# CHAPTER 149

# DESIGN AND CONSTRUCTION OF PROTECTIVE STRUCTURE FOR NEW REEF RUNWAY HONOLULU INTERNATIONAL AIRPORT

by

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## ABSTRACT

This paper describes the design and construction of the protective structure for a new Reef Runway at the Honolulu International Airport with special emphasis on the use of dolosse concrete armor units.

## INTRODUCTION

A 12,000-foot long runway located parallel to and 6,700 feet south (seaward) of the existing 12,380-foot runway 8L-26R, which will permit increased capacity, noise abatement, and increased safety to downtown Honolulu and its suburbs, is nearing completion at the Honolulu International Airport as shown in Figure 1. The Reef Runway and associated taxiways are located on land created by over 19 million cubic yards of dredged coral placed on an existing reef. In order to protect the land fill from erosion by wave action, a 16,100 foot long protective structure has been built out of stone and 18,000 dolosse concrete armor units. The protective structure, which has a top elevation varying from plus 4.0 feet to plus 20.0 feet msl, is located approximately 1,000 feet south (seaward) from the centerline of the Reef Runway.

## DESIGN STUDIES

Initial hydraulic model studies were made under contract with the University of Hawaii Look Laboratory under the Department of Ocean Engineering (1). Extensive three-dimensional and two-dimensional hydraulic model studies were

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made to facilitate design of the protective structure. The three-dimensional model was used initially to obtain storm wave information at the protective structure location to be used in two-dimensional studies, and later to study tsunami waves for possible interaction effect between the proposed structure and the adjacent harbors and shore properties and to measure run-up on the protective structure. Computer refraction studies were made to provide input for the three-dimensional study. The major conclusion resulting from the model study and refraction study was that the water depth fronting the proposed structure determines the design wave, which is a breaking wave, the size of which is dependent on the water depth at the seaside toe of the structure and bottom slope. The water depth on the reef along the protective structure varies from slightly below zero elevation msl at the shallow end to as much as 27 feet below zero msl at the deep end. A still water level of plus 3.0 feet msl was adopted for design resulting in design breaking waves of over 25 feet in part of the deep water section. The shallow water section of the structure is protected by a fringing coral reef that varies in width from 400 to over 2000 feet.

The two-dimensional study by Look Laboratory was completed to develope design criteria for overtopped and non-overtopped sections subjected to breaking waves. Armor units tested consisted of quarry stone and tribars. Subsequent to complation of the above mentioned initial studies, Tetra Tech, Inc., of Pasadena, California, was engaged to design the protective structure (2,3). Additional two-dimensional hydraulic model studies were made to develope overtopped and non-overtopped structure sections subjected to breaking waves. Quarry stone and dolosse armor units were tested. In addition to conventional side slopes, a seaside berm section was tested. Design parameters were adopted for use in design of the structure based on the above mentioned testing plus information available from previous studies by the U. S. Army Corps of Engineers (4), and the Port of East London, South Africa (5,6). For the dolos the stability factor, $K_D$, as used in the Hudson formula, was based on a certain percent damage, namely 2% and 4%, resulting in $K_D$ factors of 32 and 64, respectively, for the two conditions. This was considered acceptable in view of the infrequent occurrence of design storms. A layer coefficient $K_\Delta$, of 1.3 was used resulting in a requirement for 75 4-ton dolosse for each 1,000 square feet of area covered and 55 6-ton dolosse for each 1,000 square feet. The design as completed for advertising included five alternates for the seasied armor for the westerly 4,650 lineal feet of the deep water portion of the structure. The five alternates were as follows: 4 and 6-ton dolosse; a combination of stone and 4 and 6-ton dolosse; 8, 12, and 24-ton tribars; a combination of stone and 12 and 24-ton tribars; and all stone with a seaside berm 200-feet wide with top elevation at minus 12 feet msl. The low bidder, Hawaiian Dredging and Construction Conpany, chose the dolosse alternate. For the shallow water reach the section consisted of ledge coral protected on the seaside by 2 layers of basalt armor stone with sizes varying from 250 lb nominal size at the shallowest end to 3000 lb in the deeper water. For the deep water portion of the structure, the first 1,650 lineal feet consisted of quarry run core stone with 2 layers of basalt underlayer stone protected by 2 layers of 5-ton armor stone, with the westerly 4,650 lineal feet protected by 4 or 6-ton dolosse armor. On the land side armor stone varied from 1300 lb to 8-ton size at the head section, with the majority of the land side armor stone being 5-ton size.

