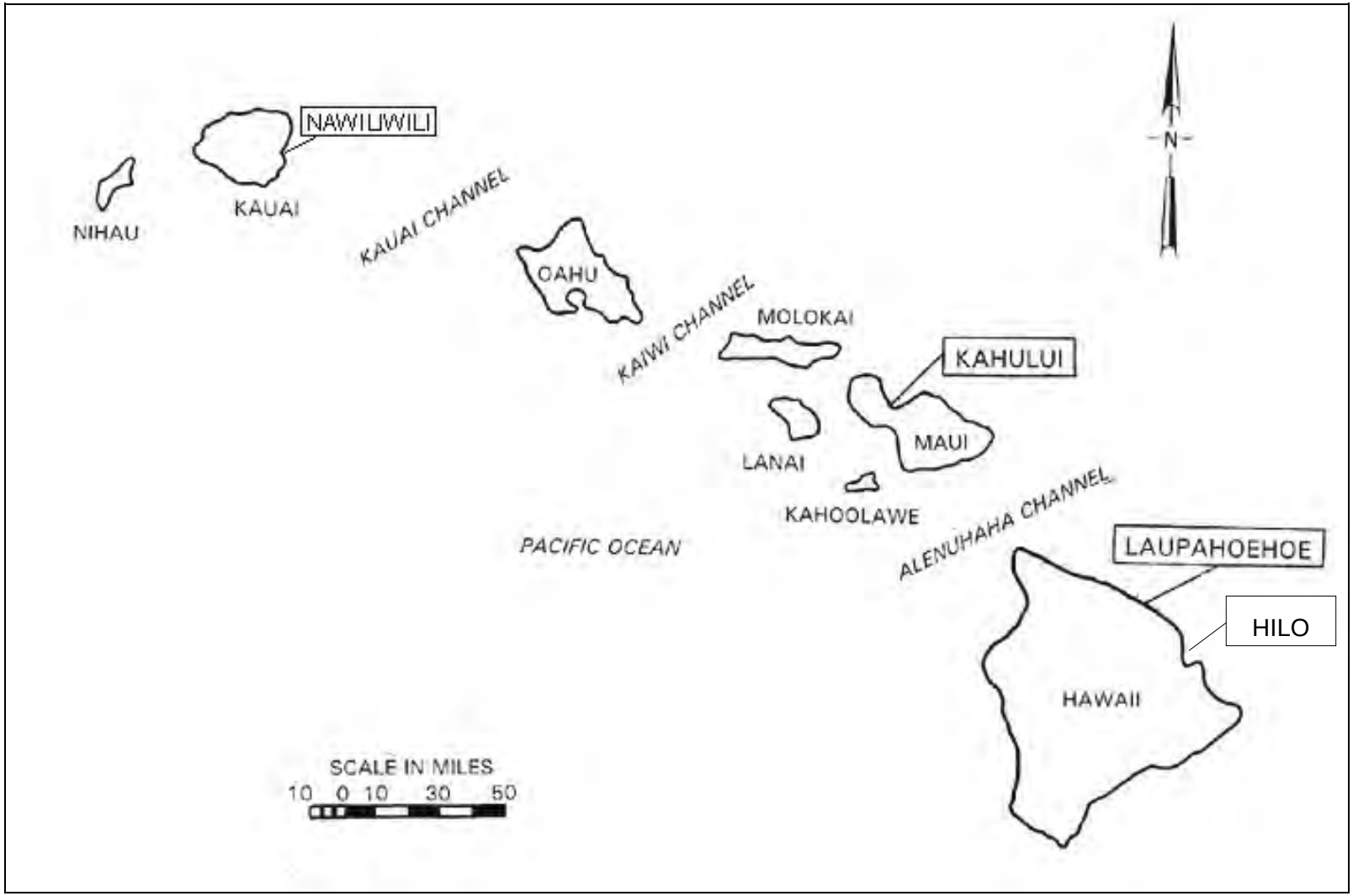

Figure 1. Project locations.

2 Project Descriptions and History

Hilo Harbor breakwater, Hawaii, HI

The Hilo Harbor breakwater, HI, is a 3,072-m- (10,080-ft-) long rubble-mound breakwater constructed by the U.S. Army Corps of Engineers in 1930. Figure 2 shows a location map and layout of the harbor.

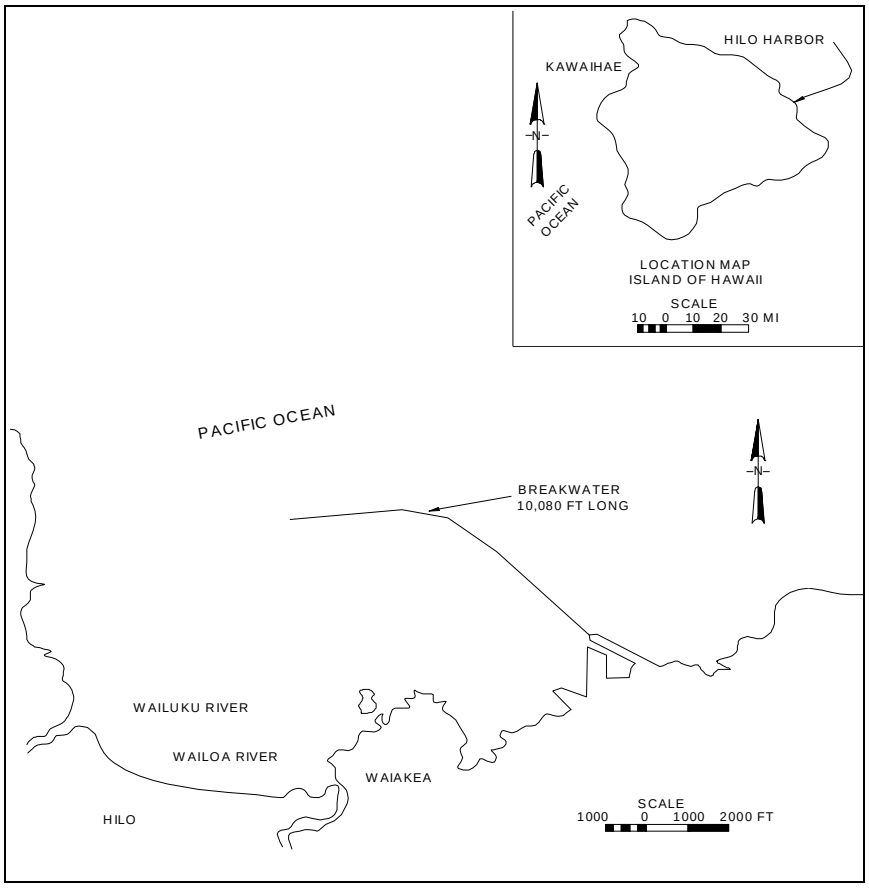

Figure 2. Location map and layout of Hilo Harbor, HI.

A tsunami in 1946 caused severe damage to approximately 1,829 m (6,000 ft) of the structure, including a 335-m (1,100-ft) breach. The breakwater was repaired to its original design in 1948 (Figure 3). Storm waves in 1951 damaged 13 areas of the structure. Repairs were completed the following year. Storms in 1954 and a tsunami in 1960 caused further damage to the structure which was again repaired to the original design. Storms during 1965 damaged the structure at sta 15+00, 36+30, 73+40, 83+00, and 90+00.

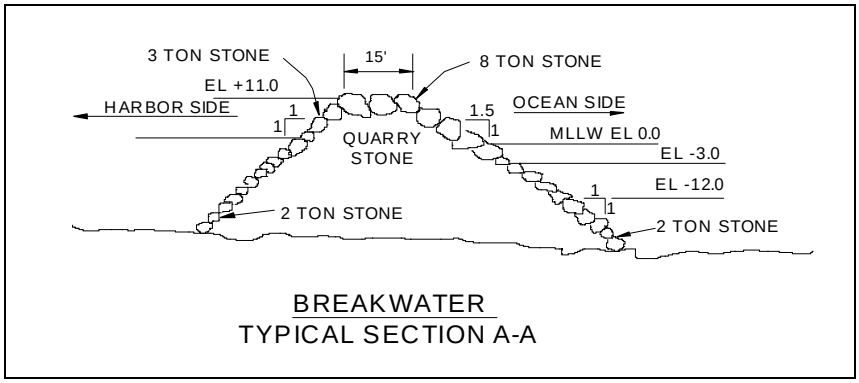

Figure 3. Cross-section of Hilo breakwater original construction.

Repairs in 1968 included an increase in armor stone size from a 7.2-tonne (8-ton) minimum to a 9-tonne (10-ton) minimum in areas of recurring damage. Other areas of the structure were repaired to the original design cross-sections. In 1971, an inspection identified 518 m (1,700 ft) of severe deterioration at the shoreward end of the breakwater. This prompted emergency repairs, completed in 1973. Hurricane Kate damaged the breakwater in 1976. Immediate repairs were not recommended, but continued sporadic damage and observed transmission through the structure prompted new repairs. These included the addition of a concrete rib cap between sta 11+00 and 20+00 with a single layer of 6.8-tonne (7.5- ton) tribars placed on a 1V: 1.5H slope on the seaward side of this reach. These repairs were completed in 1981 (Sargent et al. 1988). A cross-section of the repairs along this reach is shown in Figure 4. Figure 5 shows a photograph of the rib cap and tribar repair section in July 2005. Figure 6 shows a surface level photograph of the Hilo breakwater viewed from the center of the crest east to west.

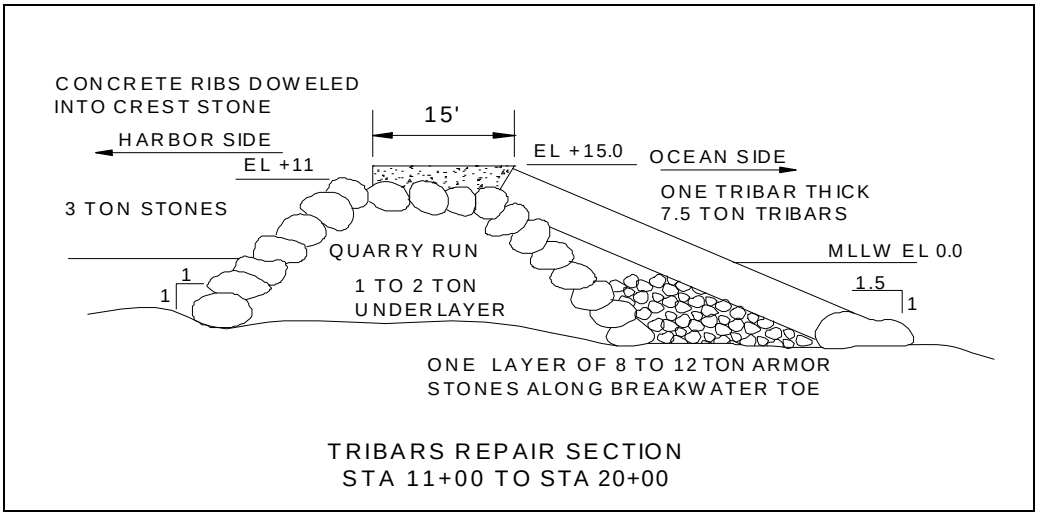

Figure 4. Cross-section of 1981 repairs.

Figure 5. Photograph of Hilo breakwater 1981 repair section viewed east to west.

Figure 6. Photograph of Hilo breakwater viewed to the northwest.

Hilo Harbor was the first Periodic Inspection structure to use LIDAR data for baseline measurements. LIDAR data were collected using a fixed wing Twin Otter aircraft outfitted with a scanning, pulsed, infrared (1064) laser

transmitter with five receiver channels. Infrared and blue-green frequencies were used to optimize air-water interface detection and water penetration, respectively. The mounted laser transmitter/receiver transmits a laser pulse, which travels to the air-water interface, where some of the energy is reflected back (Irish and Lillycrop 1999). The remaining energy propagates through the water and reflects off of the sea bottom. A measure of the difference in water surface and sea bottom provides the underwater bathymetry. LIDAR was used effectively to collect elevation data and to provide accurate mapping of the Hilo Harbor breakwater. Information obtained from the 2005 LIDAR collection will be used for future inspection comparisons.

Kahului Harbor breakwaters, Maui, HI

Kahului Harbor is located on the south side of Kahului Bay on the north side of the island of Maui. It is the only deep-draft harbor on the island and is the forth busiest within the Hawaiian chain in terms of commercial traffic. Two breakwaters protect the harbor of approximately 809,365 sq km (200 acres). The 183-m-(600-ft-) wide harbor entrance is situated between the endcaps of the two structures. Channel depth is maintained at or near 11 m (35 ft) (U.S. Coast Guard 1999).

Summertime conditions at the Kahului Harbor involve northeast trade winds and northern swells producing 6 sec to 10 sec, 1.2-m to 3.7-m (4-ft to 12-ft) deepwater waves. From October through March, northern Pacific storms produce some of the largest waves to reach the Hawaiian Islands. Deepwater waves of 9.2 m (30.2 ft) and 25 sec periods were recorded during one of the more extreme northern winter swells (data collected from NOAA-NDBC buoys #51001 – December 27-31, 1998). Hurricanes and tsunamis are the rare events that produce larger waves.

Construction began on the Kahului Harbor in 1900 by the Kahului Railroad Company. The initial harbor included a berthing area, a dredged entrance channel, and a 122-m- (400-ft-) long armor stone east breakwater. The length of the east breakwater was doubled in 1913 and a 594-m- (1,950-ft-) long west breakwater was built in 1919. The east and west breakwaters were extended to their current lengths of 843 m and 706 m (2,766 ft and 2,315 ft), respectively, in 1931. A layout of the harbor is shown in Figure 7 and an aerial view is shown in Figure 8 (Bottin and Meyers 2002b).

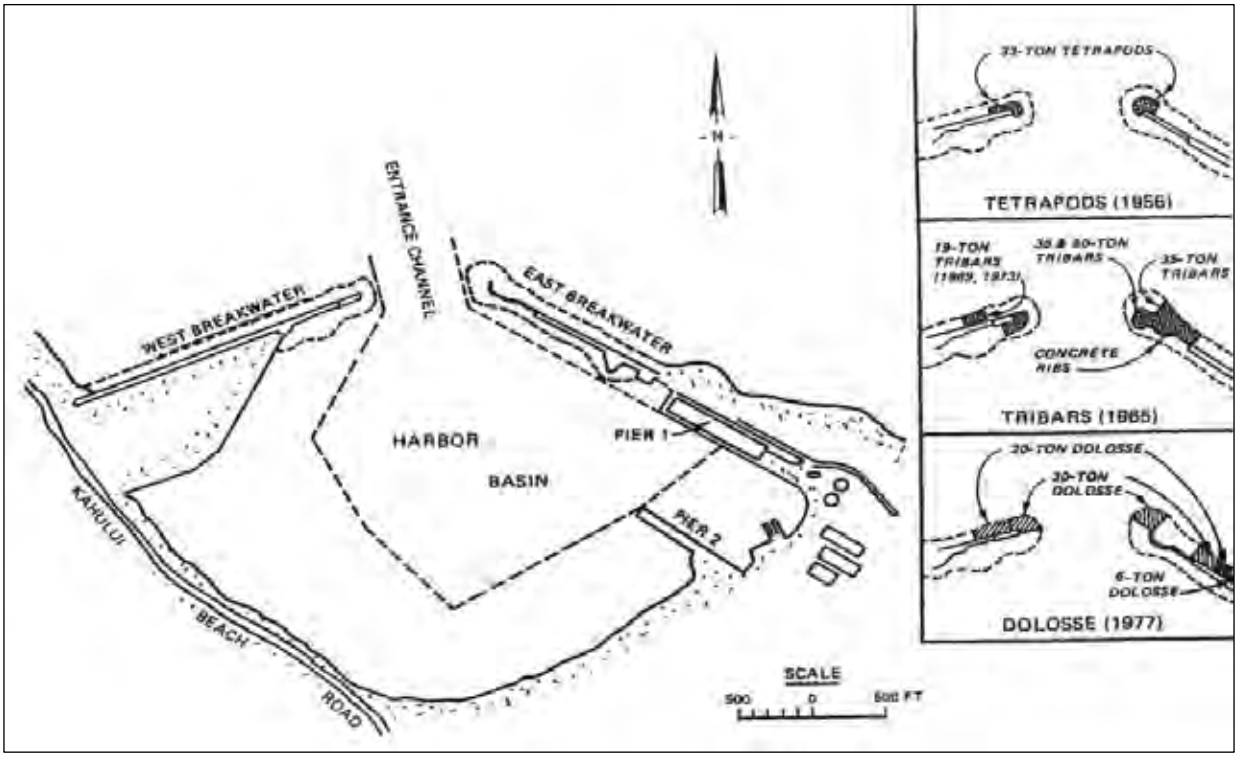

Figure 7. Layout of Kahului Harbor, Maui, HI.

The original structures included single layer keyed and fitted armor stone placed from the +4.0 m (+13 ft)[1] crest elevation (el) down to el -4.6 m (-15 ft). Side slopes above the -4.6 m (-15 ft) el were 1V:2H on the heads and 1V:1.5H on the trunks (Figure 9). Below the -4.6 m (-15 ft) el, the 1V:1H sloped structure was constructed of quarry-run stone with a minimum stone weight of 11.3 kg (25 lb) (Bottin and Meyers 2002b).

After repeated storm damages and rehabilitations, repairs in 1956 included placement of unreinforced tetrapods on both structures and the construction of a concrete rib cap on the east breakwater. A cross-section of the 1956 repairs is shown in Figure 10. The concrete cap was upgraded in 1959 and tribars were placed on the structures during a major rehabilitation in 1966 (Figure 11). A concrete rib cap was constructed and additional tribars were placed on the west breakwater in 1969. The rib cap on the west breakwater was extended and tribars were added in 1973 (Figure 12). Additional repairs completed in 1977 included placement of dolosse and tetrapods on the west breakwater, and dolosse, tetrapods, and tribars on the east breakwater. Extensive repairs occurred in 1984 and included tribars and concrete rib cap extensions for each structure (Bottin and Meyers 2002b).

[1] All elevations (el) and depths cited herein are in meters (feet) referred to mean lower low water (mllw).

Figure 8. Aerial view of Kahului Harbor (2001).

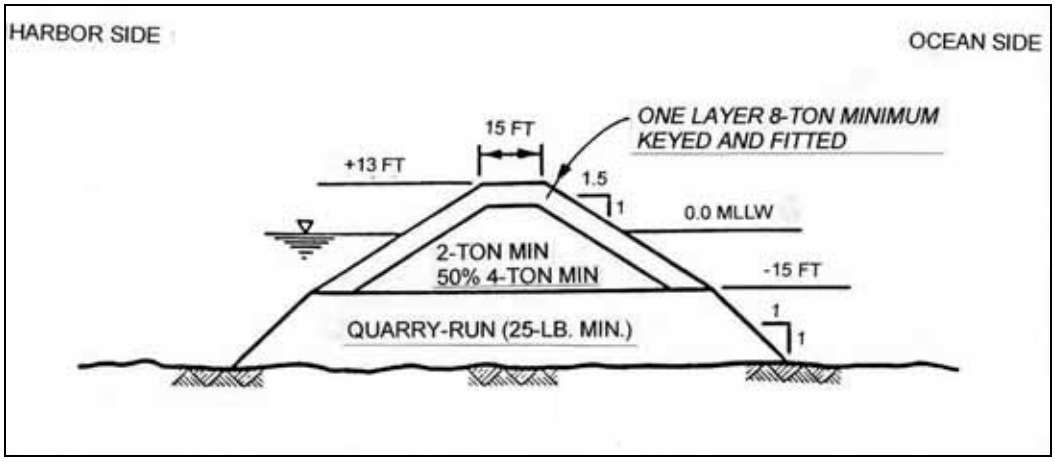

Figure 9. Typical cross-section of 1913-1931 Kahului breakwater trunk construction.

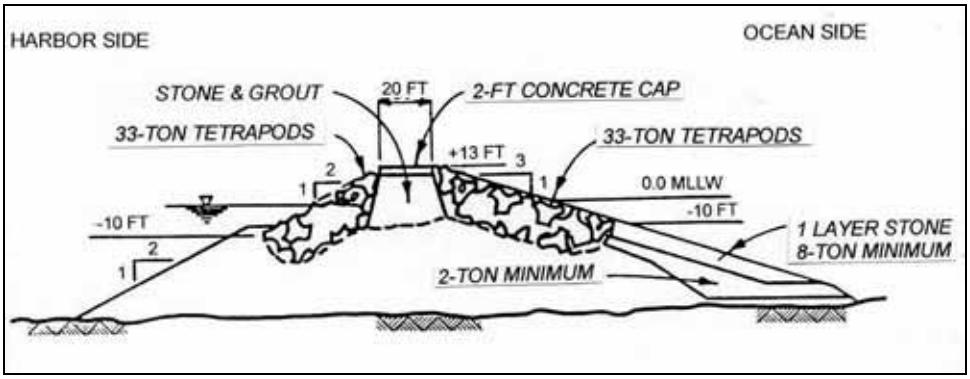

Figure 10. Typical cross-section for 1956 Kahului breakwater repairs.

