CHAPTER 67

HAWAIIAN BEACHES

BY

Frans Gerritsen
Chairman and Professor of Ocean Engineering
University of Hawaii
Honolulu, Hawaii

ABSTRACT

Hawaii's beaches are of great economical and social value; they serve a variety of purposes and are valuable both to residents and tourists alike. Like in many other parts of the world, many of Hawaii's beaches are in a state of erosion and measures of improvement must be designed to cope with this problem. Although in the past several studies have been undertaken to evaluate Hawaii's beach systems and to analyze possible measures of improvement, this study aims at an in-depth analysis of the physical factors at work in the coastal zone. A thorough understanding of these processes, it is felt, is indispensable for the application of sound and economic measures in stabilizing and maintaining Hawaii's beaches. This paper describes some preliminary results of field studies conducted in Waikiki Beach. The latter beach was chosen because of the pressing need for improvements and because of its convenient location. In order to project this study against the proper background, a short review of the general characteristics of Hawaiian beaches precedes the results of the Waikiki Beach study.

INTRODUCTION

The study of beaches in Hawaii is not new. For many years the value of these beaches has been recognized and several studies have been undertaken to define their general characteristics or to specify measures of improvement.

A prime source of information on Hawaiian beach systems is the valuable work by Moberly and Chamberlain for the State of Hawaii (ref. 1). A treatise on Hawaiian beaches can also be found in the work of Shepard and Wanless, "Our Changing Coastlines" (ref. 2).

For an evaluation of proposed measurements of improvement of several Hawaiian beaches, technical reports by the U.S. Army Engineers, Honolulu District, give background data for those projects. Previous studies of Waikiki Beach are documented in House Document No. 104, 89th Congress, 1st Session, 1965 (ref.3).

What is then the need of and use for additional studies of Hawaiian beaches? As far as improvements of Hawaiian beaches are concerned, three important factors put serious restraints on what can and what cannot be done:

-- Adverse effects to surfing should be avoided, or at least severely reduced;

-- Suitable sand for artificial nourishment is very scarce; most of it has to be trucked in or transported from the other islands;

-- Adverse effects of artificial nourishment on reef life cannot be tolerated.

The restraints mentioned above severely limit engineering solutions for the areas that need improvement. In light of recent emphasis on environmental protection, those restraints have to be considered very seriously so that more advanced and sophisticated measures have to be considered in future planning. This in turn requires a greater and more fundamental knowledge of the processes at work in the coastal zone. To provide the information that is needed for the above mentioned approach, the present beach studies at the University of Hawaii are being undertaken as part of its Sea Grant program. In order to allow a more in-depth analysis, a limited number of beach sites have been selected. These sites include Waikiki Beach, Waimanalo Beach and Haleiwa Beach on the Island of Oahu and Kaimu Beach, the black sand beach mentioned before, on the Island of Hawaii. The different beaches on Oahu are with different wave exposures; the beach at Haleiwa forms part of a hydraulic model study for Haleiwa Harbor conducted for the State of Hawaii.

CHARACTERISTICS OF HAWAIIAN BEACHES

Along most mainland beaches the littoral drift, parallel to the shoreline, plays a dominant role in the nourishment and preservation of beaches. In most Hawaiian beach systems the main transport of beach sand takes place in littoral cells, in which the transport perpendicular to the shoreline plays an essential role.

Many beaches are characterized by offshore reefs, which serve as a protection of the coastline against the attack of high waves and tsunamis. At the same time the reefs serve as an important source of (calcareous) beach sand. Chave, Smith and Roy (as reported in ref. 4) estimate that the gross production of calcium carbonate by reef communities averages between 100 and 500 tons per acre per year. This production is used for the building and maintenance of both the reef and the nearby beaches.

In many beach areas sand channels may be observed through the reef flats; these channels may serve as supply channels to nourish the beaches or they may act as rip-channels, carrying water and sand in offshore direction into deep water where extensive sand deposits may be formed. Usually these deposits of sediments consist of material finer than the beach sand (ref. 1).

Because of their important function in protecting Hawaii's shoreline, the preservation of Hawaiian reefs is a matter of great concern. Although not all damages to reefs are man-made, the interference of man with the natural environment is a major cause for this development.

The continental shelf in Hawaii is very narrow, almost non-existent. In most areas deep water is close to the shoreline. Where the protective reef does not exist, wave attack to the shoreline is very severe. An example of such heavy wave attack was experienced during the first few days of December 1969, when a severe North Pacific swell hit the north shore of Oahu causing severe damage to coastal lands and property.