Figure 2 shows the typical non-overtopped section of the deep water portion of the structure on coral foundation with dolosse armor. The structure has a 15-foot top width, with 1 vertical to 1.5 horizontal side slopes on both sides except for the head section where the slopes are 1 vertical to 2.25 horozontal. Two layers of 2000 lb underlayer stone were used underneath the 4-ton dolosse while 2 layers of 3000 lb underlayer stone were used underneath the 6-ton dolosse. The land side apron shown on figure 3 was used in 3 reaches where overtopping during design storms is expected. The seaside foundation stone blanket shown was not included in the original contract but was added after construction was started when substantial areas of sand, with depths as much as 14-feet, were discovered in the foundation as a result of an underwater survey using a jet probe. Six reaches required the protective stone blanket under the dolosse armor with a total length of 870 lineal feet.

## QUARRY OPERATIONS

Over 800,000 tons of stone was required for the core, underlayer, and armor of the protective structure. Twelve different sizes of stone were specified for use varying from quarry run core stone to 8-ton armor. The majority of the stone, 88%, was obtained from a quarry on the Island of Molokai, a distance of about 60 miles from the project location. The remainder of the stone was obtained from the Island of Oahu, including 51% of the 5-ton armor stone. The quarry at Molokai included andesite and basalt with the latter being the most predominant type of stone present. Investigations at the quarry were accomplished by percussion drilling only, no cores were obtained, thus very little was known of spacing of natural fractures in the formation. As it turned out the majority of the area opened up had quite closely spaced fractures, both vertically and horizontally, thus only a small percentage of the large size stone could be produced from any one blast.

In addition there were numerous areas where cinders and residual soil were encountered which resulted in the handling of a large quantity of waste material to permit recovery of acceptable stone. The specifications for the quarry run core stone permitted not more than 10% smaller than 4-inch size and required at least 10% exceeding 18-inch size. Because of the high percentage of small spalls and residual soil present, it was necessary to install a screening plant to scalp the core stone in order to meet the 10% maximum minus 4-inch requirement. Figure 4 is a view of the screening plant; after the large stone was picked from each blast, the quarry run material was hauled from the quarry floor to the top of bank and dumped into the hopper at the screening plant where the excess objectionable fines were removed.

Hauling of stone from the quarry to the wharf at Kaunakakai, Molokai, was done with 5 semi-trailer trucks, each carrying 2 20-ton steel containers which were picked up and dumped into barges by a crane. Figure 5 shows one of the trucks with the steel containers, while figure 6 shows the crane dumping one of the containers into a barge at the wharf. Five and six barges were generally used in the haul from Molokai to the project site with capacities varying from 600 to 1800 tons of stone per trip. The two smaller barges with 600 ton capacity were bottom dump barges used in hauling core stone for the deep portion of the structure.

## CASTING OF DOLOS ARMOR UNITS

Casting of 6-ton dolos was started during October 1973. There were a total of 29 forms available. Forms for the 4-ton dolos were available in January 1974, from that time the normal daily casting included 80 4-ton and 29 6-ton dolosse. Special steel hinged forms were fabricated in Portland, Oregon, for the project. Figure 7 shows part of a row of forms with the traveling conveyor depositing concrete into one of the forms. Figure 8 shows a form opened for cleaning after removal of the dolos cast the previous day. Consolidation of the concrete was accomplished by the use of a form vibrator located under the horizontal section of the dolos form, as well as by the use of a cylindrical hand held vibrator which was inserted from the top of the vertical leg. The forms were filled each day with crews reporting on an early shift to remove form bolts and open the forms so that a fork lift could remove the dolosse cast the previous day and place them in storage where membrane curing compound was sprayed on the concrete. Forms were immediately cleaned and re-oiled and closed so that filling could start again. Figure 9 shows a form opened with the dolos ready for removal. Figure 10 shows the fork-lift carrying the dolos to the storage area.