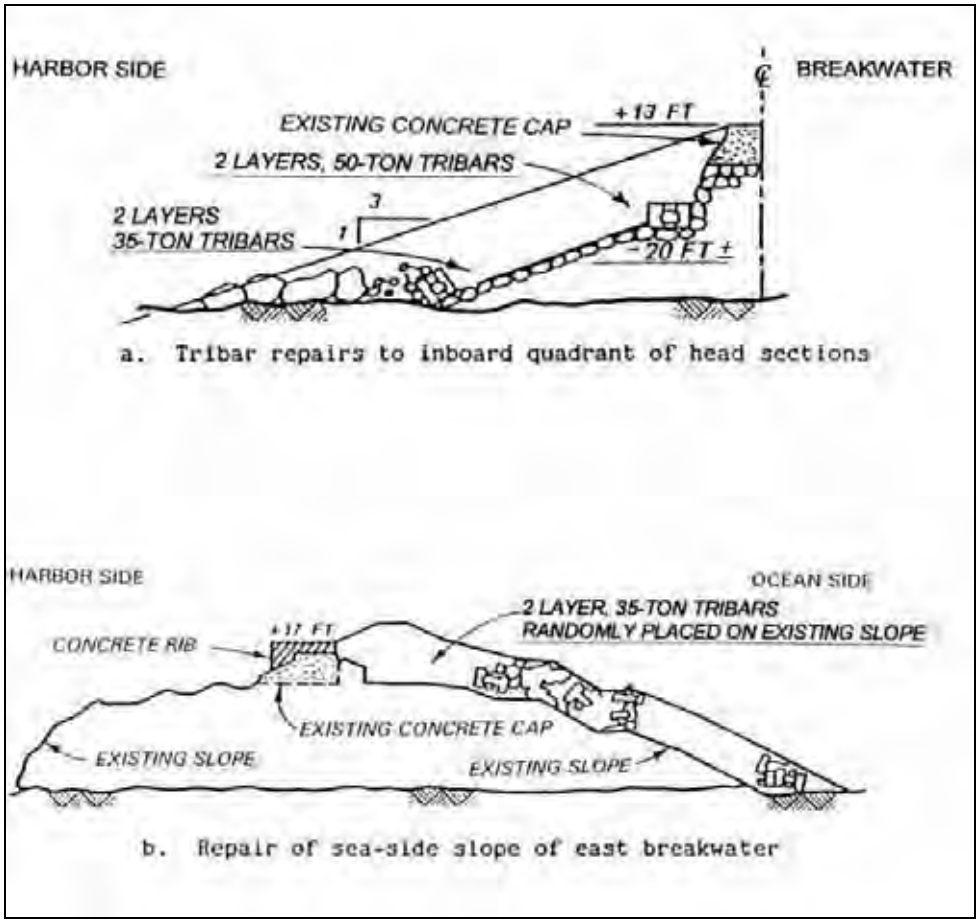

Figure 11. 1966 Kahului breakwater repairs.

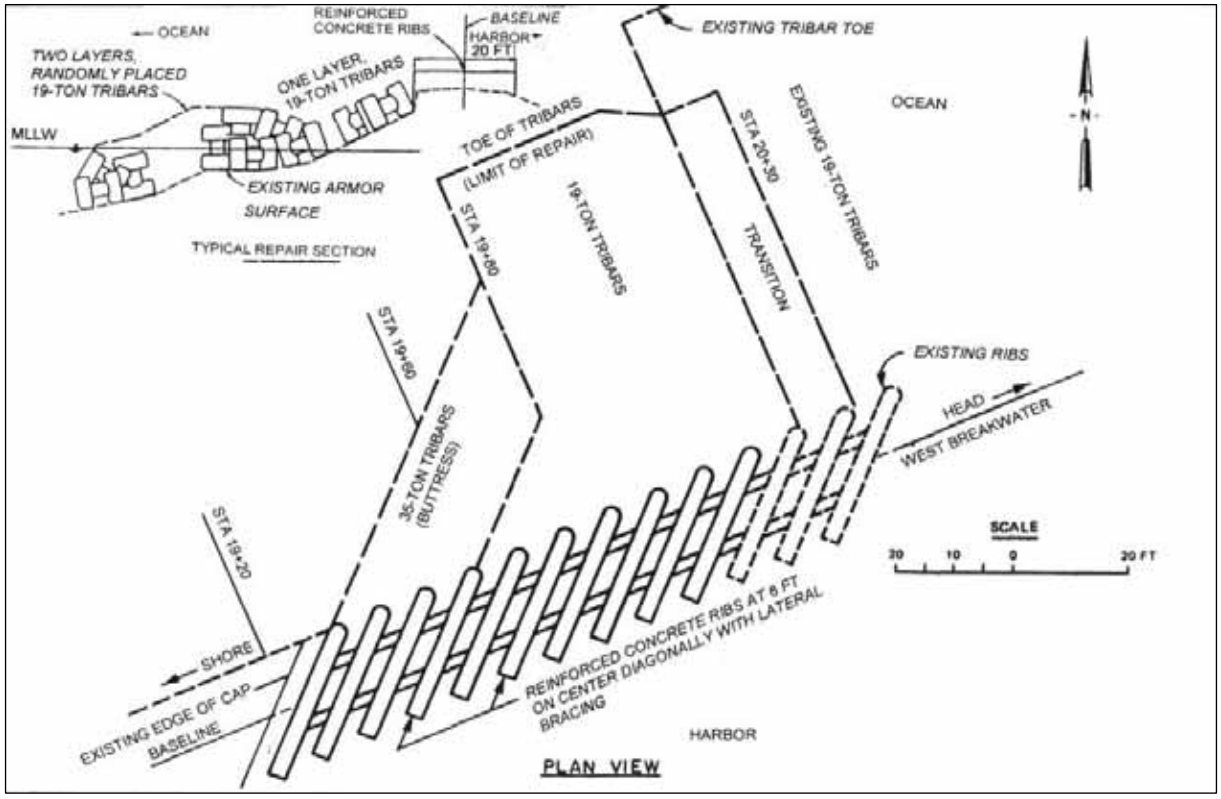

Figure 12. Kahului West Breakwater repairs of 1973.

Initial baseline conditions for monitoring the Kahului breakwaters were established during the period October 1991 - August 1993 (Markle and Boc 1994) as part of the Periodic Inspections work unit. Work included armor unit targeting, limited ground surveys, aerial photography, and a photogrammetric analyses of armor units. Very precise positions of targeted armor units were obtained. Minimal target movement occurred during the initial monitoring effort. Between October 1991 and August 1993, horizontal and vertical movements of targeted armor units ranged from 0.0 to 0.058 m (0.0 to 0.19 ft) and 0.0 to 0.091 m (0.0 to 0.3 ft), respectively, on the Kahului east breakwater; and from 0.0 to 0.061 m (0.0 to 0.2 ft) and 0.0 to 0.052 m (0.0 to 0.17 ft) on the Kahului West Breakwater. Average horizontal and vertical movements of targeted armor units, respectively, were 0.021 m and 0.021 m (0.07 ft and 0.07 ft) for the Kahului East Breakwater; and 0.046 m and 0.015 m (0.15 ft and 0.05 ft) for the Kahului West Breakwater. A walking inspection of the breakwaters in September 1992 identified 11 broken armor units on the Kahului East Breakwater and 28 broken armor units on the Kahului West Breakwater. The breakwaters were monitored again during the period August – October 2001. Between August 1993 and October 2001, horizontal and vertical movements of targeted armor units ranged from 0.0 to 0.933 m (0.0 to 3.06 ft) and

0.0 to 1.515 m (0.0 to 4.97 ft), respectively, on the Kahului East Breakwater; and from 0.0 to 1.158 m (0.0 to 3.8 ft) and 0.0 to 0.582 m (0.0 to 1.91 ft) on the Kahului West Breakwater. Average horizontal and vertical movements of targeted armor units, respectively, were 0.155 m and 0.165 m (0.51 ft and 0.54 ft) for the Kahului East Breakwater; and 0.128 m and 0.11 m (0.42 ft and 0.36 ft) for the Kahului West Breakwater.

A walking inspection conducted in August 2001 identified 29 broken/cracked armor units on the Kahului East Breakwater and 58 broken/cracked armor units on the Kahului West Breakwater. Due to the fact that no known major storm events had occurred during the time period between the walking surveys of 1992 and 2001, it was assumed that the 2001 survey was more comprehensive. Baseline conditions were re-established during the 2001 periodic inspection for future use (Bottin and Meyers, 2002b).

Laupahoehoe Point Boat Launching Facility breakwater, Hawaii, HI

Laupahoehoe Point is located approximately 40 km (25 miles) north-northwest of Hilo on the Island of Hawaii (Figure 1). A layout of the launching facility can be seen in Figure 13. The area was historically used as a park and a landing for import of livestock. In 1971, the County of Hawaii constructed a boat launch within the park in an area of the point considered to be a sheltered cove. Reflective waves from adjacent rocky shores proved the boat launch to be unsafe. The boat launch was closed in 1984, rendering Hilo Harbor as the nearest safe boat launch. The productive fishing area around Laupahoehoe Point was underutilized and the closed launching ramp could not be used for rescue efforts. At the request of the County of Hawaii and the Honolulu District, designs for a protected boat launching facility were optimized through physical model studies at ERDC (Bottin et al. 1987). Results of these studies led to the construction of a 60.1-m- (200-ft-) long rubble-mound breakwater, 2.3-m- (7.5-ft-) deep turning basin, and a boat-launching ramp, completed in 1988. A reinforced concrete pipe rib cage formed containment for core and capstone, and provided a stable crest for the 27-tonne (30-ton) reinforced dolosse armor. The toe of the armor dolosse was keyed into trenched basalt stone for added stability. These design features were unique to this structure and applicable to the research goals of the Periodic Inspections work unit (Markle and Boc 1994). A cross-section of the breakwater can be seen in Figure 14. An aerial view of the area is shown in Figure 15.

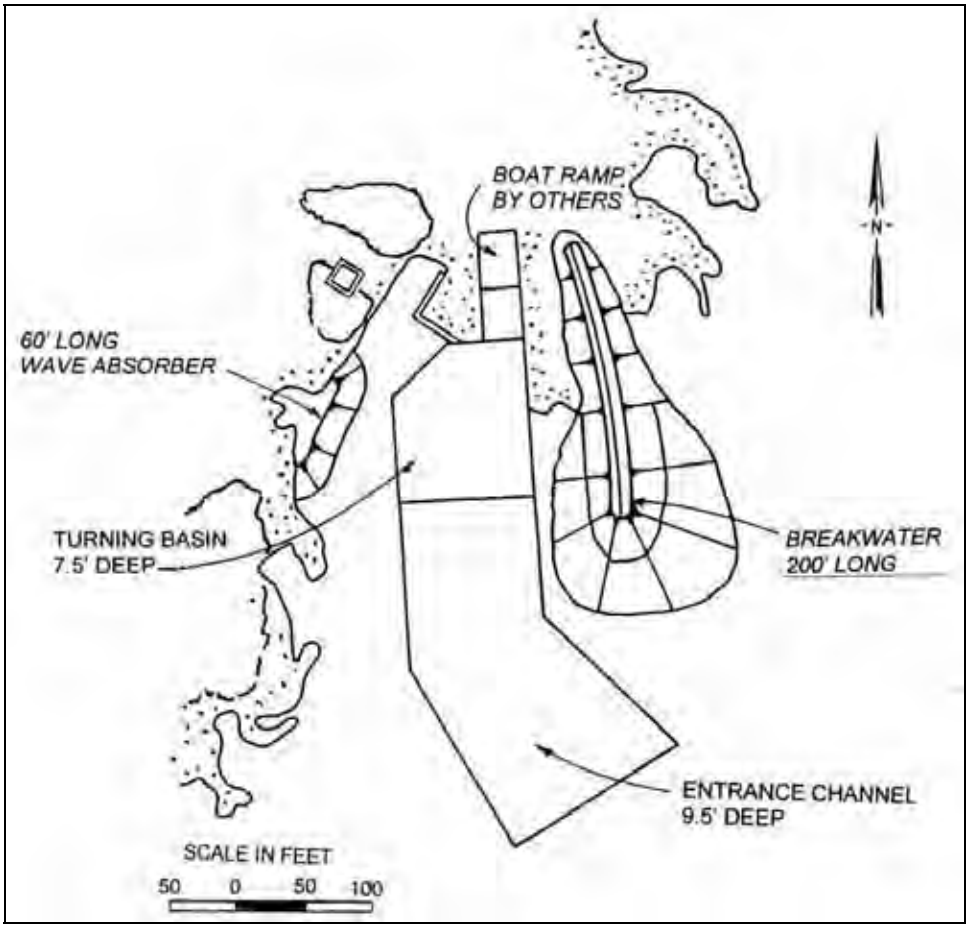

Figure 13. Layout of Laupahoehoe Boat Launching Facility.

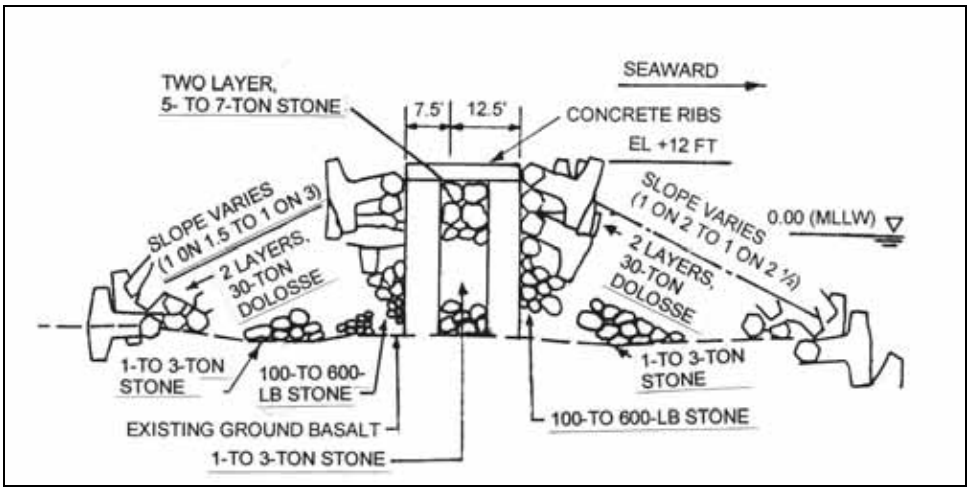

Figure 14. Cross-section of Laupahoehoe breakwater.

Figure 15. Aerial photograph of Laupahoehoe Boat Launching Facility.

Laupahoehoe breakwater was initially monitored during 1991 - 1992 (Markle and Boc 1994) as part of the Periodic Inspections work unit. Armor unit targeting, limited ground surveys, aerial photography, and photogrammetric analyses of armor units were conducted. Precise armor unit positions were obtained from aerial surveys conducted in October 1991 and November 1992. Comparisons indicated negligible horizontal and vertical movements of targeted armor units, ranging from 0.0 to 0.046 m (0.0 to 0.15 ft) and 0.0 to 0.37 m (0.0 to 0.12 ft), respectively. No broken/cracked armor units were observed during the initial walking inspection. Baseline conditions were thus established for future monitoring.

No cracked or broken armor units were found during a walking inspection of the Laupahoehoe breakwater in July 1998. The dolosse positions were visually compared to those documented in the 1992 survey and determined to be the same. The structure was considered to be in “excellent condition” (Bottin and Tolliver 1999).

Subsequent monitoring was completed from August – October 2001. Data comparison of 1992 and 2001 aerial surveys indicated horizontal and vertical movements of targeted armor units averaged 0.03 m and 0.049 m (0.1 ft and 0.16 ft), respectively. All dolosse remained intact and no severe damage to individual units was noted. Some underlayer stone fill was missing between sta 1+55 and 1+75 below the rib cap. In addition, some displaced armor stones created a small void between sta 0+85 and 0+95 of the harbor side.

Nawiliwili Harbor breakwater, Kauai, HI

Nawiliwili Harbor is located approximately 185 km (115 miles) northwest of Honolulu, Oahu, HI on the southeast coast of the island of Kauai (Figure 1). Nawiliwili breakwater protects a commercial harbor, a small boat harbor, a Coast Guard dock, and industrial facilities along its shore area. The breakwater extends 625 m (2,050 ft) from the harbor's southern shore in a straight northeasterly orientation toward Kukii Point (Figure 16). The breakwater has served as harbor protection since initial construction in 1922. An aerial photograph of the harbor can be seen in Figure 17.

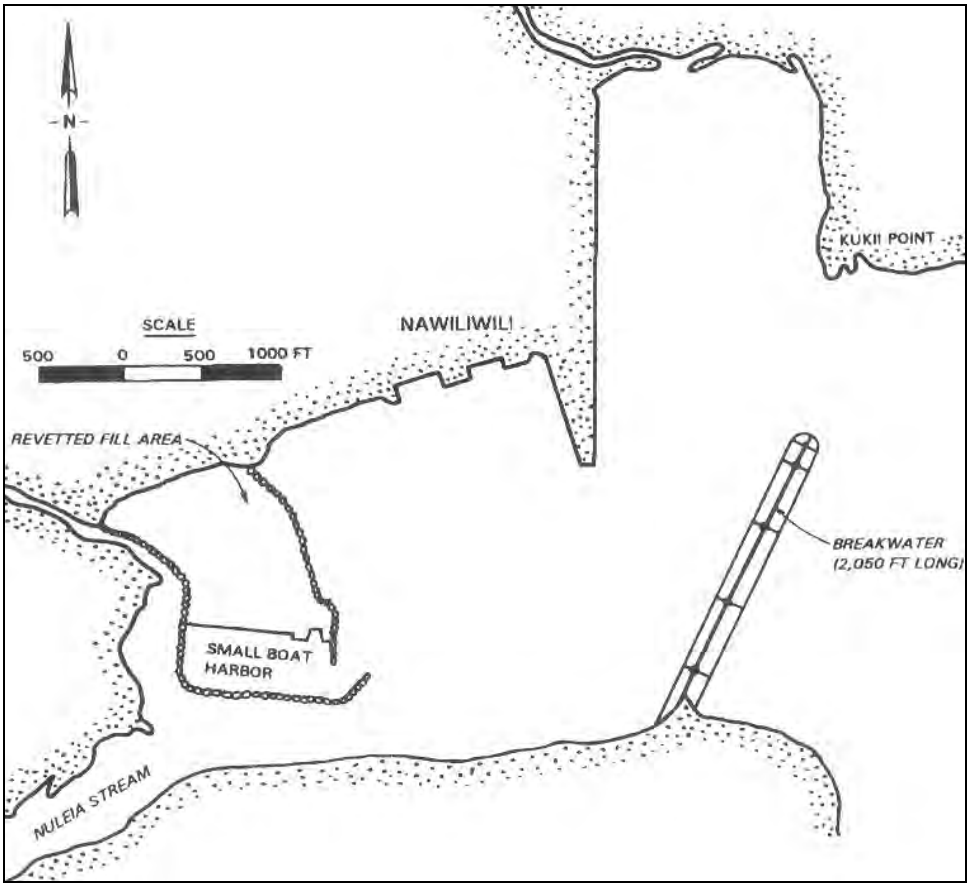

Figure 16. Layout of Nawiliwili Harbor.

Figure 17. Aerial photograph of Nawiliwili Harbor.

The breakwater was originally a single layer of keyed and fitted armor stone placed over core stone. A cross-section of the original structure is shown in Figure 18. The first major rehabilitation of the structure occurred in 1959. This rehabilitation included 598 16.2-tonne (17.8-ton) tribar armor units and a concrete rib cap. Typical cross-sections for the 1959 repair are shown in Figure 19. A second rehabilitation in 1977 added 934 unreinforced 10-tonne (11-ton) dolosse armor. Cross-sections of the 1977 repairs are shown in Figure 20. A breakwater survey conducted in 1980 indicated that the breakwater was in good condition with minimal armor unit breakage. A repair in 1987 added 230 21-tonne (23-ton) dolosse armor to the head section and in random low areas on the ocean side, 6-tonne (6.5-ton) pattern-placed tribars on the leeside, and extended the rib cap. Cross-sections of the 1987 repairs are shown in Figure 21.

Since the major rehabilitation in 1959, the structure has been hit by Hurricane Dot in 1959, Hurricane Iwa in 1983, and Hurricane Iniki in 1992. Hurricane Iniki produced the following breaks: three of the 230 21-tonne (23-ton) dolosse, seven of the 934 10-tonne (11-ton) dolosse, and six of the 598 16.2-tonne (17.8-ton) tribar (Turk et al. 1995). The cumulative number of breaks reported in 1992 was eight 21-tonne (23-ton) dolosse, 44 10-tonne (11-ton) dolosse, 111 16.2-tonne (17.8-ton) tribar, and an unknown number of the 6-tonne (6.5-ton) leeside tribar.