Sources of Beach Sand

Sand from the Hawaiian beaches come from different sources. The most important are:

-- coastal streams and rivers
-- coastal erosion (e.g. weathering of beach rock)
-- destruction of reef by wave action
-- from organic matter by biochemical action
-- volcanic action

In Hawaii the unique situation exists that geologic activity in the form of volcanic action is still a source of both land formation and production of beach sand. This activity is concentrated on the Island of Hawaii where active volcanoes sometimes pour lava into the ocean, which is a source for the black sand beaches.

Apart from the latter, most other beaches on the islands are of composite nature; the beach sand is composed of two general types of sand mixed together in proportions that vary from place to place; the light colored calcareous grains and the darker colored silicate grains of volcanic origin (ref. 1). The calcareous sands are mostly composed of the remains of organisms that lived in the sea. Foraminifera predominate in most beaches and appear to be useful as natural tracers in the study of the beach processes. By staining the foraminifera with Rose Bengal dye it can be determined whether or not they have living protoplasm. Coral fragments usually constitute only a minor portion of the calcareous beach sands. Quartz is absent from most Hawaiian beaches; it is found in a few areas only. Most island beaches have sand of medium grain-size (0.2 - 0.6 mm). The windward beaches have usually a smaller grain-size than the leeward beaches. Courser sand is also formed on the exposed north and west coasts.

The Hawaiian Wave Climate

The natural characteristics and behavior of various Hawaiian beaches is closely associated with wave climate and exposure. The following general types of wave conditions can be recognized:

1. Northeast trade waves - generated by the northeasterly tradewinds that prevail 75-80 percent of the year.

2. Southern swell - generated by storms in the southern hemisphere. These waves have travelled over long distances, are usually of long (14-22 sec) period and low (1-4 ft) height. Time of occurrence is from April through October.

3. Kona storms - generated by local storms of extra tropical nature. They usually occur during the winter months.

4. North Pacific swell - generated by low pressure areas on the North Pacific and arriving at the Hawaiian Islands as swell. These waves create unique surfing conditions on the north and northwest coasts and are sometimes of destructive nature.

5. Hurricane waves - generated by tropical storms that travel in the vicinity of the Islands.

Whereas the wave conditions mentioned under 1-5 occur regularly in the Hawaiian waters, hurricane waves occur only with a low frequency.

Although of less serious nature than on the U.S. mainland, hurricanes do occur and their effect should be taken into consideration, in particular when the design of coastal structures is concerned. In the latter case hurricane waves may very well produce the most critical design conditions.

A special cause of change and of destruction in Hawaii are tsunamis. Examples of destruction are the heavy damages in Hilo on the Big Island during the 1946 and 1960 tsunamis. Under certain conditions the tsunami wave assumes the characteristics of a bore; the latter type is particularly destructive.

Differences in wave exposure cause beaches on opposite sides of the Islands to have different characteristics. On the windward side of the Island of Oahu, for example, a fringing reef is present along most of the shoreline. After breaking and regeneration waves arrive at the beach with reduced height and period. The beach at Waimanalo along the southeast side of the island is an example of this type of beach. It is one of the most beautiful beaches on the islands (fig. 1).

Waikiki Beach (fig. 2) is on the leeward side; waves that affect this beach are turned shoreward by refraction. Direct wave attack on this beach only occurs occasionally, e.g. during Kona storms or with a southern swell.

Wave action on the beach in Waikiki is generally mild, offering good opportunities for safe swimming. Because of the long and relatively low swell, surfing conditions in the Waikiki area are usually good, both for the experienced surfer and the beginner.

On the north shore the fringing reef is either small or non-existent. Wave attack on this coastal part is very heavy during high waves during the North Pacific swell. Surfing conditions are excellent but only for the experienced surfer.