## CONSTRUCTION OF THE PROTECTIVE STRUCTURE

Construction was started at both ends. The bottom dump barges were used to dump core stone along the centerline at the west end with alignment provided by a laser beam. Also a floating crane was used to unload core and underlayer stone from non-dump barges at the deep end. At the east end ledge coral existed in a thin layer, 6 to 12 inches thick in the safety areas, where it was ripped by a D-9 tractor and loaded by drag line on trucks for hauling to the structure alignment. After the seaside slope was completed, a clamshell crane followed along and placed two layers of the size armor specified for the area involved. Armor stone which was off-loaded at a temporary wharf at the east end was hauled by truck and dumped on the adjacent work road on the landward side which is part of the safety area fill; the work road was keot at elevation plus 2 to 3 feet msl. A gradall and a crane were both used for placing the 250 and 550 lb stone; cranes only were used for the larger sizes of armor stone. At station 149+00, 6,400 feet from the west end of the structure, the transition to the deep section was started and core stone was trucked from the temporary wharf and end dumped to continue the work. Two layers of underlayer stone were placed by crane and another crane followed up after a short interval placing two layers of 5-ton armor stone. This continued for 1,750 lineal feet where the seaside armor changed to dolosse. Four-ton dolos were used for a total of 3,550 lineal feet, 13,692 were placed, while 6-ton dolos were used for a total of 1,100 lineal feet, including the head section, 4,317 were placed. The underlayer and back side armor for a major portion of the deep section of the structure was initially placed by one or two floating cranes, however, a great deal of work was required by cranes working on top of the structure. 7 to 9 feet below final crest, in straightening the sections to conform to plans. Batter boards were installed at regular intervals to assist the crane operators in placing the stone to line. Even with the use of batter boards it was noted that below the water surface a few feet the tendency was for the slope to steepen from 1 vertical to 1.5 horizontal specified since the natural angle of repose of the stone was steeper than the required slope. In order to check the seaside toe of the core, underlayer, and mark the toe for the dolosse, an offset centerline was established by divers on the sea bottom by anchored cables 25 or so feet seaward of the final structure toe. This facilitated locating the toe line for each item. Floats were placed for each toe line in turn which guided the crane operators in placing stone and dolosse.

## DOLOSSE PLACING

Placing of dolosse concrete armor units was started during October 1974. A Manitowac 3000 crane equipped with special steel tongs was used for handling the dolos. At first the dolosse were loaded by fork lift truck on flat bed semi-trailors and hauled along the work road to the location where needed. Six 4-ton dolosse were hauled per load while four 6-ton dolosse were hauled per load. Figure 11 shows a load of 4-ton dolosse which have been delivered to the unloading point with the crane ready to lift a dolos prior to placing in the structure. The placing rate averaged about 20 dolosse per hour. Later a small barge with a capacity to haul 70 4-ton dolosse was used as shown in figure 12, however, because of the time required to load the barge and tow it from the east end temporary wharf out to sea and around the west end of the structure to a location behind the structure, placing of dolosse was limited to 70 per day, or less when swells would not permit the small tow boats to operate in the open sea. The use of flat bed semi-trailer trucks was resumed for hauling dolosse from the storage area to the structure and placing continued intermittently until the project was completed. One crane worked ahead on preparation of underlayer stone to final line for the dolosse, however, it could not keep ahead of dolosse placement so that at times two cranes worked on underlayer, and when 100 feet or so was approved dolosse placement would resume. Figure 13 shows a crane placing dolos as well as a view from the sea side showing a portion of completed dolosse armor. Figure 14 is a view of completed dolosse from the back side prior to placement of back-up stone.

Breakage of dolosse during placing operations amounted to 1.4% of the unreinforced units handled. Although the design specified two layers of dolosse, the requirement to place 75 4-ton and 55 6-ton dolosse for each 1,000 square feet of area to be protected resulted in a three-layer cover. A large percentage of the breakage resulted from trying to fit the top layer of dolosse in place. Data resulting from studies by the Waterways Experiment Station, U. S. Army Corps of Engineers, completed subsequent to design of this project, indicate that a layer coefficient, $K_\Delta$, of 1.0 rather than 1.3 could be used to provide a two-layer cover without any loss of stability (7). Using this lower value would result in a requirement of 51 4-ton and 39 6-ton dolosse per 1,000 square feet of area protected, a considerable reduction from the number used on this project. This should be considered for future projects. Another interesting item on this project based on sections adopted where dolosse armor were used and unit prices for the stone and dolosse, is that protection by the 6-ton dolosse cost less than protection by the 4-ton dolosse, amounting to nearly $1500 less cost for each 1,000 square feet of area protected by the 6-ton dolosse, as compared with the 4-ton dolosse. This is important to consider when design contemplates accepting a percentage damage of dolosse armor. It could be less costly to design for no-damage with larger units than to accept damage of smaller units. Although the present structure was designed based on accepting 2% and 4% damage of the dolosse armor units, a calculation of the actual stability factors, $K_D$, along the structure based on actual depths of water at the seaward toe and slope of ocean bottom indicates that for a majority of the area stability factors fall well below the no-damage range as shown in the U. S. Army Corps of Engineers Shore Protection Manual (7). The Manual does recommend minimum slopes of 1 vertical to 2 horizontal for dolos armor until further test data is available*. However, the Reef Runway Protective Structure is designed for breaking waves throughout, thus there should be no question of adequacy of the present design where stability factors are below the values considered adequate for the no-damage condition.