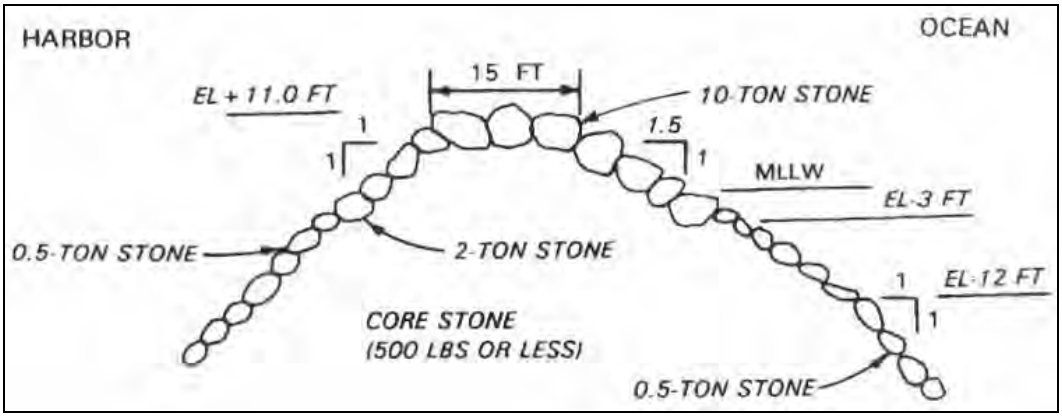

Figure 18. Cross-section of original structure.

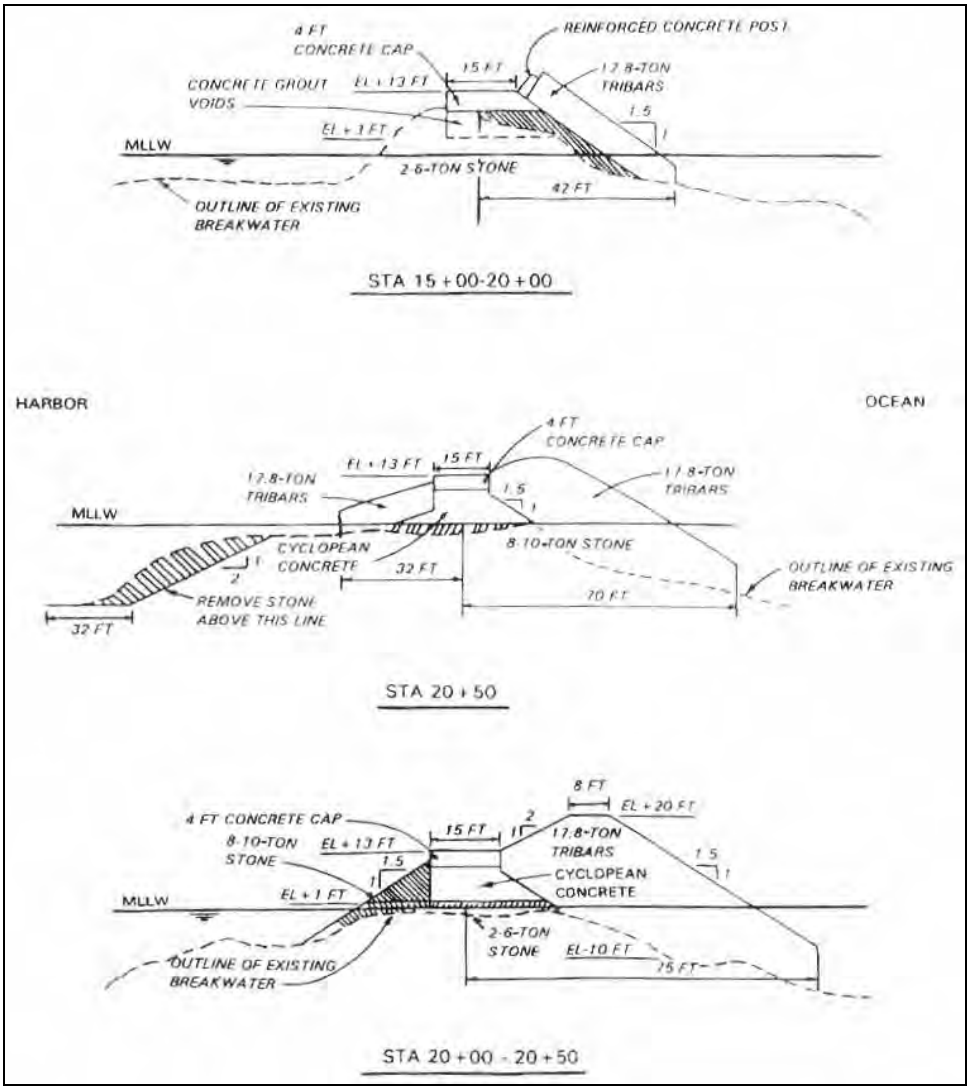

Figure 19. Typical cross-sections of 1959 repairs.

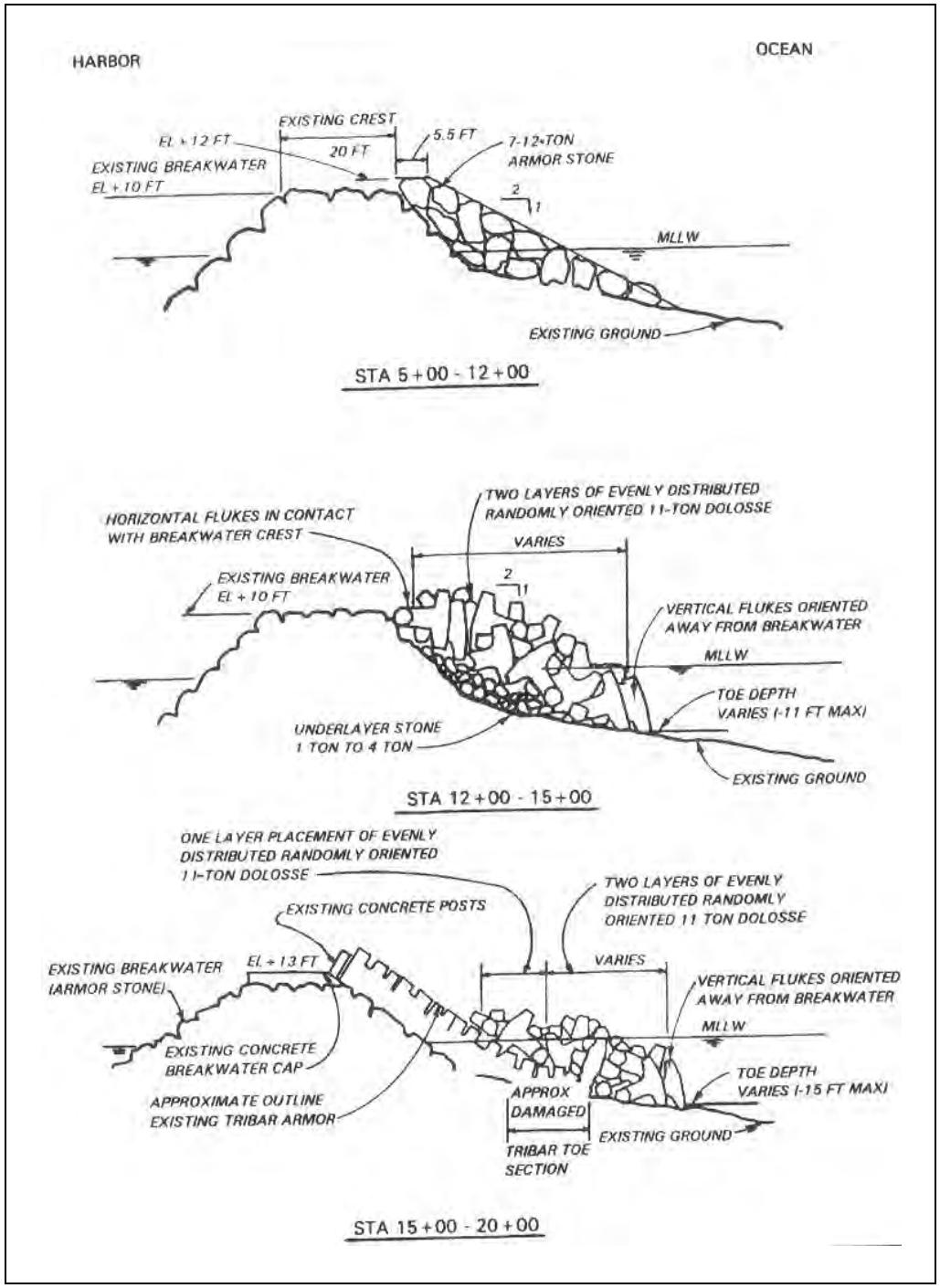

Figure 20. Typical cross-sections of 1977 repairs.

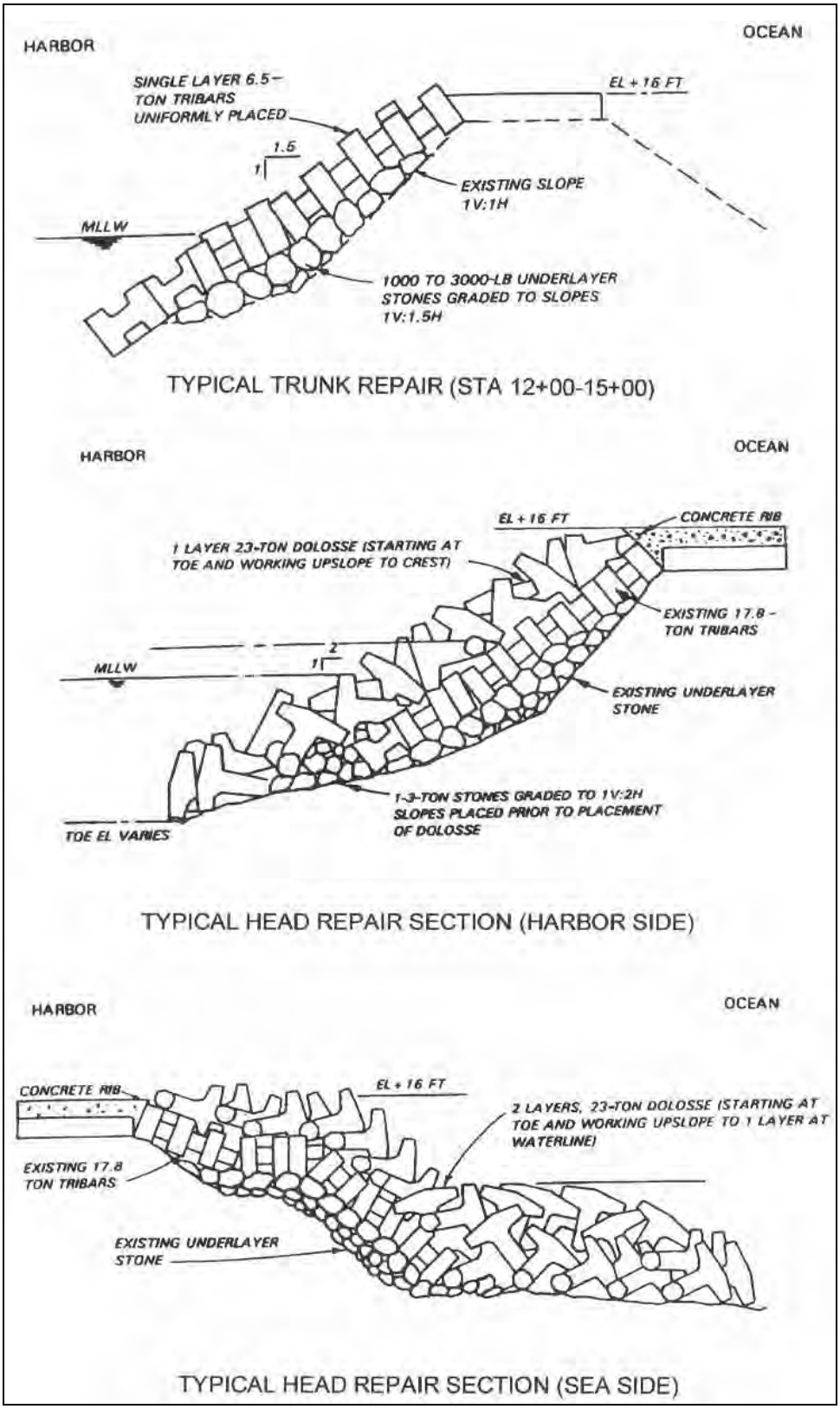

Figure 21. Typical cross-sections of 1987 repairs.

A baseline periodic inspection was conducted for the Nawiliwili breakwater in October 1995 (Bottin and Boc 1996). Precise positions of targeted armor units, including coordinates of the centroid (center of mass) and orientations of each targeted armor unit, were collected along with limited ground surveys, aerial photography, photogrammetric analysis of armor units, and a broken armor unit survey. The broken armor unit survey revealed 70 broken/cracked armor units existed on the structure during this baseline measurement.

Position coordinates of targeted armor units (Figure 22) were used for horizontal and vertical movement measurements for the period between October 1995 and October 2001, when the Nawiliwili breakwater was next monitored. Comparisons showed horizontal movements averaged 0.03 m (0.1 ft) and vertical movements 0.046 m (0.15 ft). Rotational movement was minimal.

Figure 22. Example of a targeted 11-ton dolosse.

Seventy-seven damaged armor units were observed during the survey conducted in August 2001 (Bottin and Meyers 2002a). The breakage survey of 1992 was more comprehensive than the latter surveys and, therefore, revealed more breaks. Unfortunately, comprehensive breakage surveys during walking inspections are dangerous and difficult, and are typically avoided.

3 2005 Broken Armor Unit Walking Inspection Surveys

During the period of July 14-July 25, 2005, personnel from CHL and POH conducted comprehensive walking inspection and breakage surveys on breakwaters at Hilo Harbor, Kahului Harbor, Laupahoehoe Point Boat Launching Facility, and Nawiliwili Harbor. Past experience has shown that aerial photography, while useful, cannot achieve the level of detail provided by walking inspections for the purpose of armor damage assessments. Cracks and breaks often occur on the underside of armor units, while others are often hidden beneath top layers. Walking inspections can be an inexpensive, expedient, and effective damage assessment method.

Photographs, locations, and damage descriptions were recorded for each damaged armor unit above the water line. Details are provided in Appendices A-D. The approximate centerline of the crest was used for a horizontal baseline. Breakwater length (sta) locations were based on previously established markers at the root of each structure, usually on the adjacent shore. Measurements were manually taken from established markers to the crest of breakwater heads and validated by previously set station markers along the structures. Damaged armor unit locations were recorded relative to station location. Voids and subsidence areas were noted and recorded, as were perched, misplaced, or missing stones when identified.

Armor Break Descriptions

Hairline cracks and spalling were not counted as part of damage assessments, but were often noted as possible indicators of future breaks. Complete breaks and cracks appearing to run completely through an armor unit or stone were recorded as “broken/cracked.” Damage is described in terms of armor geometric elements. A dolosse is composed of a central section (shank) with two end pieces (flukes).

Specific break types for dolosse are:

- Mid-shank – break occurs across the shank and is not adjacent to the fluke (Figure 23);
- Flute-shank – break occurs across the fluke near the intersection of the fluke and shank (Figure 24);

Figure 23. Typical dolosse mid-shank crack/break.

Figure 24. Typical dolosse fluke-shank break.

- Shank-fluke – break occurs across the shank near the intersection of the shank and fluke (Figure 25).

Figure 25. Typical dolosse shank-fluke break.

The breaks were further characterized as either straight or angled, and cracked or broken.

Tribar breaks/cracks were differentiated by either (a) a center section break/crack, usually where one or more legs (cans) had been separated from the unit (Figure 26), or (b) as damage to leg sections only (Figure 27).

Armor stones and stone sections were listed as "broken, missing, perched, or containing voids." Damaged armor stone and void examples are shown in Figures 28-30.

Tetrapod breaks were described in relation to their orientation on the breakwater (broken top), or simply listed as broken.

Hilo Harbor breakwater, Hawaii, HI

The 2005 walking inspection and previously discussed LIDAR bathymetric and topographic data established the Periodic Inspections baseline for the Hilo Harbor breakwater. Four broken tribars and 12 broken or cracked armor stones were identified on the breakwater. Other deficiencies noted

Figure 26. Typical tribar center section break.

Figure 27. Typical tribar leg break.

Figure 28. Typical armor stone break.

Figure 29. Example of perched armor stones.

Figure 30. Example of a breakwater void.

during the inspection include settling, numerous voids, missing armor stones, and perched or flipped armor stones. Detailed information regarding these deficiencies can be found in Appendix A.

Kahului Harbor breakwaters, Maui, HI

The 2005 walking inspection of the Kahului breakwaters identified such breakwater damage as broken/cracked armor units, displaced stones, settling, and voids. Deficiencies were photographed and approximate locations relative to stations were noted. Detailed information regarding these deficiencies can be found in inspection notes of Appendix B. Figures 31 and 32 show the approximate damage locations for the Kahului East Breakwater, and Figures 33 and 34 identify approximate damage locations for the Kahului West Breakwater. Aerial photograph location numbers correspond to numbers in the notes and photographs found in Appendix B.

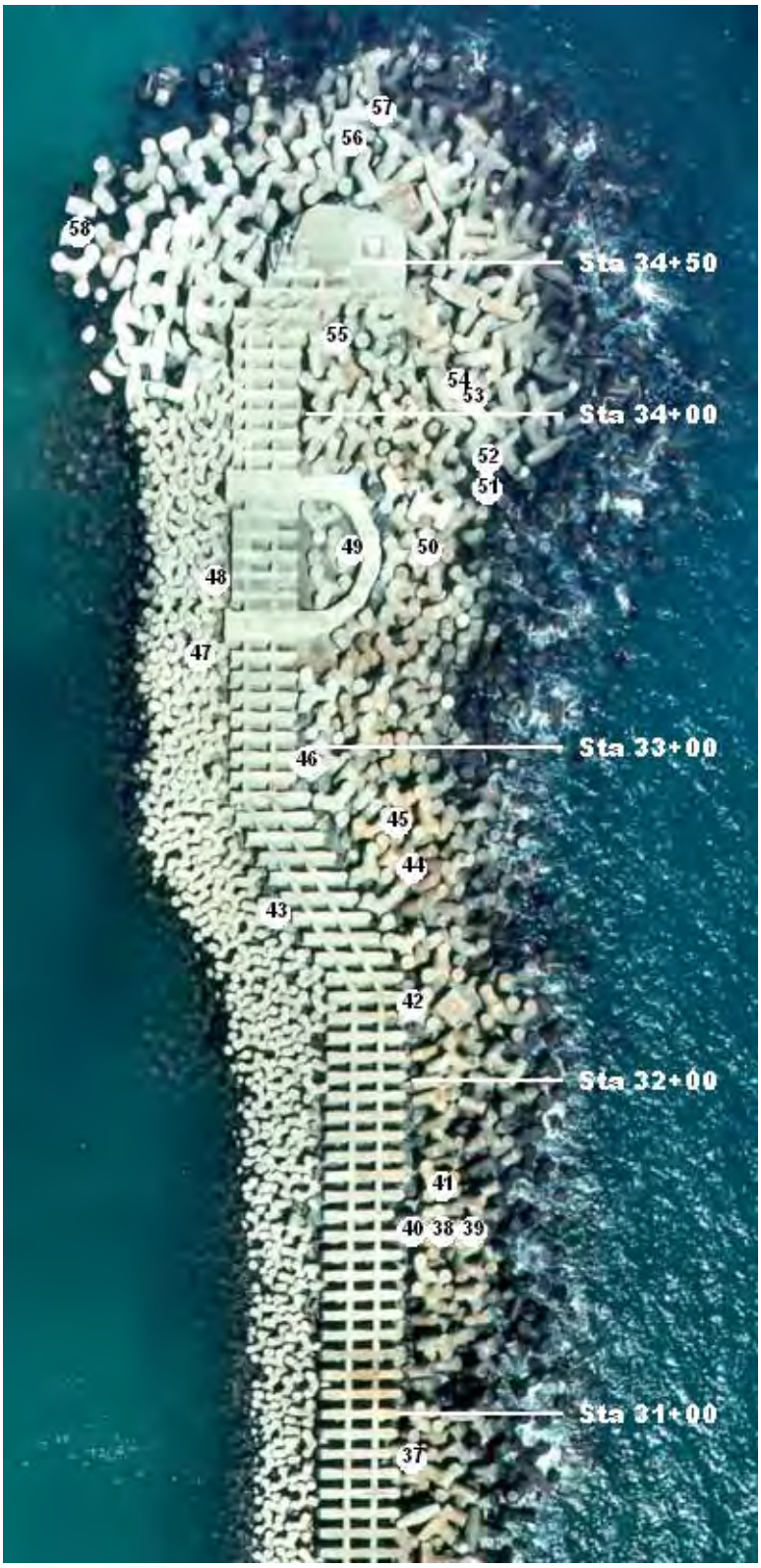

Figure 31. Approximate damage locations on Kahului East Breakwater, photograph 1.