Figure 1

Waimanalo Beach
Southeast Coast, Oahu

Figure 2

Waikiki Beach, Honolulu

Figure 3

Island of Hawaii

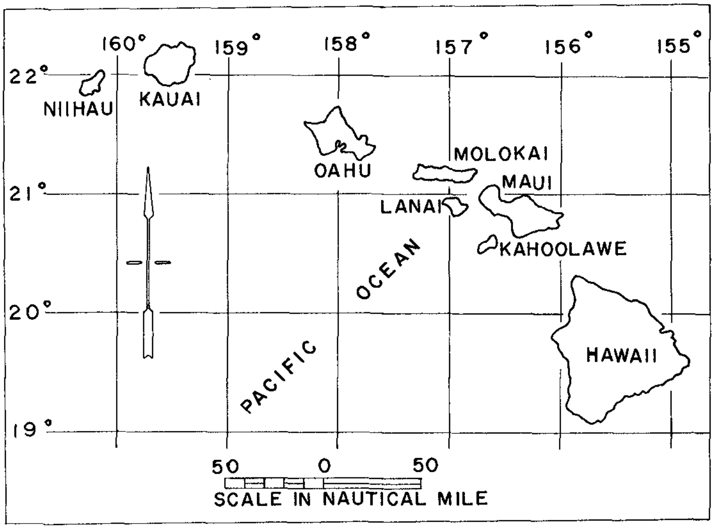

Figure 4 Hawaiian Islands

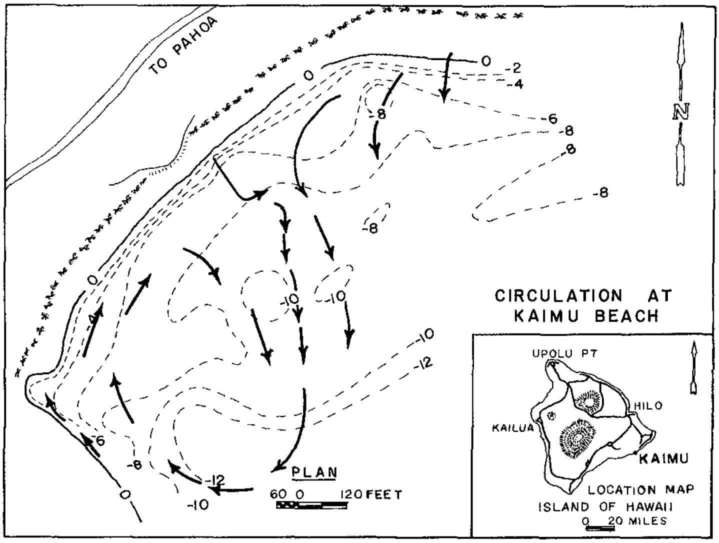

Figure 5 Current Pattern at Kaimu Beach

The scope of this paper does not allow to mention general characteristics of all neighbor island beaches. Figure 4 shows the situation of the major islands in the Hawaiian archipelago. We will mention Kaimu Beach, however, the well known black sand beach on the Island of Hawaii situated on the southeast coast of this island. Figure 3 shows a picture of this characteristic beach that is subject to serious erosion. The developing of this erosion is due, at least partly, to a lowering of the sea floor associated with a local earthquake in 1868 so that the beach became more exposed to the windward trade waves. The current circulation in the bay off Kaimu Beach, as observed on April 7, 1972 is shown in Figure 5.

The Corps of Engineers is presently studying measures to stabilize this beach. One of the solutions under consideration is the construction of a low dam across the bay, which project has met with serious resistance from various groups, because of its doubtful effectiveness and its adverse effect on the coastal environment.

DEVELOPMENT OF WAIKIKI BEACH

The site of Waikiki Beach has undergone drastic changes during the last decade, a process that is continuing today. Started as a very rural area with fishponds and insignificant beaches, its proximity to Honolulu and the ideal swimming and surfing conditions have developed it the way it did. Most of the sand in the Waikiki Beach area is brought in artificially during the various improvements that have been carried out over the years. The last improvement project, which is portion of works of larger scope presently being developed, has just been terminated; it involved artificial nourishment of a section, known as Kuhio Beach, during which about 250,000 cubic yards of sand was trucked in and deposited on the beach. The project also included some minor groin construction and a realignment of the seawall with extensive landscaping and beautification. Over the years, sand that was deposited on the beach in Waikiki has gradually moved away from the beach and deposited on the relatively shallow offshore reefs. Although the losses do not amount to great quantities, the gradual process requires a systematic nourishment of the beach areas. Whether or not the deposition of sand on the reef flats is the cause for the dying of the living reef in this area is not certain; although some reef life can be found, most of it is dead at the present time.