## ACKNOWLEDGEMENT

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*Dr. Robert Whalin, Chief, Wave Dynamics Division, U. S. Army Waterways Experiment Station, Corps of Engineers, indicated during the conference that additional testing of dolosse armor units has indicated that slopes of 1 vertical to 1.5 horizontal are stable and the Shore Protection Manual will be revised accordingly.

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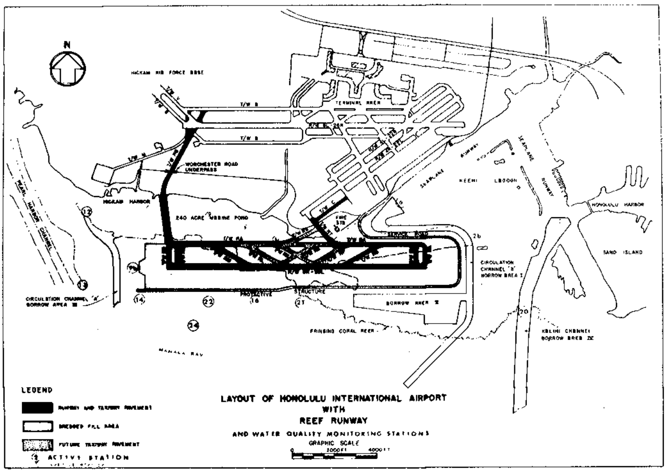

FIGURE 1 Layout of Honolulu International Airport with Reef Runway.

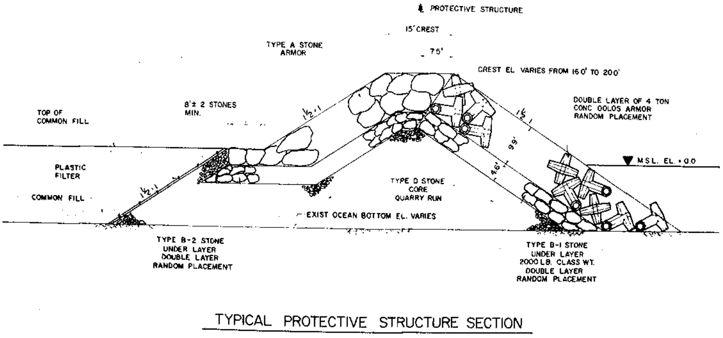

FIGURE 2 Non-overtopped Protective Structure Section.

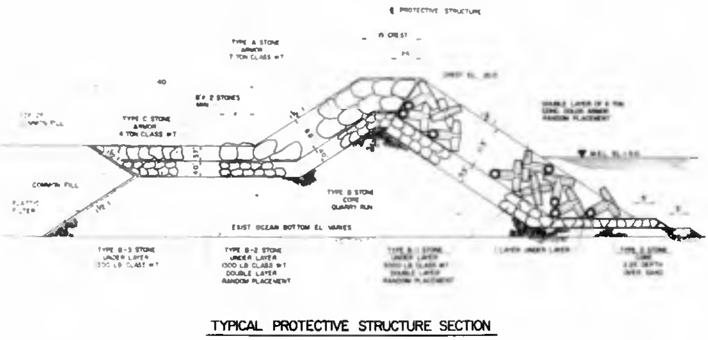

FIGURE 3 Over-topped Protective Structure Section.

FIGURE 4 Molokai Quarry - Screening Plant

FIGURE 5 Molokai Quarry - Stone Hauling Truck.

FIGURE 6 Kaunakakai, Molokai Wharf - Crane Loading Barge.

FIGURE 7 Casting Concrete Dolos

FIGURE 8 Dolos Form Open

FIGURE 9 Fork lift removing dolos from form

FIGURE 10 Fork lift placing dolos in storage yard

FIGURE 11 Dolosse on flat bed truck

FIGURE 12 Dolosse on barge

FIGURE 13 Crane placing dolos - Showing a view from ocean of completed dolosse armor.

FIGURE 14 View along backside of structure showing dolosse in place prior to placing back up armor stone.