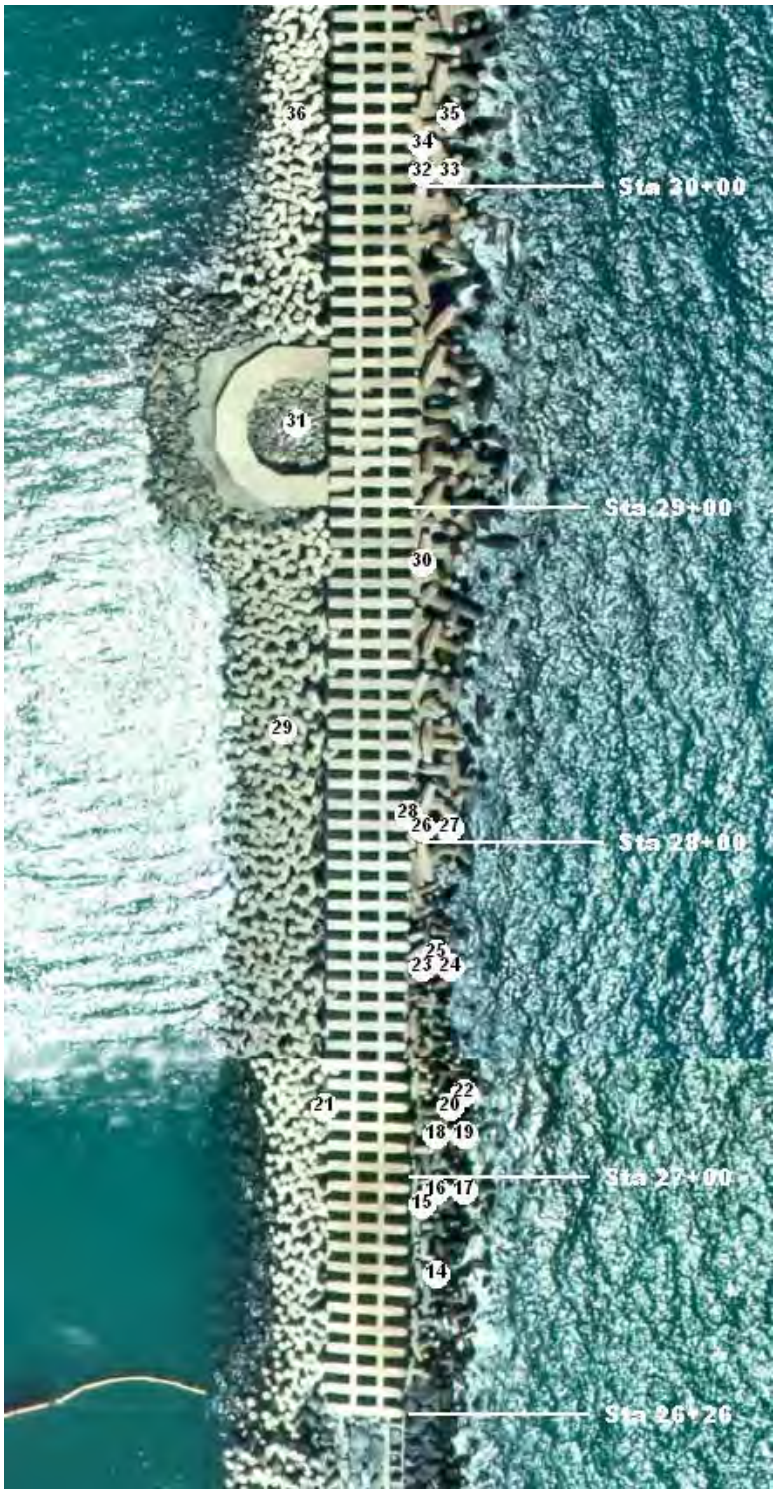

Figure 32. Approximate damage locations on Kahului East Breakwater, photograph 2.

Figure 33. Approximate damage locations on Kahului West Breakwater, photograph 1.

Kahului East Breakwater

Thirty-six broken or cracked units were identified on the Kahului East Breakwater. In 2001, 29 were identified for an increase of seven new breaks. Of the total broken/cracked units on the Kahului East Breakwater, three were cracked armor stones located at the beginning of the structure, 23 were dolosse, and 10 were tribars. Over 50 percent of the broken dolosse were located on the ocean side of the structure between sta 26+50 and 28+00.

Also recorded was separation between armor units and the rib cap at sta 27+16, 28+10, 30+16, 30+88-31+48, 31+54-32+04, 32+80-33+04, and 33+40-33+64.

It should be noted that the station numbers used on the Kahului East Breakwater during the 2005 inspection differ from the station numbers used in previous years. The current stationing was established by the Honolulu District and will be used for future inspections. Appendix references denote former station numbers in parentheses.

Kahului West Breakwater

The Kahului West Breakwater walking inspection identified 80 total broken/cracked units. This was significantly higher than the 58 found in 2001, a 27.5 percent increase or 22 total new broken/cracked armor units.

There were 48 broken or cracked dolosse, 26 broken/cracked tribars, and six broken tetrapods on the Kahului West Breakwater. The broken units were concentrated on the ocean side of the structure between sta 21+00 and 23+00, and around the head of the structure (Figures 33 and 34).

Other deficiencies noted during the inspection included settling and separation between the rib cap and armor, and severe cracking and spalling of the concrete rib cap on the Kahului west breakwater.

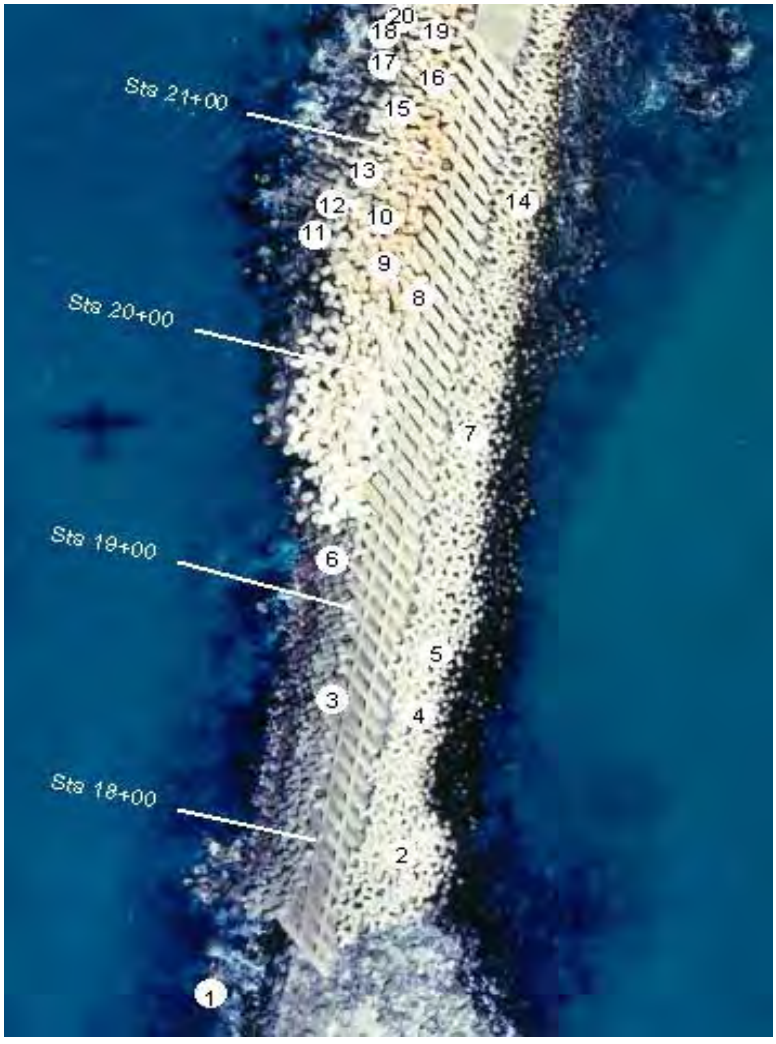

Figure 34. Approximate damage locations on the Kahului West Breakwater, photograph 2.

Laupahoehoe Point Boat Launching Facility breakwater, Hawaii, HI

As with previous inspections, the 2005 walking inspection of Laupahoehoe breakwater revealed no broken or cracked armor units. Damage to the breakwater was limited to armor and underlayer stones. There were several voids and perched or flipped armor stones at the structure root. There was a noticeable shift of underlayer stones and loss of underlayer between the cap ribs. Numerous stones had been displaced and tossed onto the harbor side dolosse. These were assumed to have come from the underlayer. Chipping on the rib cap and harbor side dolosse may have been caused by displaced armor and/or underlayer stones. Photographs of these deficiencies are compiled in Appendix C.

Nawiliwili Harbor breakwater, Kauai, HI

Eighty-one broken or cracked units were identified on the breakwater during the 2005 inspection. This was only slightly more than the 77 found in 2001. Figures 35, 36, and 37 show approximate locations of damaged areas identified during the 2005 survey. The damage location numbers correspond to the numbers in the tables and photographs found in Appendix D.

Of the broken units on the Nawiliwili breakwater, three were cracked armor stones located at the beginning of the structure, 58 were dolosse, and 20 were tribars.

In addition to broken/cracked armor units, other deficiencies in the structure were noted. The armor stone portion of the breakwater between sta 0+00 and 12+00 (the beginning of the rib cap) had numerous voids and perched or dislodged armor stones. Several stones contained large cracks or were completely broken. Of particular concern is the void noted at sta 10+40. This void is located at the centerline of the structure and extends to the waterline. Areas of bridging and settling of armor stones were evident in the armor stone section as well.

Settling of armor units along the structure has occurred causing a void between the rib cap and armor units (Figure 38a and b). The circle on Figure 38a indicates an example of a void created as the result of tribar detaching from the rib cap. The side slope subsidence of dolosse is shown in Figure 38b.

These deficiencies were not noted during previous inspections.

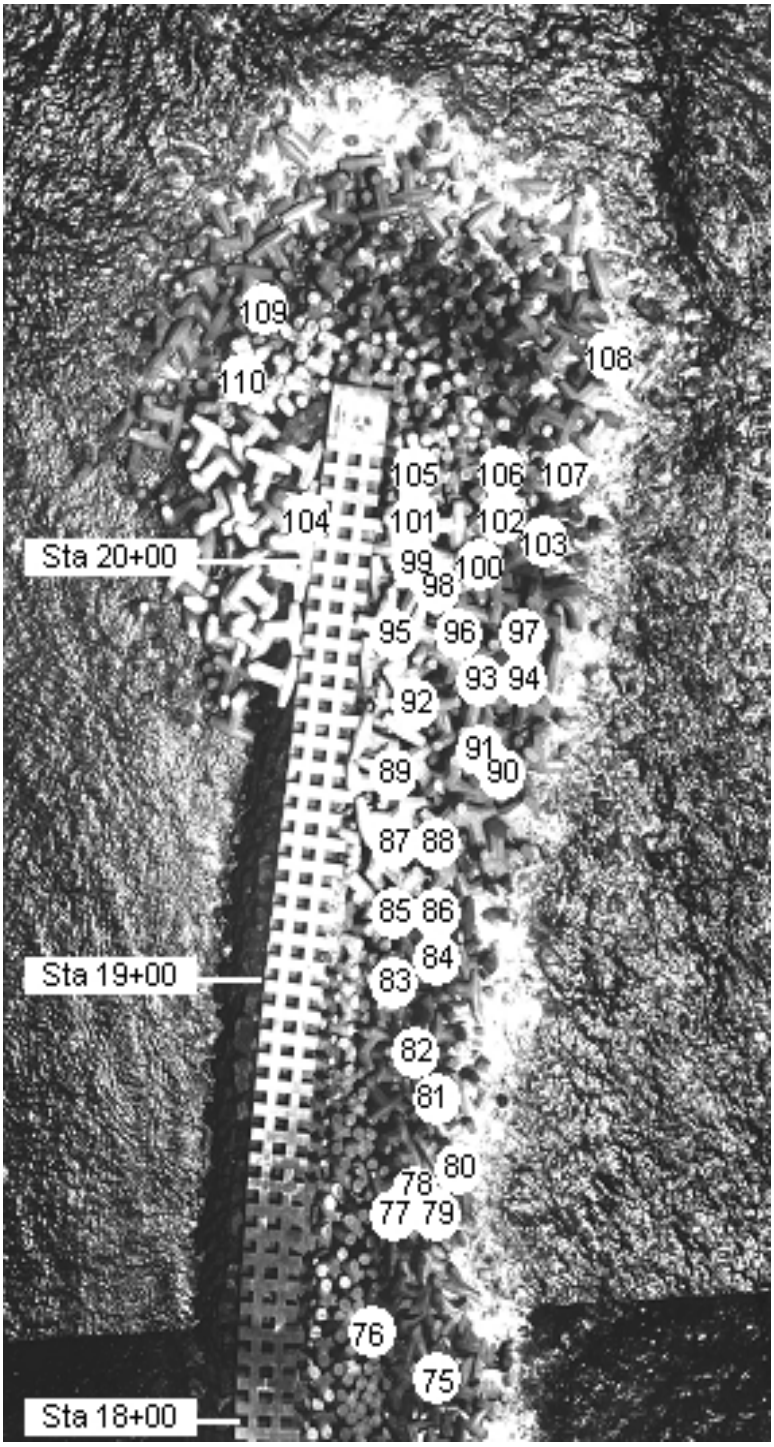

Figure 35. Approximate damage locations on Nawiliwili breakwater, photograph 1.

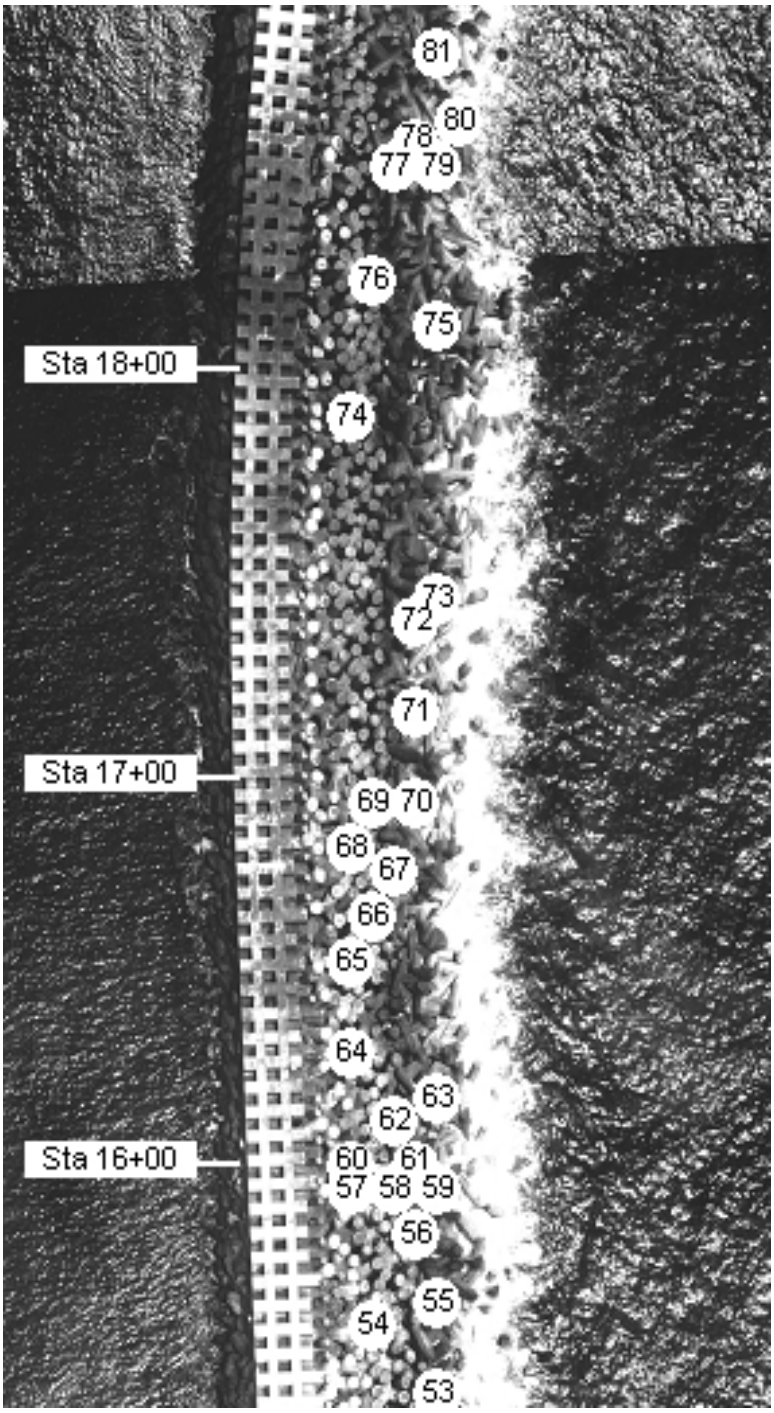

Figure 36. Approximate damage locations on Nawiliwili breakwater, photograph 2.

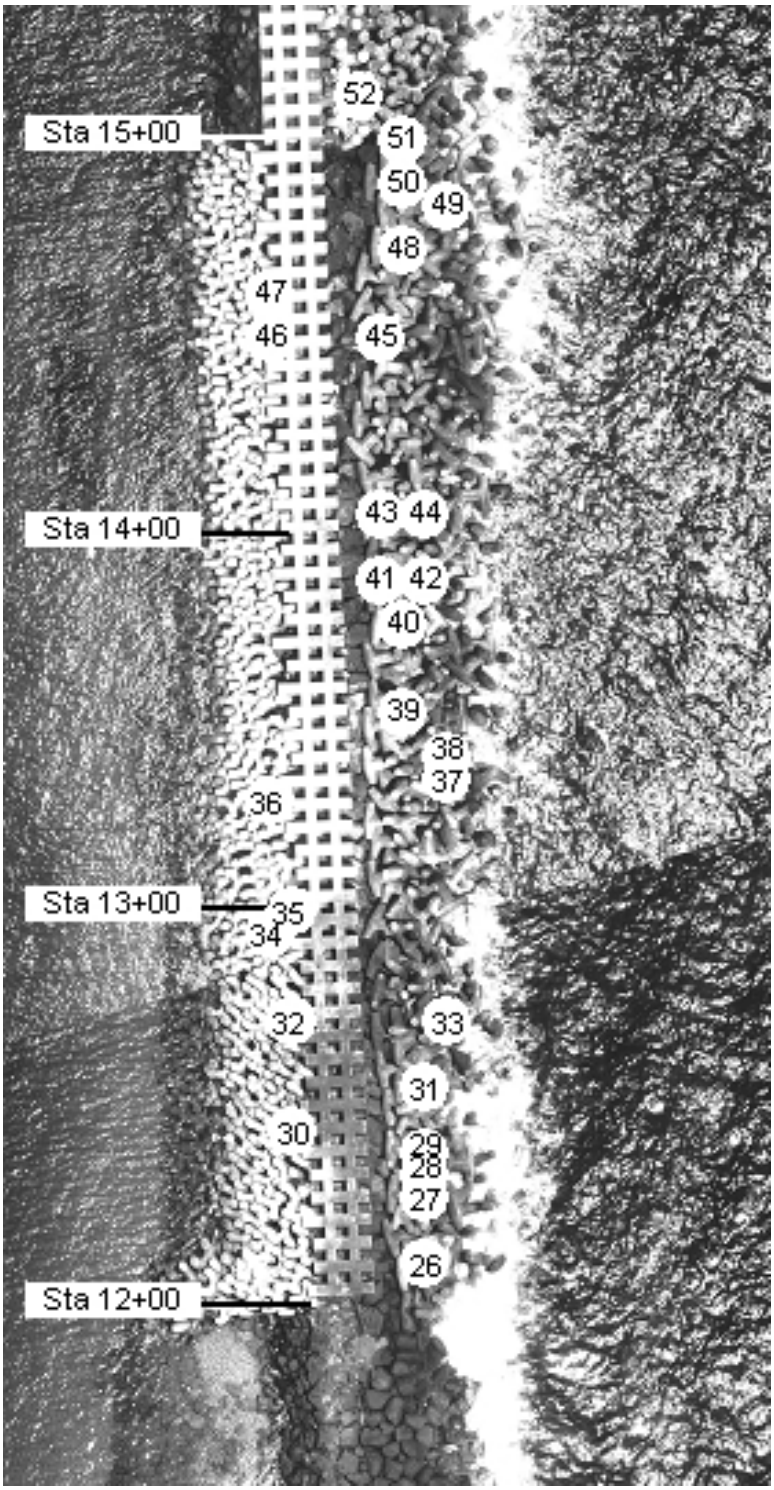

Figure 37. Approximate damage locations on Nawiliwili breakwater, photograph 3.

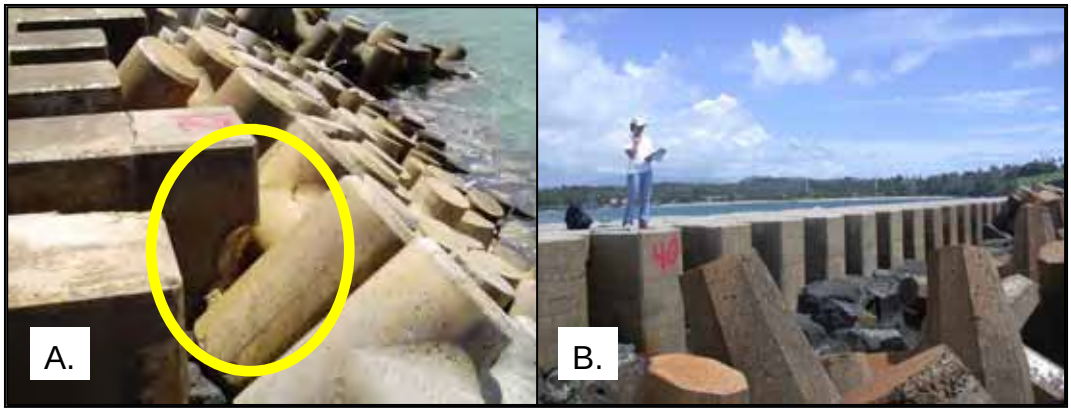

Figure 38. Evidence of armor stone subsidence.

Detailed information and photographs of Nawiliwili breakwater damage locations can be found in Appendix D.

Additionally, a LIDAR survey was used to generate imagery and data for baseline detailed conditions of the Hilo Harbor breakwater in lieu of photogrammetry.

4 Summary of Findings

The comprehensive broken armor unit walking survey of July 2005 was conducted to establish Periodic Inspections baseline conditions for the Hilo Harbor breakwater and to survey the conditions of breakwaters at the Kahului Harbor, Laupahoehoe Boat Launch Facility, and Nawiliwili Harbor. Previous baseline conditions were established in 1993 (Kahului), 1992 (Laupahoehoe), and 1995 (Nawiliwili). Prior monitoring of the aforementioned breakwaters showed relatively small movements of targeted armor units and/or armor stones (Table 1) but a slow progression in the number of broken/cracked armor over time, with the exception of Laupahoehoe which continues to reveal no armor breakage.

Due to relatively small target movements (Tables 2-4) of two previous monitoring periods and budget constraints associated with increases in the cost of aerial photography and photogrammetry, walking inspections were chosen as the preferred method for the 2005 periodic inspections.

Table 1 provides a summary of the total number of broken armor units found during baseline condition surveys and succeeding monitoring periods.

With each new armor break, the possibility of subsidence, voids, bridging, and other breakwater failure increases. The most significant increase in broken/cracked armor was on the Kahului West Breakwater where 22 new damaged units were discovered over a 4-year monitoring period. In contrast, Laupahoehoe had no increase in broken armor units, but problems were found with core stone displacement.

Four broken tribars and 12 broken or cracked armor stones were identified on the Hilo breakwater. Other deficiencies noted during the inspection include settling, numerous voids, missing armor stones, and perched or flipped armor stones. The 1981 addition of a rib cap and tribars between sta 11+00 and 20+00 eliminated the observed transmission and has endured well. No repairs have been completed since 1981, but the breakwater remains in fair to good condition.

Table 1. Historical and current broken armor counts for monitored breakwaters of Hawaii.

Project	November, 1992 and October, 1993 survey results	Aug/Sept 1996 survey results	August, 2001 Survey Results	July, 2005 Survey Results	Increase in # of Broken/Cracked Armor units from baseline conditions to 2005 survey
Hilo Breakwater	NA	NA	NA	4 CAU 12 Stones	NA
Kahului East Breakwater	13*	NA	29**	36	7
Kahului West Breakwater	40*	NA	58**	80	22
Laupahoehoe Breakwater	0*	NA	0	0	0
Nawiliwili Breakwater	NA	70*	77	81	11
* Denotes Periodic Inspections Baseline Conditions ** Re-established Baseline Conditions at Kahului					

Table 2 Targeted armor unit movement for Kahului Harbor, Maui, HI.

	Kahului East Breakwater		Kahului West Breakwater	
Monitoring Period	Range of Horizontal Movement	Range of Vertical Movement	Range of Horizontal Movement	Range of Vertical Movement
October 1991-August 1993, Baseline	0.0 to 0.058 m (0.0 to 0.19 ft)	0.0 to 0.091 m (0.0 to 0.3 ft)	0.0 to 0.061 m (0.0 to 0.2 ft)	0.0 to 0.052 m (0.0 to 0.17 ft)
August 1993-October 2001	0.0 to 0.933 m (0.0 to 3.06 ft)	0.0 to 1.515 m (0.0 to 4.97 ft)	0.0 to 1.158 m (0.0 to 3.8 ft)	0.0 to 0.582 m (0.0 to 1.9f t)
Monitoring Period	Average Horizontal Movement	Average Vertical Movement	Average Horizontal Movement	Average Vertical Movement
October 1991-August 1993, Baseline	0.021 m (0.07 ft)	0.021 m (0.07 ft)	0.046 m (0.15 ft)	0.015 m (0.05 ft)
August 1993-October 2001	0.155 m (0.51 ft)	0.165 m (0.54 ft)	0.128 m (0.42 ft)	0.11 m (0.36 ft)

Table 3. Targeted armor unit movement for Laupahoehoe breakwater, Hawaii, HI.

	Laupahoehoe Breakwater	
Monitoring Period	Range of Horizontal Movement	Range of Vertical Movement
October 1991-November 1992, Baseline	0.0 to 0.046 m (0.0 to 0.15 ft)	0.0 to 0.37 m (0.0 to 0.12 ft)
November 1992-October 2001	0.0 to 0.104 m (0.0 to 0.34 ft)	0.0 to 0.131 m (0.0 to 0.43 ft)
Monitoring Period	Average Horizontal Movement	Average Vertical Movement
October 1991-November 1992, Baseline	0.009 m (0.03 ft)	0.012 m (0.04 ft)
November 1992-October 2001	0.03 m (0.1 ft)	0.049 m (0.16 ft)

Table 4. Targeted armor unit movement for Nawiliwili Harbor, Kauai, HI.

	Nawiliwili Breakwater	
Monitoring Period	Range of Horizontal Movement	Range of Vertical Movement
October 1995, Baseline	No movement	No movement
October 1995-October 2001	0.0 to 0.13 m (0.0 to 0.42 ft)	0.0 to 0.137 m (0.0 to 0.45 ft)
Monitoring Period	Average Horizontal Movement	Average Vertical Movement
October 1995, Baseline	No movement	No movement
October 1995-October 2001	0.03 m (0.1 ft)	0.046 m (0.15 ft)

Kahului West and East Breakwaters contained 22 and seven new breaks, respectively, relative to the most recent inspection in 2001. Of the five breakwaters inspected, the Kahului West Breakwater contained the most new breaks.

The Laupahoehoe Boat Launching Facility breakwater armor and rib cap continued to remain undamaged; however, many core stones from inside the rib cage containment area were missing. In addition, extra stones had accumulated on the interior shoreline, many presumed from the core of the breakwater.

Nawiliwili breakwater contained only four new breaks above the water line compared to the previous inspection in 2001 and 11 new breaks from the 1996 baseline survey. Slope subsidence on the ocean side of the breakwater created voids in areas between the crest and the dolosse. There was splash overtopping from the trunk of the structure to the beginning of the rib cap at sta 12+00 on the day of the inspection, but no wave transmission was observed through the breakwater.

5 Conclusions

The overall condition of the Hilo harbor breakwater was fair to good. Some damage was noted on the old stone portions of the breakwater.

The Kahului breakwaters contain some of the largest armor units of the four harbors with 31.7-tonne (35-ton) and 45.4-tonne (50-ton) tribars, and 27-tonne (30-ton) dolosse, but are directly exposed to northern storm swell. The west breakwater seems particularly vulnerable to armor breakage with a 27.5 percent increase in breakage (22 new breaks) over the 4-year period of 2001-2005. A future monitoring effort is needed to determine if this trend continues.

The Laupahoehoe breakwater's unique design of fitting the toe of 27-tonne (30-ton) dolosse into trenched basalt seafloor has so far proven effective for armor units. However, the concrete pipe rib cage for containment of core and capstone has experienced progressive damage. Obvious voids created by missing stones should be monitored often. The rib cap and dolosse units remain in good condition, but wave transmission appears excessive. The locally maintained boat ramp is in poor condition. The local government has expressed interest in feasibility studies for possible future modifications to the breakwater, but lack of funding has limited efforts (POH 2005). Subsequently, repairs have also been deferred. No repairs have been made to the structure since its construction in 1988. In addition to broken armor surveys, future periodic inspection monitoring should include detailed prototype long-term wave data along with quantifiable measurements of the amount of core and capstone missing or displaced from the structure.

The Nawiliwili Harbor breakwater showed little change from the previous inspection in 2001. The next monitoring should include measurements of side slope subsidence for comparison purposes and a closer evaluation of breaks below the upper layer should be conducted. Voids and perched stones in the first 366 m (1200 ft) of the structure are possible future problems, and the large ocean side void at sta 10+40 should be closely monitored. Currently, the structure remains in good condition overall.

Additional information

Additional information concerning the MCNP program, the Periodic Inspections work unit, and the structures discussed in this report can be found in the following:

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Appendix A: Inspection Tables and Photographs for Hilo Harbor Breakwater, Hawaii, HI.

Table A gives the station number and a description of each damage location observed during the walking inspection. Figure A1 is a photograph of the breakwater and Figures A2-A73 show the damage locations noted during inspection.

Table A. Hilo breakwater inspection notes.

Damage Location No.	Station No.	Description
		Overview of structure
1	2+60	HS, missing armor stone, erosion, 8 ft x 4 ft void
2	4+00	HS, minor settling on crest and side slope
3	8+15	OS, 4-ft-wide void, 6.5 ft deep; slight sinking
4	9+08	OS, void
5	10+05	HS, void
6	10+80	OS, dislodged stone
7	10+80	HS, void approximately 5' deep
8	11+18	Tribars separating from rib cap; side slope steepening
9	11+24	Tribar separating from rib cap
10	11+44	Tribar separating from rib cap
11	12+24	Settling of stone under ribs
12	12+50	Tribar separating from rib cap
13	13+10	Rib 36, tribar w/ broken leg
		Note: tribars separating from rib cap throughout section
		Note: Example of target reach marker
14	14+80	Rib 65, tribar w/ broken leg
		Note: tribars placed in steep angle from ribs 70-100
15	16+00	Rib 85, tribar broken through center
16	17+40	Ribs 108-111, 3 broken units at waterline
		Note: Surplus tribars stacked at ribs 139-146, 150 total ribs
17	19+52	Rib 143, tribar 64, broken leg
	19+90	End of Ribs, overview looking north
18	20+30	OS, void
19	22+10	HS, sloped crest
20	22+80	HS, missing armor stone at hinge
21	22+90	Cracked armor stone
22	23+40	OS, sharp drop
23	23+90- 24+15	OS, void and settling
24	25+00	Hinge stone breaking apart
25	25+30	Hinge stone separating
26	25+70	OS, dislodged stone
27	25+85	Void at crest
28	25+95	Void at crest
29	26+49	HS, broken armor stone
30	27+28	Hinge stone settling

(Sheet 1 of 3)

Table A. (Continued).

Damage Location No.	Station No.	Description
31	28+78	Missing crest stone
32	29+35	OS, hinge stone settling
33	29+38	Crest settling
34	30+40	Broken stone on crest
35	30+25	Overhanging hinge stone
36	32+25	HS, void on edge of crest
37	33+00	OS, void with dislodged hinge stone
38	33+65	Void at crest (3 ft x 6 ft x 4.5 ft)
39	34+40	OS, settled hinge stone; void at crest
40	35+84	Void at crest
41	36+10	Large void at crest from centerline to HS, toe stone missing at waterline; two large rock separations
42	36+50	Void at crest
43	37+25	OS, bridging at crest
44	38+85	Two perched armor stones
45	40+55	Major settling and bridging from centerline to waterline; void extends to HS but is not completely breached
46	43+80	HS, void at crest (4 ft x 3 ft x 4 ft)
47	45+80	Bridging
48	48+29	Broken stone on crest
49	49+15	OS, broken stone on crest
50	50+70	Bridging
51	52+60	Bridging
52	52+95	Perched armor stone
53	54+30	Broken stone on crest
54	56+10	OS, void at crest
55	57+35	Void at crest (10 ft x 2 ft x 4 ft)
56	57+58	Void at crest (2 ft x 4 ft x 3 ft)
57	55+56-59+30	OS, settling at crest
	60+20	HS, unmarked copper disk
58	60+10	OS, major settling and breaching
59	60+80	HS, void at crest (2 ft x 4 ft x 4 ft)
60	61+13-61+50	Numerous armor stone separations and voids
61	62+00	Perched stone
62	62+30-63+50	OS, hinge bowing out, bridging

(Sheet 2 of 3)

Table A. (Concluded).

Damage Location No.	Station No.	Description
63	66+17	Broken armor stone on centerline of crest
64	66+35	Bridging
65	67+19	OS, void at hinge (2 ft x 3 ft x 4 ft)
66	68+45	HS, 2-ft void
67	68+78	OS, perched armor stone "Tombstone"
68	69+98	HS, void at crest (3 ft x 6 ft x 10 ft)
	70+50	OS, brass disk not found
69	71+10	OS, void (3 ft x 5 ft)
70	72+00	OS, hinge settling; end reach
71	73+00	HS, slight settling on crest
72	74+40	Broken armor stones and bridging at crest
73	74+90	Broken stone at crest
74	75+85	Broken stone
75	75+95	Void
76	77+30	OS, bridging and settling
77	77+80	Cracked armor stone on centerline of crest
78	81+47	Voids at centerline of crest
79	81+61	HS, void (4 ft x 4 ft x 3 ft)
80	89+30	Bridging
81	90+00	HS, aerial survey marker (white cross), settling at hinge, void at centerline of crest, bridging
82	92+20	OS, broken stone and bridging
83	93+90	Bridging and fissure at crest
84	94+10	OS, void and bridging
85	95+50	OS, separation of slope; flipped stone
86	95+70	OS, flipped stone at hinge
		Note: Crest elevation lowers for last 200 ft
87	98+50	OS, fissure extending from crest down to waterline; about 2 ft wide
		Note: Erosion at head from centerline to ocean side

(Sheet 3 of 3)

Figure A1. Overview of structure.

Figure A2. Damage location 1, sta 2+60, harbor side, missing armor stone, 8-ft x 4-ft void.

Figure A3. Damage location 2, sta 4+00, harbor side, minor settling on crest and side slope.

Figure A4. Damage location 3, sta 8+15, ocean side, 4-ft-wide void, 6.5 ft deep, slight sinking.

Figure A5. Damage location 4, sta 9+08, ocean side, void.

Figure A6. Damage location 5, sta 10+05, harbor side, void.

Figure A7. Damage location 6, sta 10+80, ocean side, dislodged stone.

Figure A8. Damage location 7, sta 10+80, harbor side, void approximately 5 ft deep.

Figure A9. Damage location 8, sta 11+18, tribars separating from rib cap, side slope steepening.

Figure A10. Damage location 9, sta 11+24, tribar separating from rib cap.

Figure A11. Damage location 13, sta 13+10, ocean side, rib #36, tribar with broken leg.

Figure A12. Damage location 14, sta 14+80, rib #65, tribar with broken leg.

Figure A13. Damage location 15, sta 16+00, rib #85, tribar broken through center.

Figure A14. Damage location 16, sta 17+40, ocean side, broken tribar at waterline.

Figure A15. Damage location 16, sta 17+40, ocean side, broken tribar at waterline.

Figure A16. Damage location 16, sta 17+40, ocean side, broken tribar at waterline.

Figure A17. Damage location 17, sta 19+52, rib #143, tribar #64, broken leg.

Figure A18. Sta 19+90, end of rib cap, overview looking north.

Figure A19. Damage location 18, sta 20+30, ocean side, void.

Figure A20. Damage location 19, sta 22+10, harbor side, sloped crest.

Figure A21. Damage location 20, sta 22+80, harbor side, missing armor stone at hinge.

Figure A22. Damage location 21, sta 22+90, ocean side, cracked armor stone.

Figure A23. Damage location 22, sta 23 +40, ocean side, sharp drop.

Figure A24. Damage location 23, sta 23+90-24+15, ocean side, void and settling.

Figure A25. Damage location 24, sta 25+00, hinge stone breaking apart.

Figure A26. Damage location 25, sta 25+30, hinge stone separating.

Figure A27. Damage location 26, sta 25+70, ocean side, dislodged stone.

Figure A28. Damage location 27, sta 25+85, void at crest.

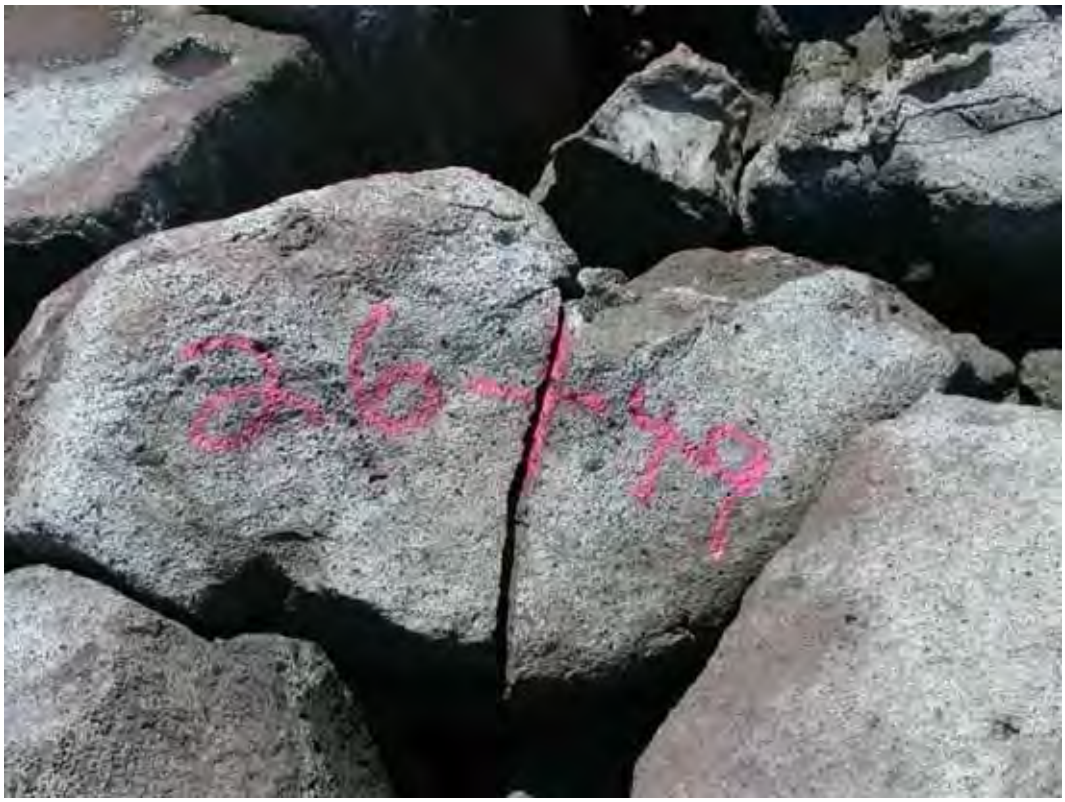

Figure A29. Damage location 29, sta 26+49, harbor side, broken armor stone.

Figure A30. Damage location 30, sta 27+28, ocean side, hinge stone settling.

Figure A31. Damage location 31, sta 28+78, missing crest stone.

Figure A32. Damage location 34, sta 30+40, broken stone on crest.

Figure A33. Damage location 35, sta 30+25, ocean side, overhanging hinge stone.

Figure A34. Damage location 36, sta 32+25, harbor side, void on edge of crest.

Figure A35. Damage location 37, sta 33+00, ocean side, void with dislodged hinge stone.

Figure A36. Damage location 38, sta 33+65, void at crest (3 ft x 6 ft x 4.5 ft).

Figure A37. Damage location 39, sta 34+40, ocean side, settled hinge stone, void at crest.

Figure A38. Damage location 40, sta 35+84, void at crest.

Figure A39. Damage location 41, sta 36+10, large void at crest from centerline to harbor side, missing toe stone, two large rock separations.

Figure A40. Damage location 42, sta 36+50, void at crest.

Figure A41. Damage location 43, sta 37+25, ocean side, bridging at crest.

Figure A42. Damage location 44, sta 38+85, two perched armor stones.

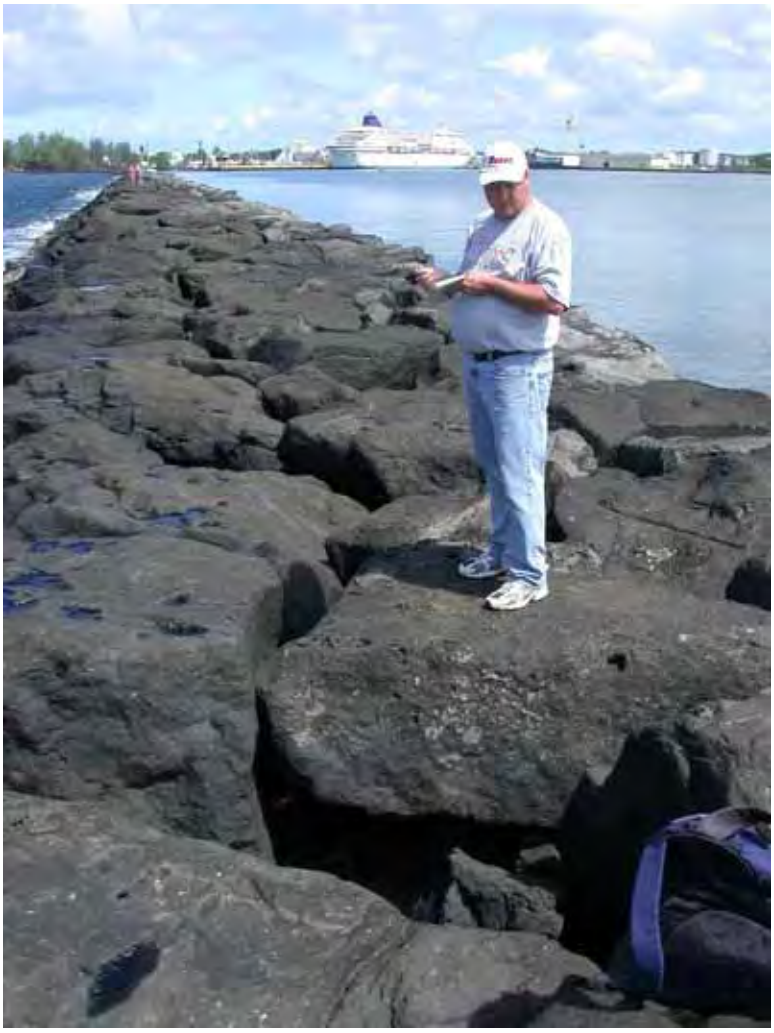

Figure A43. Damage location 45, sta 40+55, major settling and bridging from centerline to waterline; void extends to waterline but structure is not completely breached.

Figure A44. Damage location 46, sta 43+80, harbor side, void at crest (4 ft x 3 ft x 4 ft).

Figure A45. Damage location 48, sta 48+29, broken stone on crest.

Figure A46. Damage location 49, sta 49+15, ocean side, broken stone on crest.

Figure A47. Damage location 51, sta 52+60, bridging.

Figure A48. Damage location 52, sta 52+95, ocean side, perched armor stone.

Figure A49. Damage location 53, sta 54+30, broken stone on crest.

Figure A50. Damage location 54, sta 56+10, ocean side, void at crest.

Figure A51. Damage location 55, sta 57+35, void at crest (10 ft x 2 ft x 4 ft).

Figure A52. Damage location 56, sta 57+58, void at crest (2 ft x 4 ft x 3 ft).

Figure A53. Damage location 57, sta 55+56-and 59+30, ocean side, settling at crest.

Figure A54. Sta 60+20, harbor side, unmarked copper disk.

Figure A55. Damage location 59, sta 60+80, harbor side, void at crest (2 ft x 4 ft x 4 ft).

Figure A56. Damage location 60, sta 61+13-and 61+50, numerous armor stone separations and voids.

Figure A57. Damage location 61, sta 62+00, perched stone.

Figure A58. Damage location 62, sta 62+30 - 63+50, ocean side, hinge bowing out, bridging.

Figure A59. Damage location 67, sta 68+78, ocean side, perched armor stone "Tombstone."

Figure A60. Damage location 68, sta 69+98, harbor side, void at crest (3 ft x 6 ft x 10 ft).

Figure A61. Damage location 70, sta 72+00, ocean side, hinge settling.

Figure A62. Damage location 71, sta 73+00, harbor side, slight settling of crest.

Figure A63. Damage location 72, sta 74+40, broken armor stones and bridging at crest.

Figure A64. Damage location 75, sta 75+95, void.

Figure A65. Damage location 76, sta 77+30, ocean side, bridging and settling.

Figure A66. Damage location 77, sta 77+80, cracked armor stone on centerline of crest.

Figure A67. Damage location 80, sta 89+30, bridging.

Figure A68. Damage location 81, sta 90+00, harbor side, aerial survey marker; settling at hinge; void at centerline of crest; bridging.

Figure A69. Damage location 82, sta 92+20, ocean side, broken armor stone and bridging.

Figure A70. Damage location 84, sta 94+10, ocean side, void and bridging.

Figure A71. Damage location 85, sta 95+50, ocean side, separation of slope, flipped stone.

Figure A72. Damage location 86, sta 95+70, ocean side, flipped stone at hinge.

Figure A73. Damage location 87, sta 98+50, ocean side, 2-ft-wide fissure extending from crest down to waterline.

Appendix B: Inspection Tables and Photographs for Kahului Harbor, Maui, HI.

Table B1 gives the station number and a description of each damage location observed during the walking inspection of Kahului East Breakwater. Figures B1-B43 show the damage locations noted during inspection.

Table B2 gives the station number and a description of each damage location observed during the walking inspection of Kahului West Breakwater. Figures B44-B100 show the damage locations noted during inspection.

Kahului East Breakwater

Table B1. Kahului East Breakwater inspection notes.

Damage Location No.	Station (Former Station)	Description
	0+00	Beginning of rubble mound structure
	2+18	Light pole 18 marks station
1	3+08	Harbor side, cracked armor stone
	4+90	Light pole 15 marks station
	7+44	Light pole 12 marks station
	9+70	Light pole 9 marks station
	11+95	End of new repair
2	13+08	HS, broken armor stone
3	13+43	OS, adjacent stones not from structure
4	14+11	OS, dislodged armor stone at toe
5	14+90	Bridging of armor stone at crest
	15+00	Survey marker
6	16+85	Dislodged armor stone at WL and possible void
7	17+05	Settling at crest
	18+86	Beginning of concrete wall adjacent to structure (marker shows 18+25)
8	19+00-21+00	Side slope flattening
9	21+60	Broken armor stone
	21+85	Air survey marker
10	22+40	Transition of repair zones, crest elevation drop, monitor side slope settling
11	23+20	OS, slight settling
12	23+20-24+67	Settling; flipped armor stone at sta 24+50
	26+26	Begin rib cap; extension of Pier 1 harbor side of breakwater
	26+26	New dolphin and walkway adjacent to breakwater, built 2005
13	26+26	HS, eroded side slope
14	26+70 (19+60)	Rib 8, OS, dolosse w/ fluke tip break (old sta 25+00)
15	26+92 (19+82)	Rib 12, OS, dolosse w/ straight shank-fluke break
16	26+97 (20+15)	OS, dolosse w/ mid shank break
17	26+97 (20+16)	OS, dolosse w/ shank-fluke break
18	27+09 (20+20)	Rib 15, OS, dolosse w/ shank-fluke break; dolosse settling and separation approx. 9 in., target dolosse KEJ 1
19	27+09 (20+22)	Rib 15, OS, dolosse w/ shank-fluke break
20	27+09 (20+24)	Rib 15, OS, dolosse w/ shank-fluke break
21	27+16	Rib 16, HS, tribar separation from rib cap

(Sheet 1 of 3)

Table B1. (Continued).

Damage Location No.	Station (Former Station)	Description
22	27+19 (20+50)	Rib 17, OS, dolosse w/ straight shank-fluke break
23	27+69 (20+75)	Rib 23, OS, dolosse w/ fluke-shank break
24	27+69 (20+80)	Rib 23, OS, dolosse w/ shank-fluke break
25	27+69 (20+84)	Rib 23, OS, dolosse w/ shank-fluke break
26	28+04	Rib 30, OS, dolosse w/ tip chip
27	28+04	Rib 30, OS, dolosse w/ tip chip
28	28+10	Rib 31, OS, 10 in. separation of dolosse from rib cap
	28+28	Rib 32, red cross painted on rib cap
	28+34	Rib 33, KE1-3 target dolos
29	28+30	Rib 34, HS, tribar w/ break through center
30	28+84	Rib 43, OS, dolosse w/ tip chip
31	29+27	Rib 50, HS, centerline of first turnaround; settling of armor stone - unsupported rib cap
	29+74	Rib 58, red cross painted on rib cap
32	30+04	Rib 63, OS, dolosse w/ tip chip
33	30+04	Rib 63, OS, dolosse w/ tip chip
	30+10	Rib 64, red cross painted on rib cap, beginning of tribar on OS
34	30+16	Rib 65, OS, separation of rib and dolos
35	30+28	Rib 67, OS, dolosse w/ tip chip
36	30+28 (23+32)	Rib 67, HS, tribar w/ break through center
	30+64-30+70	Ribs 73-74, OS, transition of dolosse to tribar
37	30+88-31+48	Rib 77-87, OS, 10 ft tribar separation from rib cap
38	31+54	Rib 88, OS, tribar w/ leg crack
39	31+54	Rib 88, OS, tossed 9-ton tribar
40	31+54-32+04	Ribs 88-97, OS, 8 ft tribar separation from rib cap
41	31+66	Rib 90, OS, tribar w/ center crack
42	32+16	Rib 98, OS, cracked and spalling rib cap, red cross painted on rib cap
43	32+38-32+44	Ribs 102-103, HS, settling and void
44	32+62 (25+47)	Rib 106, OS, tribar w/ broken leg
45	32+74	Rib 108, OS, tribar w/ spalling
46	32+80-33+04	Ribs 109-113, OS, stones tossed up between ribs and tribars
47	33+22 (26+31)	Rib 116, HS, tribar w/ crack through center
48	33+40-33+64	Ribs 119-123, HS, settling of tribar and separation from rib cap
	33+52	Rib 121, OS, centerline of second turnaround
49	33+52	Spalling of turnaround rib

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Table B1. (Concluded).

Damage Location No.	Station (Former Station)	Description
50	33+52 (26+59)	Rib 121, OS, tribar w/ top of leg broken
51	33+70 (26+87)	Rib 124, OS, dolosse w/ shank-fluke break
52	33+82	Rib 126, OS, dolosse w/ fluke tip break
53	34+09	Rib 129, OS, dolosse w/ fluke tip break
54	34+15	Rib 130, OS, dolosse w/ crack through shank
55	34+27 (27+35)	Rib 132, OS, tribar w/ mid leg break
	34+27	Rib 132, aerial cross
	34+50	Rib 135, end of rib cap
56		Head, 0 deg, dolosse w/ tip chip
57		Head, 0 deg, dolosse w/ fluke break
58		Head, HS, tribar w/ cracking and spalling
		Harbor side, NavAid blown from crest onto head of structure

(Sheet 3 of 3)

Figure B1. Damage location 1, sta 3+08, harbor side, broken armor stone.

Figure B2. Sta 18+86, beginning of concrete wall adjacent to structure (marker shows 18+25).

Figure B3. Damage location 8, sta 19+00-21+00, ocean side, side slope flattening.

Figure B4. Damage location 9, sta 21+60, crest, broken armor stone.

Figure B5. Damage location 10, sta 22+40, transition of repair zones, crest elevation drop, monitor side slope settling.

Figure B6. Damage location 11, sta 23+20, ocean side, slight settling.

Figure B7. Damage location 12, sta 24+50, ocean side, flipped armor stone.

Figure B8. Sta 26+26, begin rib cap; extension of Pier 1 harbor side of breakwater.

Figure B9. Sta 26+26, harbor side, New Dolphin and walkway adjacent to breakwater; built 2005.

Figure B10. Damage location 13, sta 26+26, harbor side, eroded side slope.

Figure B11. Damage location 14, sta 26+70, ocean side, rib #8, dolosse with fluke tip break.

Figure B12. Damage location 15, sta 26+92, ocean side, rib #12, dolosse with straight shank-fluke break.

Figure B13. Damage location 16, sta 26+97, ocean side, dolosse with mid-shank break.

Figure B14. Damage location 17, sta 26+97, ocean side, dolosse with shank-fluke break.

Figure B15. Damage location 18, sta 27+09, ocean side, rib #15, dolosse with shank-fluke break.

Figure B16. Damage location 19, sta 27+09, ocean side, rib #15, dolosse with shank-fluke break.

Figure B17. Damage location 20, sta 27+09, ocean side, rib #15, dolosse with shank-fluke break.

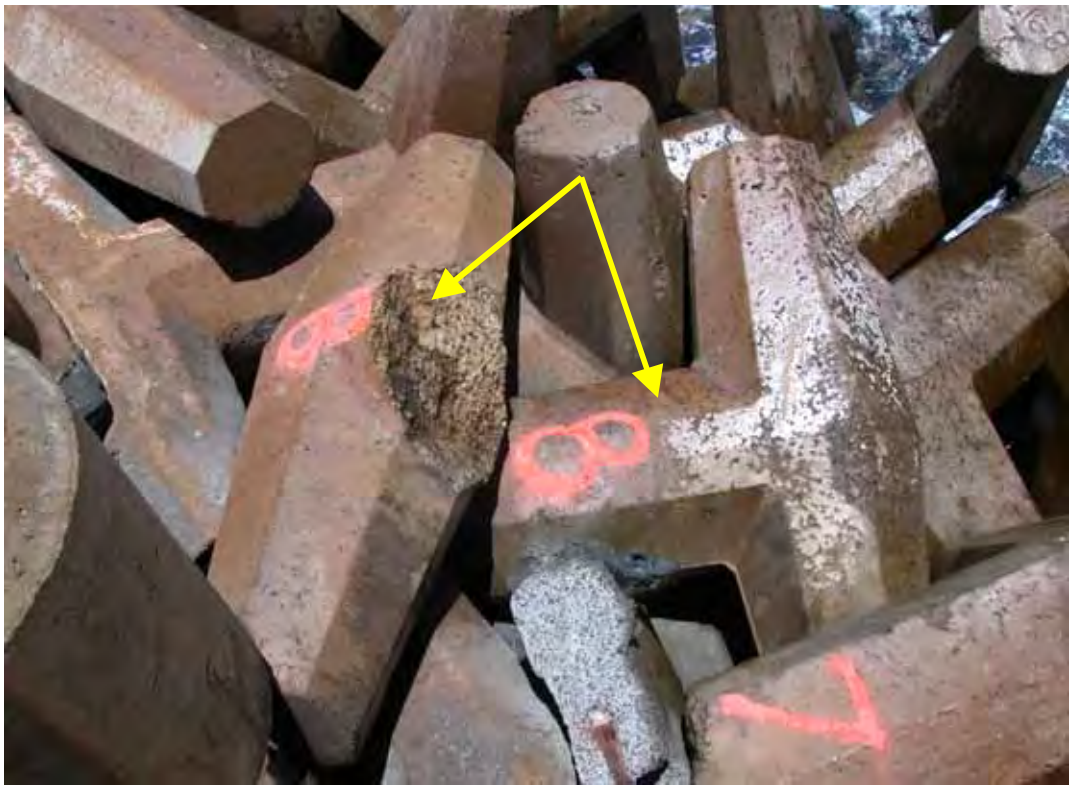

Figure B18. Damage location 22, sta 27+19, ocean side, rib #17, dolosse with straight shank-fluke break.

Figure B19. Damage locations 23 & 24, sta 27+69, ocean side, rib #23, dolosse with fluke-shank break and dolosse with shank-fluke break.

Figure B20. Damage location 25, sta 27+69, ocean side, rib #23, dolosse with shank-fluke break.

Figure B21. Damage location 26, sta 28+04, ocean side, rib #30, dolosse with tip chip.

Figure B22. Damage location 27, sta 28+04, ocean side, rib #30, dolosse with tip chip.

Figure B23. Sta 28+34, ocean side, rib #33, KE1-3 Target dolos.

Figure B24. Damage location 29, sta 28+30, harbor side, rib #34, tribar with break through center.

Figure B25. Damage location 31, sta 29+27, harbor side, rib #50, Centerline of first turnaround; settling of armor stone - unsupported rib cap.

Figure B26. Damage locations 32 and 33, sta 30+04, ocean side, rib #63, two dolosse with tip chips (one visible in photograph).

Figure B27. Sta 30+64 – 30+70, ocean side, ribs #73 - #74, transition of dolosse to tribar.

Figure B28. Damage location 37, sta 30+88 - sta 31+48, ocean side, rib #77 - #87, 10 ft separation of tribar from ribcap.

Figure B29. Damage location 38, sta 31+54, ocean side, rib #88, tribar with leg crack.

Figure B30. Damage location 39, sta 31+54, ocean side, rib #88, tossed 9-ton tribar.

Figure B31. Damage location 40, sta 31+54 - 32+04, ocean side, rib #88 - 97, 8 ft separation of tribar from ribcap.

Figure B32. Damage location 42, sta 32+16, ocean side, rib #98, cracked and spalling rib cap, red cross painted on rib cap.

Figure B33. Damage location 44, sta 32+62, ocean side, rib #106, tribar with broken leg.

Figure B34. Damage location 45, sta 32+74, ocean side, rib #108, tribar with spalling.

Figure B35. Damage location 46, sta 32+80 – 33+04, ocean side, rib #109 - 113, stones tossed up between ribs and tribars.

Figure B36. Damage location 48, sta 33+40 – 33+64, harbor side, rib #119 - 123, settling of tribar and separation from rib cap.

Figure B37. Damage location 50, sta 33+52, ocean side, rib #121, tribar with top of leg broken.

Figure B38. Damage locations 52 & 53, sta 33+82 and sta 34+09, ocean side, rib #126 and 129, dolosse with fluke tip breaks.

Figure B39. Damage location 54, sta 34+15, ocean side, rib #130, dolosse with crack through shank.

Figure B40. Damage location 55, sta 34+27, ocean side, rib #132, tribar with mid leg break.

Figure B41. Damage location 56, head, 0 deg, dolosse with tip chip.

Figure B42. Damage location 57, head, 0 deg, dolosse with fluke break.

Figure B43. Damage location 58, harbor side of head, tribar with cracking and spalling.

Kahului West Breakwater

Table B2. Kahului West Breakwater inspection notes.

Damage Location No.	Station	Description
1	17+10	OS, tribar out of place at waterline
2	18+08	Rib 6, HS, tribar w/ broken can
3	18+74	Rib 13, OS, 8" separation of tribar from ribcap
4	18+82	Rib 14, HS, tribar w/ crack through center
5	18+90	Rib 15, HS, tribar w/ crack through center
6	19+14	Rib 18, OS, tribar w/ break through center and 4" separation from ribcap
7	19+78	Rib 26, HS, tribar w/ spalling
8	20+58	Rib 36, red cross painted on ribcap and spalling
		OS, transition of tribar to dolos
9	20+66	Rib 37, OS, tribar w/ can break
10	20+74	Rib 38, OS, tribar w/ broken leg
11	20+74-20+90	Ribs 38-40, OS, two tribar pieces at waterline
12	20+74-20+90	Ribs 38-40, OS, broken dolosse at waterline
13	20+90	Rib 40, OS, tribar w/ can missing
14	20+90	Rib 40, HS, tribar w/ crack through center
15	21+22	Rib 44, OS, tribar broken into three pieces
16	21+38	Rib 46, OS, dolosse w/ multiple breaks
17	21+38	Rib 46, OS, tribar w/ broken leg
18	21+54	Rib 48, OS, tribar w/ can missing
19	21+54	Rib 48, OS, tribar w/ multiple cracks through center
20	21+54-21+60	Ribs 48-49, OS, tribar w/ cracks through center
	21+60	Note: End of ribcap; harbor side tribar dated 12/82 - 1/83
21	21+81	OS, tribar w/ cracks through center
22	21+81	OS, broken tetrapod at waterline
23	21+83	OS, spalling of dolosse and concrete cap
24	21+90	OS, tribar broken into three pieces
25	21+95	OS, tribar w/ crack
26	22+10	OS, tribar w/ crack held together by rebar
27	22+10	OS, dolosse w/ tip chip and crack
28	22+14	OS, tribar w/ broken can held together by rebar
29	22+14	OS, dolosse w/ spalling

(Sheet 1 of 3)

Table B2. (Continued).

Damage Location No.	Station	Description
30	22+20	OS, dolosse w/ shank-fluke break held together by rebar
31	22+20	OS, dolosse w/ shank-fluke break at waterline
32	22+20	OS, armor stone at concrete cap
33	22+35	OS, dolosse w/ fluke tip break
34	22+35	OS, dolosse w/ fluke tip break
35	22+38	OS, dolosse w/ tip break
36	22+48	HS, dolosse w/ fluke tip break
	22+48-22+65	Note: Survey target dolosse KHW located on HS between breaks 75 and 76
37	22+49	OS, tetrapod w/ broken top
38	22+50	HS, center of turnaround, settling and unsupported ribcap
39	22+65	HS, tetrapod w/ broken top at waterline
40	22+70	OS, dolosse w/ spalling and exposed rebar on fluke tip
41	22+72	OS, dolosse w/ shank-fluke break
42	22+74	OS, dolosse w/ shank-fluke break
43	22+74	OS, dolosse w/ shank-fluke break
44	22+80	OS, tetrapod w/ broken top
45	22+80	OS, dolosse w/ shank-fluke break
46	22+88	OS, dolosse w/ fluke tip break
47	22+89	OS, dolosse w/ mid shank break
48	22+90	HS, tribar w/ broken can
49	22+92	OS, dolosse w/ shank-fluke break (missed this one)
50	22+94	OS, dolosse w/ mid shank break
51	22+98	HS, tribar w/ broken can
52	22+98	HS, cracked tribar
53	23+00	OS, dolosse w/ shank-fluke break
54	23+05	OS, dolosse w/ mid shank break
55	23+19	OS, dolosse w/ shank-fluke break
56	23+19	OS, dolosse w/ shank-fluke break
57	23+19	OS, dolosse w/ shank-fluke break
58	23+25	OS, dolosse w/ shank-fluke crack
59	23+28	OS, tetrapod w/ missing top
	23+28	Note: End of concrete
60	23+30	OS, dolosse w/ mid-shank break
61	23+30	OS, dolosse w/ shank-fluke break
	23+38	Note: Aerial Survey Marker
		Note: 0 deg is straight through the centerline of the head of the structure

(Sheet 2 of 3)

Table B2. (Concluded).

Damage Location No.	Station	Description
62		Head, 90 deg, OS, dolosse w/ shank-fluke break at waterline
63		Head, 90 deg, OS, dolosse w/ fluke-shank crack throughout
64		Head, 80 deg, OS, dolosse w/ shank-fluke break
65		Head, 80 deg, OS, dolosse w/ shank-fluke break
66		Head, 70 deg, OS, dolosse w/ shank-fluke break
67		Head, 45 deg, OS, dolosse w/ spalling
68		Head, 45 deg, OS, broken tetrapod
69		Head, 45 deg, OS, dolosse w/ fluke-shank crack
70		Head, 45 deg, OS, dolosse w/ fluke crack and spalling
71		Head, 30 deg, OS, dolosse w/ spalling and exposed rebar
72		Head, 30 deg, OS, dolosse w/ fluke tip chip
73		Head, 30 deg, OS, dolosse w/ shank-fluke break at waterline
74		Head, 15 deg, OS, dolosse w/ fluke-shank break
75		Head, 0 deg, dolosse w/ longitudinal fluke crack and spalling
76		Head, 3 deg, HS, dolosse w/ spalling and exposed rebar on fluke tip
77		Head, 2 deg, HS, dolosse w/ shank-fluke break
78		Head, 5 deg, HS, dolosse w/ spalling, exposed rebar, and fracturing on fluke tip
79		Head, 6 deg, HS, dolosse w/ spalling and exposed rebar on fluke
80		Head, 10 deg, HS, dolosse w/ mid shank break
81		Head, 15 deg, HS, dolosse w/ fluke-shank break
		Note: Tribars begin at head, 25 deg, HS
82		Head, 35 deg, HS, dolosse w/ mid shank break
83		Head, 45 deg, HS, rusted rebar in center of tribar
84		Head, 90 deg, HS, tribar w/ exposed and rusted rebar at center
85		Head, 90 deg, HS, tribar w/ spalling at center
		Note: Tribars from OS Ribs 0-32 are dated 1973; tribars from OS Ribs 32-head of structure are dated 1969
		Sheet 3 of 3

Figure B44. Damage location 1, sta 17+10, ocean side, tribar out of place at waterline.

Figure B45. Damage location 2, sta 18+08, harbor side, rib #6, tribar with broken can.

Figure B46. Damage location 3, sta 18+74, ocean side, rib #13, 8" separation of tribar from rib cap.

Figure B47. Damage location 4, sta 18+82, harbor side, rib #14, tribar with crack through center.

Figure B48. Damage location 5, sta 18+90, harbor side rib #15, tribar with crack through center.

Figure B49. Damage location 6, sta 19+14, ocean side, rib #18, tribar with break through center and 4" separation from rib cap.

Figure B50. Damage location 8, sta 20+58, rib #36, red cross painted on rib cap (not visible in photograph) and spalling.

Figure B51. Damage location 9, sta 20+66, ocean side, rib #37, tribar with can break.

Figure B52. Damage location 10, sta 20+74, ocean side, rib #38, tribar with broken leg.

Figure B53. Damage location 13, sta 20+90, ocean side, rib #40, tribar with can missing.

Figure B54. Damage location 15, sta 21+22, ocean side, rib #44, tribar broken into three pieces.

Figure B55. Damage location 17, sta 21+38, ocean side, rib #46, tribar with broken leg.

Figure B56. Damage location 18, sta 21+54, ocean side, rib #48, tribar with can missing.

Figure B57. Damage location 19, sta 21+54, ocean side, rib #48, tribar with multiple cracks through center.

Figure B58. Damage location 20, sta 21+54 – 21+60, ocean side, rib #48-49, tribar with cracks through center.

Figure B59. Damage location 21, sta 21+81, ocean side, tribar with cracks through center.

Figure B60. Damage location 23, sta 21+83, ocean side, spalling of dolosse and concrete rib cap.

Figure B61. Damage location 24, sta 21+90, ocean side, tribar broken into three pieces.

Figure B62. Damage location 25, sta 21+95, ocean side, tribar with crack.

Figure B63. Damage location 26, sta 22+10, ocean side, tribar with crack held together by rebar.

Figure B64. Damage location 27, sta 22+10, ocean side, dolosse with tip chip and crack.

Figure B65. Damage location 28, sta 22+14, ocean side, tribar with broken can held together by rebar.

Figure B66. Damage location 29, sta 22+14, ocean side, dolosse with spalling.

Figure B67. Damage location 30, sta 22+20, ocean side, dolosse with shank-fluke break held together by rebar.

Figure B68. Damage location 31, sta 22+20, ocean side, dolosse with shank-fluke break at waterline.

Figure B69. Damage locations 33 & 34, sta 22+35, ocean side, two dolosse with fluke tip breaks.

Figure B70. Damage location 35, sta 22+38, ocean side, dolosse with tip break.

Figure B71. Damage location 36, sta 22+48, harbor side, dolosse with fluke tip break.

Figure B72. Damage location 37, sta 22+49, ocean side, tetrapod with broken top.

Figure B73. Damage location 38, sta 22+50, harbor side, center of turnaround, settling and unsupported rib cap.

Figure B74. Damage location 40, sta 22+70, ocean side, dolosse with spalling and exposed rebar on fluke tip.

Figure B75. Damage location 41, sta 22+72, ocean side, dolosse with shank-fluke break.

Figure B76. Damage locations 42 & 43, sta 22+74, ocean side, two dolosse with shank-fluke breaks.

Figure B77. Damage location 46, sta 22+88, ocean side, dolosse with fluke tip break.

Figure B78. Damage location 47, sta 22+89, ocean side, dolosse with mid shank break.

Figure B79. Damage location 48, sta 22+90, harbor side, tribar with broken can.

Figure B80. Damage location 49, sta 22+92, ocean side, dolosse with shank-fluke break.

Figure B81. Damage location 50, sta 22+94, ocean side, dolosse with mid shank break.

Figure B82. Damage location 51, sta 22+98, harbor side, tribar with broken can.

Figure B83. Damage location 52, sta 22+98, harbor side, cracked tribar.

Figure B84. Damage location 53, sta 23+00, ocean side, dolosse with shank-fluke break.

Figure B85. Damage location 54, sta 23+05, ocean side, dolosse with mid shank break.

Figure B86. Damage location 55, sta 23+19, ocean side, dolosse with shank-fluke break.

Figure B87. Damage locations 56 & 57, sta 23+19, ocean side, two dolosse with shank-fluke breaks.

Figure B88. Damage location 58, sta 23+25, ocean side, dolosse with shank-fluke crack.

Figure B89. Damage location 59, sta 23+28, ocean side, tetrapod with missing top.

Figure B90. Damage locations 60 & 61, sta 23+30, ocean side, dolosse with mid-shank break and dolosse with shank-fluke break.

Figure B91. Damage location 67, 45 deg ocean side of head, dolosse with spalling.

Figure B92. Damage location 70, 45 deg ocean side of head, dolosse with fluke crack and spalling.

Figure B93. Damage location 71, 30 deg ocean side of head, dolosse with spalling and exposed rebar.

Figure B94. Damage location 72, 30 deg ocean side of head, dolosse with fluke tip chip.

Figure B95. Damage location 75, head, 0 deg, dolosse with longitudinal fluke crack and spalling.

Figure B96. Damage location 78, 5 deg harbor side of head, dolosse with spalling, exposed rebar, and fracturing on fluke tip.

Figure B97. Damage location 79, 6 deg harbor side of head, dolosse with spalling and exposed rebar on fluke.

Figure B98. Damage location 81, 15 deg harbor side of head, dolosse with fluke-shank break.

Figure B99. Damage location 84, 90 deg harbor side of head, tribar with exposed and rusted rebar at center.

Figure B100. Damage location 85, 90 deg harbor side of head, tribar with spalling at center.

Appendix C: Inspection Tables and Photographs for Laupahoehoe Breakwater, Hawaii, HI

Table C gives the notes associated with each photograph of the damaged locations along the structure (Figures C1-C22).

Table C. Laupahoehoe breakwater inspection notes.

Station No.	Description
0+25, 0+26, 0+28	Voids and missing armor stones
0+40	Cracked armor stone
	Void
	Void
	Void
	Flipped armor stones, OS
	Perched armor stone, HS
	Shifting of stones between ribs
	Displaced armor stone, tossed onto dolos
	Underlayer loss and shifting of stones between ribs
	Displaced armor stone, tossed onto dolos
	Displaced armor stone, tossed onto dolos
	Displaced armor stone, tossed onto dolos
	Displaced armor stone, tossed onto dolos
	Rib 9, cracked
	Underlayer loss and shifting of stones between ribs
	Rib damage possibly caused by displaced armor stones
	dolosse damage possibly caused by displaced armor stones
	Rib damage possibly caused by displaced armor stones
	Undermining of concrete slab adjacent to breakwater and boat launch
	Displaced armor stones at wave absorber along shoreline, harbor side of breakwater
	Displaced armor stones at wave absorber along shoreline, harbor side of breakwater

Figure C1. Sta 0+25 - 0+28, voids and missing armor stones.

Figure C2. Sta 0+40, cracked armor stone.

Figure C3. Void.

Figure C4. Void.

Figure C5. Void.

Figure C6. Oceanside, flipped armor stones.

Figure C7. Harbor side, perched armor stone.

Figure C8. Shifting of stones between ribs.

Figure C9. Displaced armor stone, tossed onto dolosse.

Figure C10. Underlayer loss and shifting of stones between ribs.

Figure C11. Displaced armor stone, tossed onto dolosse.

Figure C12. Displaced armor stone, tossed onto dolosse.

Figure C13. Displaced armor stone, tossed onto dolos.

Figure C14. Displaced armor stone, tossed onto dolos.

Figure C15. Rib #9, cracked.

Figure C16. Underlayer loss and shifting of stones between ribs.

Figure C17. Rib damage possibly caused by displaced armor stones.

Figure C18. dolosse damage possibly caused by displaced armor stones.

Figure C19. Rib damage possibly caused by displaced armor stones.

Figure C20. Undermining of concrete slab adjacent to breakwater and boat launch.

Figure C21. Displaced armor stones at wave absorber along shoreline, harbor side of breakwater.

Figure C22. Displaced armor stones at wave absorber along shoreline, harbor side of breakwater.

Appendix D: Inspection Tables and Photographs for Nawiliwili Breakwater, Kauai, HI

Table D gives the station number and a description of each damage location observed during the walking inspection. Figure D1 is a photograph of a Corps of Engineers survey marker and Figures D2-D80 show the damage locations noted during inspection.

Table D. Nawiliwili breakwater inspection notes.

Damaged Location No.	Station No.	Description
	4+55	COE survey marker
1	5+50	OS, dislodged armor stone at toe
2	5+70	OS, void at hinge
3	5+80	OS, void at toe
4	5+85	OS, void on side slope
5	6+28	Cracked armor stone on crest
	6+40	Survey marker
6	6+60	OS, dislodged armor stone at toe
7	6+90	OS, perched armor stone
	7+02	Stone on crest with 7+04 etched in it
8	7+11	Perched armor stone on crest
9	7+58	Settling of crest
10	7+69	OS, bridging
	8+02	Survey marker
11	8+62	OS, perched armor stone with void
12	8+92	OS, void
13	9+20	HS, cracked armor stone at hinge
14	9+20	OS, flipped armor stone and void
15	9+38	HS, cracked armor stone at hinge
16	9+67	OS, void at hinge
17	9+87	OS, perched armor stone

(Sheet 1 of 4)

Table D. (Continued).

Damaged Location No.	Station No.	Description
18	10+09	Perched armor stone on crest with void
	10+21	Survey marker
19	10+35	Perched armor stone on crest
20	10+40	Void at centerline of crest - 10' deep to waterline
21	10+54	HS, perched armor stone at hinge
22	10+56	HS, perched armor stone at hinge
23	10+76	Flipped armor stone, perched armor stone, bridging and void
24	10+91	OS, flipped armor stone, settling, bridging, void
25	11+39	OS, depression/settling of crest, 5'x4' void on crest
	12+00	Rib cap begins (Note: Centerline to centerline of rib dimension = 6 ft)
26	12+06	Rib 2, OS, dolosse w/ shank-fluke break
27	12+24	Rib 5, OS, dolosse w/ mid shank break
28	12+30	Rib 6, OS, detached dolosse fluke tip (original location unknown)
29	12+36	Rib 7, OS, dolosse w/ mid shank and shank-fluke breaks
30	12+36	Rib 7, HS, 6" separation between ribcap and tribar
31	12+54	Rib 10, OS, dolosse w/ multiple breaks at waterline
32	12+66-12+78	Ribs 12-14, HS, 18" separation between ribcap and tribar
33	12+72	Rib 13, OS, dolosse w/ shank-fluke break at waterline, oceanside of target dolosse NA
34	12+90	Rib 16, HS, tribar w/ leg broken at center
35	12+96	Rib 17, HS, tribar separated from rib
36	13+32	Rib 23, HS, tribar separated from rib
37	13+38-13+44	Ribs 24-25, OS, dolosse w/ fluke-shank break
38	13+44-13+50	Ribs 25-26, OS, dolosse w/ mid-shank break
39	13+62	Rib 28, OS, dolosse w/ fluke-shank break
40	13+80	Rib 31, OS, dolosse w/ shank-fluke break at waterline
41	13+92-13+98	Ribs 33-34, OS, dolosse w/ fluke-shank break
42	13+98	Rib 34, OS, dolosse w/ shank-fluke break
43	14+04	Rib 35, OS, dolosse w/ mid shank break
44	14+04	Rib 35, OS, dolosse w/ mid shank break
45	14+52	Rib 43, OS, dolosse w/ shank-fluke break
46	14+52	Rib 43, HS, tribar separated from rib cap
47	14+76	Rib 47, HS, tribar separated from rib cap
48	14+88	Rib 49, OS, dolosse w/ mid shank break

(Sheet 2 of 4)

Table D (Continued).

Damaged Location No.	Station No.	Description
49	14+88	Rib 49, OS, dolosse w/ fluke shank break
50	14+94	Rib 50, OS, dolosse w/ shank-fluke break
	15+00	Note: Survey marker at Rib 51
51	15+00	Rib 51, OS, tribar w/ 3-way split
52	15+12	Rib 53, OS, dolosse w/ shank-fluke break at waterline
53	15+30	Rib 56, OS, dolosse w/ shank-fluke break at waterline
54	15+42	Rib 58, OS, dolosse w/ mid shank break at waterline
		Note: Extensive abrasion of tribar at mid slope on ocean side of structure
55	15+60	Rib 61, OS, tribar w/ 3 way-break at center
56	15+84	Rib 65, OS, dolosse w/ fluke-shank break at waterline
57	15+96	Rib 67, OS, dolosse w/ shank-fluke break at waterline
58	15+96	Rib 67, OS, dolosse w/ shank-fluke break at waterline
59	15+96	Rib 67, OS, dolosse w/ mid shank break
60	16+02	Rib 68, OS, dolosse w/ mid shank break
61	16+02	Rib 68, OS, dolosse w/ mid shank break
62	16+14	Rib 70, OS, dolosse w/ fluke tip break
63	16+14	Rib 70, OS, tribar w/ broken can
64	16+32	Rib 73, OS, dolosse w/ fluke tip break
65	16+50	Rib 76, OS, tribar w/ broken leg
66	16+68	Rib 79, OS, tribar broken through center - no separation
67	16+74	Rib 80, OS, dolosse w/ shank-fluke break
68	16+80	Rib 81, OS, dolosse w/ shank-fluke break
69	16+98	Rib 84, OS, detached fluke tip, origin unknown
70	16+98	Rib 84, OS, dolosse w/ crack through fluke, still intact - no separation
71	17+22	Rib 88, OS, dolosse w/ shank-fluke break at waterline
72	17+52	Rib 93, OS, dolosse w/ multiple breaks at waterline
73	17+58	Rib 94, OS, dolosse w/ shank-fluke break
74	17+94	Rib 100, OS, detached fluke tip
	18+00	Note: Survey marker at Rib 101
75	18+18	Rib 104, OS, dolosse w/ shank break
76	18+24	Rib 105, OS, dolosse w/ fluke tip break
	18+54	Note: Target dolosse at Rib 110
77	18+54	Rib 110, OS, dolosse w/ fluke break at waterline
78	18+54	Rib 110, OS, dolosse w/ fluke-shank break
79	18+54	Rib 110, OS, dolosse w/ multiple breaks
80	18+54	Rib 110, OS, dolosse w/ shank break
81	18+72	Rib 113, OS, tribar w/ broken can

Table D. (Concluded).

Damaged Location No.	Station No.	Description
82	18+84	Rib 115, OS, tribar w/ broken can
83	19+08	Rib 119, OS, dolosse w/ shank-fluke break
84	19+14	Rib 120, OS, dolosse w/ shank-fluke break
85	19+20	Rib 121, OS, tribar broken through center
86	19+20	Rib 121, OS, broken tribar under dolosse at waterline
87	19+42	Rib 123, OS, dolosse w/ crack through fluke - still intact
88	19+48	Rib 124, OS, tribar w/ broken leg
89	19+60	Rib 126, OS, dolosse w/ shank-fluke crack - still intact
90	19+60	Rib 126, OS, dolosse w/ shank-fluke break
91	19+66	Rib 127, OS, dolosse w/ multiple breaks
92	19+72	Rib 128, OS, dolosse w/ fluke tip break at waterline
93	19+78	Rib 129, OS, target dolosse cracked through fluke
94	19+78	Rib 129, OS, dolosse w/ mid-shank break
95	19+90	Rib 131, OS, tribar w/ broken leg
96	19+90	Rib 131, OS, dolosse w/ shank break
97	19+96	Rib 132, OS, dolosse w/ fluke-shank crack
98	20+08	Rib 134, OS, tribar w/ broken leg
99	20+14	Rib 135, OS, tribar w/ break through center
100	20+14	Rib 135, OS, tribar w/ 3-way break through center
101	20+20	Rib 136, OS, tribar w/ broken leg
102	20+20	Rib 136, OS, tribar w/ broken leg
103	20+20	Rib 136, OS, broken tribar
104	20+20	Note: Rib 136 is cracked on the harbor side
105	20+26	Rib 137, OS, dolosse w/ multiple breaks
106	20+26	Rib 137, OS, tribar w/ broken leg
107	20+32	Rib 138, OS, tribar w/ broken leg
		Note: 0 deg is straight through centerline of head, end of crest is sta 20+45
108		Head, 70 deg, OS, dolosse w/ shank-fluke break at waterline
109		Head, 25 deg, HS, dolosse w/ shank crack
110		Head, 25 deg, HS, dolosse w/ shank break
		Head, 90 deg, HS, 4 tribars that are extremely abraded with coral growth. Appear to have been moved from below the waterline to the harbor side slope

(Sheet 4 of 4)

Figure D1. Sta 4+55, Corps of Engineers survey marker.

Figure D2. Damage location 1, sta 5+50, ocean side, dislodged armor stone at toe.

Figure D3. Damage location 2, sta 5+70, ocean side, void at hinge.

Figure D4. Damage location 3, sta 5+80, ocean side, void at toe.

Figure D5. Damage location 4, sta 5+85, ocean side, void on side slope.

Figure D6. Damage location 5, sta 6+28, cracked armor stone on crest.

Figure D7. Sta 6+40, survey marker.

Figure D8. Sta 7+02, stone on crest with 7+04 etched in it.

Figure D9. Damage location 8, sta 7+11, perched armor stone on crest.

Figure D10. Damage location 9, sta 7+58, settling of crest.

Figure D11. Damage location 10, sta 7+69, ocean side, bridging.

Figure D12. Damage location 11, sta 8+62, ocean side, perched armor stone with void.

Figure D13. Damage location 12, sta 8+92, ocean side, void.

Figure D14. Damage location 13, sta 9+20, harbor side, cracked armor stone at hinge.

Figure D15. Damage location 14, sta 9+20, ocean side, flipped armor stone and void.

Figure D16. Damage location 15, sta 9+38, harbor side, cracked armor stone at hinge.

Figure D17. Damage location 16, sta 9+67, ocean side, void at hinge.

Figure D18. Damage location 17, sta 9+87, ocean side, perched armor stone.

Figure D19. Damage location 18, sta 10+09, perched armor stone with void on crest.

Figure D20. Sta 10+21, survey marker.

Figure D21. Damage location 20, sta 10+40, void (depth to waterline) at centerline of crest.

Figure D22. Damage location 24, sta 10+91, ocean side, flipped armor stone, settling, bridging, void.

Figure D23. Damage location 25, sta 11+39, ocean side, depression/settling of crest, 5 ft x 4 ft void on crest.

Figure D24. Sta 12+00, rib cap begins (Note: Centerline to centerline of rib dimension = 6 ft).

Figure D25. Damage location 26, sta 12+06, ocean side, rib #2, dolosse with shank-fluke break.

Figure D26. Damage location 27, sta 12+24, ocean side, rib #5, dolosse with mid-shank break.

Figure D27. Damage location 28, sta 12+30, ocean side, rib #6, detached dolosse fluke tip, origin unknown.

Figure D28. Damage location 29, sta 12+36, ocean side, rib #7, dolosse with mid-shank and shank-fluke breaks.

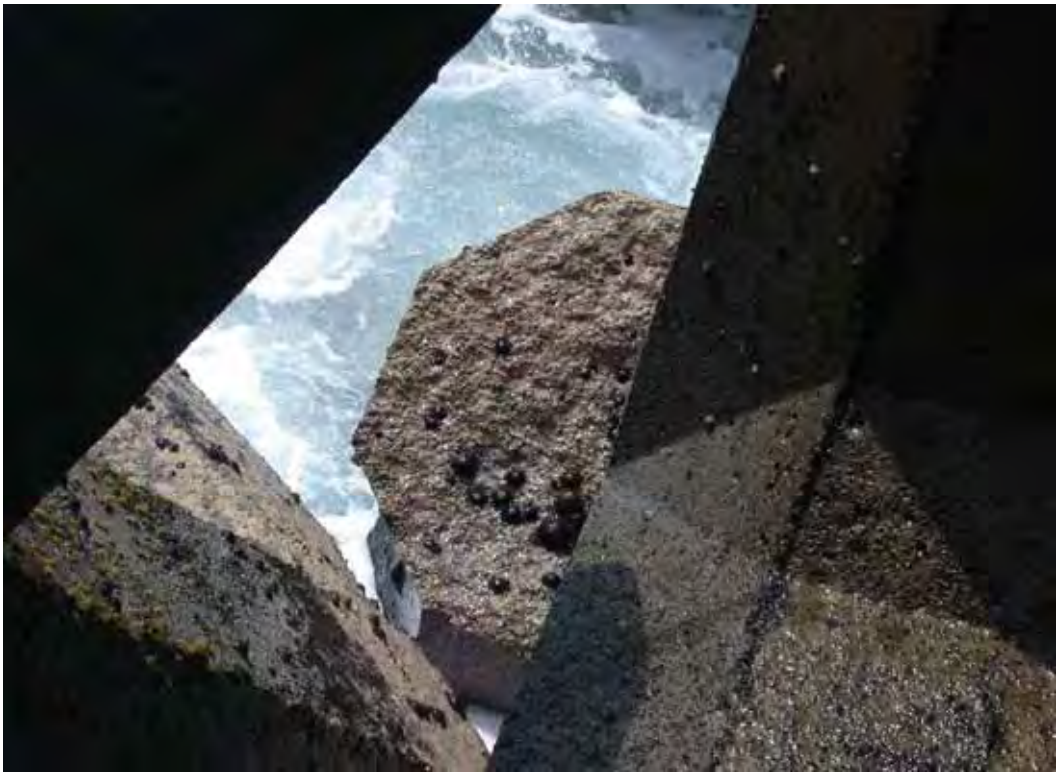

Figure D29. Damage location 31, sta 12+54, ocean side, rib #10, dolosse with multiple breaks at waterline.

Figure D30. Damage location 33, sta 12+72, ocean side, rib #13, dolosse with shank-fluke break at waterline, ocean side of target NA.

Figure D31. Damage location 34, sta 12+90, harbor side, rib #16, tribar with leg broken at center.

Figure D32. Damage location 37, sta 13+38 – 13+44, ocean side, rib #24 & 25, dolosse with fluke-shank break.

Figure D33. Damage location 38, sta 13+44 – 13+50, ocean side, rib #25 & 26, dolosse with mid-shank and fluke-shank breaks.

Figure D34. Damage location 39, sta 13+62, ocean side, rib #28, dolosse with fluke-shank break.

Figure D35. Damage location 40, sta 13+80, ocean side, rib #31, dolosse with shank-fluke break at waterline.

Figure D36. Damage location 41, sta 13+92 – 13+98, ocean side, rib #33 & 34, dolosse with fluke-shank break.

Figure D37. Damage location 43, sta 14+04, ocean side, rib #35, dolosse with mid-shank break.

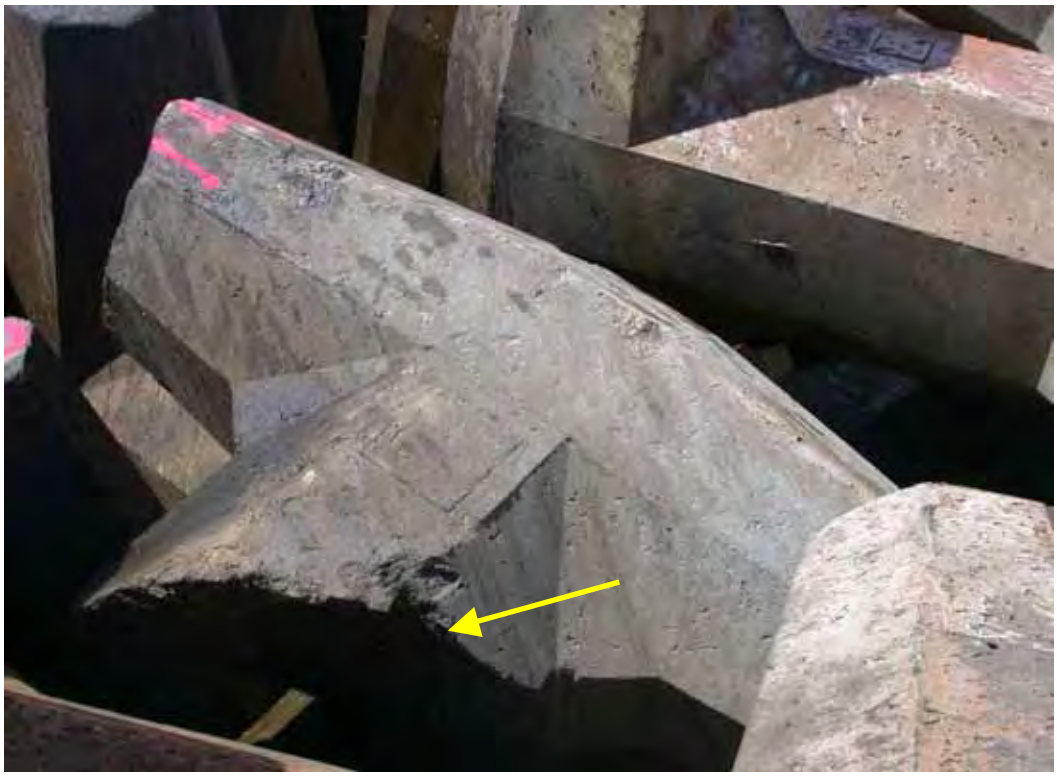

Figure D38. Damage location 44, sta 14+04, ocean side, rib #35, dolosse with mid-shank break.

Figure D39. Damage location 45, sta 14+52, ocean side, rib #43, dolosse with shank-fluke break.

Figure D40. Damage location 49, sta 14+88, ocean side, rib #49, dolosse with fluke-shank break.

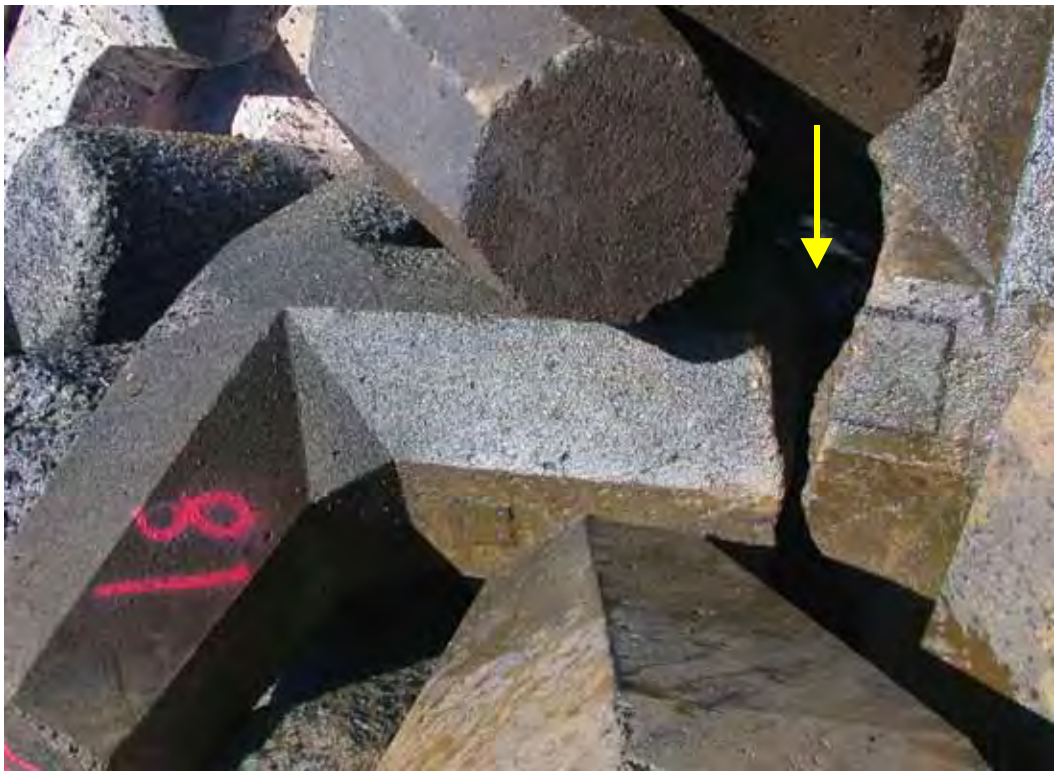

Figure D41. Damage location 50, sta 14+94, ocean side, rib #50, dolosse with shank-fluke break.

Figure D42. Damage location 51, sta 15+00, ocean side, rib #51, tribar with 3-way split.

Figure D43. Damage location 55, sta 15+60, ocean side, rib #61, tribar with 3-way break at center.

Figure D44. Damage locations 59 & 60, sta 15+96 – 16+02, ocean side, rib #67 & 68, two dolosse with mid-shank breaks.

Figure D45. Damage location 61, sta 16+02, ocean side, rib #68, dolosse with mid-shank break.

Figure D46. Damage location 63, sta 16+14, ocean side, rib #70, dolosse with fluke tip break.

Figure D47. Damage location 64, sta 16+14, ocean side, rib #70, tribar with broken can.

Figure D48. Damage location 64, sta 16+32, ocean side, rib #73, dolosse with fluke tip break.

Figure D49. Damage location 65, sta 16+50, ocean side, rib #76, tribar with broken leg.

Figure D50. Damage location 66, sta 16+68, ocean side, rib #79, tribar broken through center-no separation.

Figure D51. Damage location 67, sta 16+74, ocean side, rib #80, dolosse with shank-fluke break.

Figure D52. Damage location 68, sta 16+80, ocean side, rib #81, dolosse with shank-fluke break.

Figure D53. Damage location 69, sta 16+98, ocean side, rib #84, detached dolosse fluke tip, origin unknown.

Figure D54. Damage location 71, sta 17+22, ocean side, rib #88, dolosse with multiple breaks at waterline.

Figure D55. Damage location 73, sta 17+58, ocean side, rib #94, dolosse with shank-fluke break.

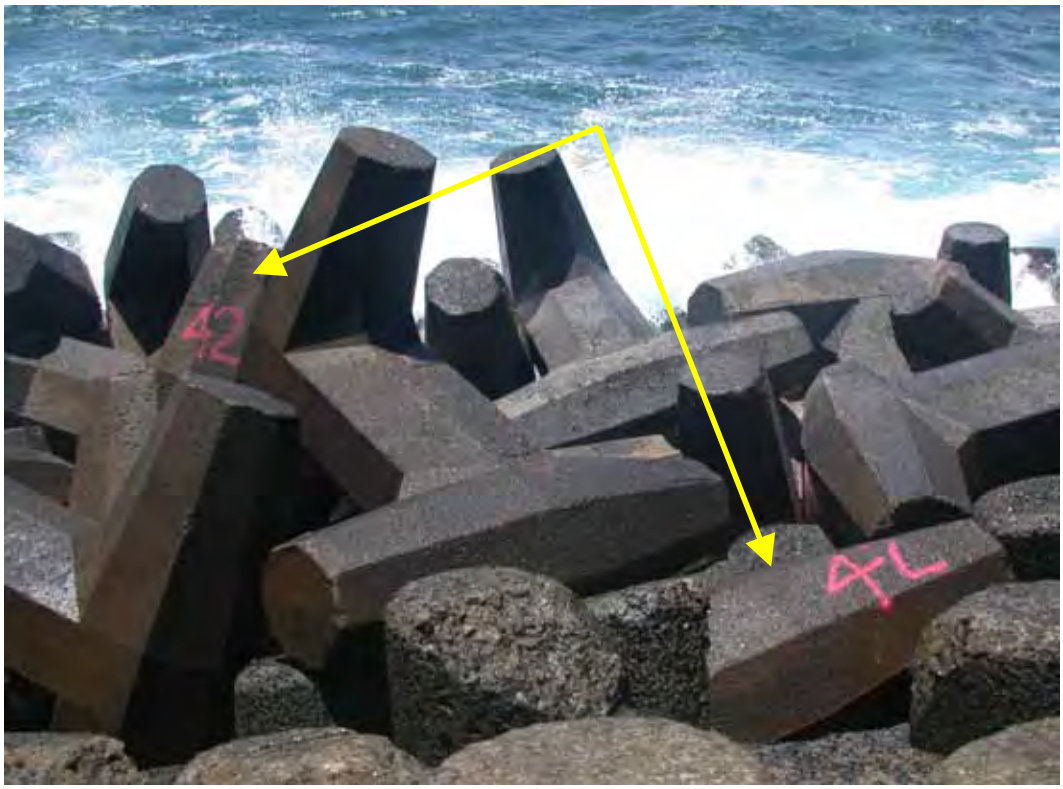

Figure D56. Damage location 74, sta 17+94, ocean side, rib #100, dolosse with broken fluke tip.

Figure D57. Damage location 75, sta 18+18, ocean side, rib #104, dolosse with shank break.

Figure D58. Damage location 76, sta 18+24, ocean side, rib #105, dolosse with fluke tip break.

Figure D59. Damage location 79, sta 18+54, ocean side, rib #110, dolosse with multiple breaks.

Figure D60. Damage location 81, sta 18+72, ocean side, rib #113, tribar with broken can.

Figure D61. Damage location 82, sta 18+84, ocean side, rib #115, tribar with broken can.

Figure D62. Damage location 83, sta 19+08, ocean side, rib #119, dolosse with shank-fluke break.

Figure D63. Damage location 84, sta 19+14, ocean side, rib #120, dolosse with shank-fluke break.

Figure D64. Damage location 85, sta 19+20, ocean side, rib #121, tribar broken through center.

Figure D65. Damage location 87, sta 19+42, ocean side, rib #123, dolosse with crack through fluke, still intact.

Figure D66. Damage location 88, sta 19+48, ocean side, rib #124, tribar with broken leg.

Figure D67. Damage location 89, sta 19+60, ocean side, rib #126, dolosse with shank-fluke crack, still intact.

Figure D68. Damage location 91, sta 19+66, ocean side, rib #127, dolosse with multiple breaks.

Figure D69. Damage location 93, sta 19+78, ocean side, rib #129, target dolosse cracked through fluke.

Figure D70. Damage location 94, sta 19+78, ocean side, rib #129, dolosse with mid-shank break.

Figure D71. Damage location 96, sta 19+90, ocean side, rib #131, dolosse with shank break.

Figure D72. Damage location 97, sta 19+96, ocean side, rib #132, dolosse with fluke-shank crack.

Figure D73. Damage location 99, sta 20+14, ocean side, rib #135, tribar with break through center.

Figure D74. Damage location 105, sta 20+26, ocean side, rib #137, dolosse with multiple breaks.

Figure D75. Damage location 106, sta 20+26, ocean side, rib #137, tribar with broken leg.

Figure D76. Damage location 107, sta 20+32, ocean side, rib #138, tribar with broken leg.

Figure D77. 0 deg is straight through centerline of head, end of crest is sta 20+45.

Figure D78. Damage location 108, 70 deg ocean side of head, dolosse with shank-fluke break at waterline.

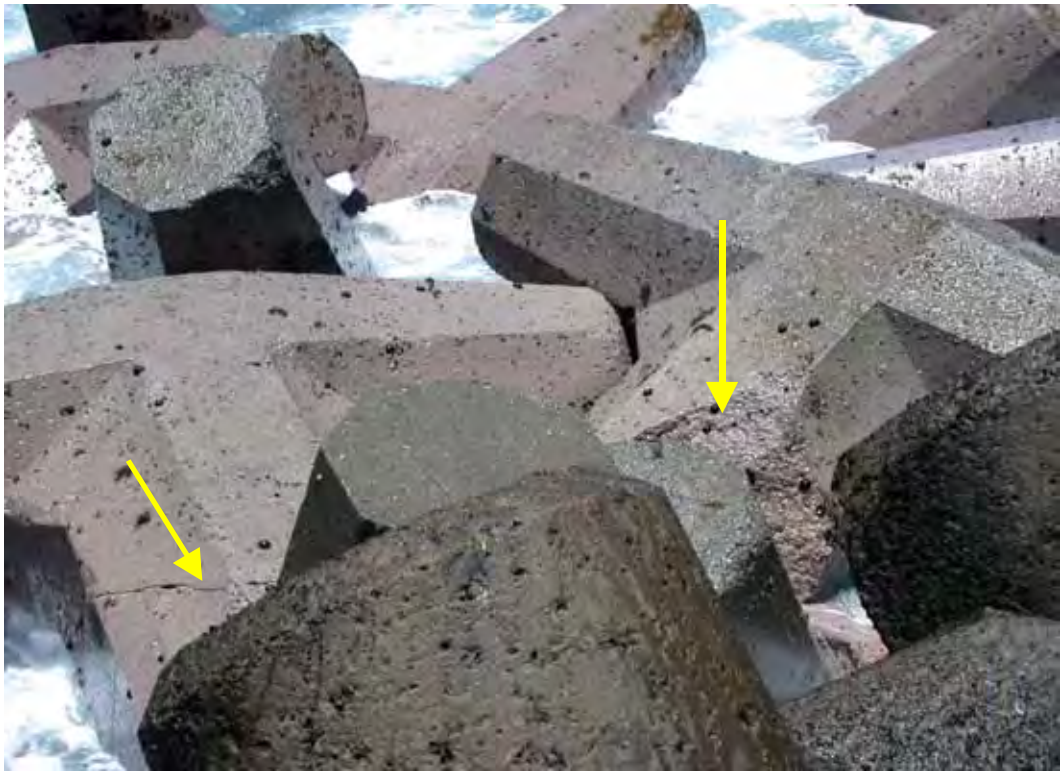

Figure D79. Damage locations 109 & 110, 25 deg harbor side of head, dolosse with shank crack and dolosse with shank break.

Figure D80. 90 deg harbor side of head, four tribars that are extremely abraded and have coral growth, appear to have been moved from below waterline to harbor side slope.

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14. ABSTRACT

As part of the Monitoring Completed Navigation Projects (MCNP) program "Periodic Inspections" Work Unit, five breakwaters from the Hawaiian Islands were inspected. The Hilo, Kahului East and West, Laupahoehoe, and Nawiliwili breakwaters were examined by walking inspection in the summer of 2005. Broken, cracked, and shifted concrete armor units and stones were recorded and overall performance of the structure was noted. Photographs were taken and detailed notes recorded at each damage site. Observations and assessments are included for each of the five breakwaters inspected.

15. SUBJECT TERMS

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Laupahoehoe
Nawiliwili
Rib cap

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