METHOD OF APPROACH

For each selected site a program of field observations is scheduled in which the dominant physical parameters are measured either continuously or intermittently and the behavior of the beach is analyzed by measuring of beach profiles. As many littoral variables as possible are being measured and evaluated. The success of a study, based on field observations, is highly dependent on the quality and accuracy of the data collected. For this reason suitable instrumentation is a first order of concern and much emphasis is therefore placed on obtaining and installing adequate instrumentation.

The following types of observation are being undertaken:

1. measurements of offshore wave conditions (wave height and period) with in situ wave recorders in depth of approximately 50 feet.

2. measurement of wave direction by aerial photography.

3. measurement of wave conditions on reef flat by means of self-supported capacitance wave gages.

4. measurement of currents by means of current meters, dye and drogue measurements.

5. water level recorders for measurement of vertical tide.

6. measurement of sand transport by means of sand traps and flourescent tracers.

Wave conditions and currents are basic parameters that affect the movement of sand in a beach area. It is not sufficient to characterize the wave climate offshore, but it is essential in Hawaii to evaluate energy losses over the reef and the change in wave characteristics. Often the larger waves break in deeper water, and the larger period waves break down in components of smaller period. The latter represents the effective energy available for the littoral processes in the nearshore region.

Wave Conditions and Measurements

Wave data available at present as support for the present studies include the following information:

1. a study by "Marine Advisors" regarding the wave conditions around the Islands. The results of this study of about one year came partly from hindcasting, partly from observations (ref. 1).

2. staff gage readings in the Waikiki area by the U.S. Army Corps of Engineers (about one year).

3. measurements with two bottom mounted self-recording pressure wave gages in 50 feet of water off Waikiki Beach.

4. wave measurements by pressure transducer at 36 feet depth near the entrance of Kewalo Basin, a small craft harbor west of Waikiki Beach (continuous, over about one year).

5. computations on significant wave height and period associated with a number of storms by the U.S. Army Corps of Engineers.

In order to evaluate the frequency of occurrence of waves of a given height on the leeward coast south of Honolulu, the data mentioned under 1, 4 and 5 have been used to construct a frequency diagram. Various ways of constructing such diagram have been evaluated; the form that seems most promising is presented in fig. 6. The offshore waves (representing conditions at 30-40 ft. depth) have a frequency distribution that is built up from two different categories of waves: the distribution of wave height according to daily observations, measured near the entrance to Kewalo Basin (4), and the distribution of waves obtained from hindcasting during a number of storms (5).

The data available for storm waves is of limited scope and does not allow a further breakdown as to wave period and distribution, so that a refraction and shoaling coefficient can be applied. A practical approach is to use an average value for refraction and shoaling to obtain nearshore conditions from deep water values.

The available data suggest that for Mamala Bay (fig. 6a) a combined frequency diagram, representing all conditions can best be obtained by two different lines, intersecting each other on the diagram: a steep line, representing the storm wave conditions and a more gently sloping line, representing the ordinary daily observations. The part of the frequency diagram that is to be used depends on the purpose of the analysis. When a design wave for a structure is needed, the steeper portion will have to be used; for workability and possibly littoral drift phenomena the more gentle sloping portion of the frequency diagram may be the most interesting part. A similar analysis was made for the west shore of the Island of Oahu regarding wave conditions prevailing near Pokai Bay, whereby the same distinction was made between daily wave conditions and storm waves (fig. 6b). For this area the two groups merge into one working line on the frequency diagram.

The next problem is to define the frequency distribution for shallow water (above the reef) given the conditions at 30-50 ft. depth. Under the assumption that the frequency diagrams for offshore conditions represent the significant wave height, the significant wave height for shallow water may be derived utilizing an assumed wave height distribution and a breaking criterion.

Using a Rayleigh distribution for the wave height and a simple breaking criterion: $H_b = \alpha h_b$ for the maximum wave height H_b, in which h_b represents the water depth; the significant wave heights for shallow water can be obtained by constructing diagrams of the form of fig. 6. The latter figure presents the significant shallow water wave height for various depths, given an offshore wave height of 17.5 ft. In this manner frequency distributions for shallow water can be constructed as shown in fig. 6a.

It is of interest to compare the results of this type of analysis with the North Sea investigation as reported by Paape (1969) (ref. 5). Paape reported a ratio between maximum breaking wave height and significant breaking wave of 1.5. Using an average value $\alpha = 0.78$ (from solitary wave theory) this ratio becomes about 1.34 for 30 ft., 1.04 for 20 ft. and 1.0 for 10 ft. depth.

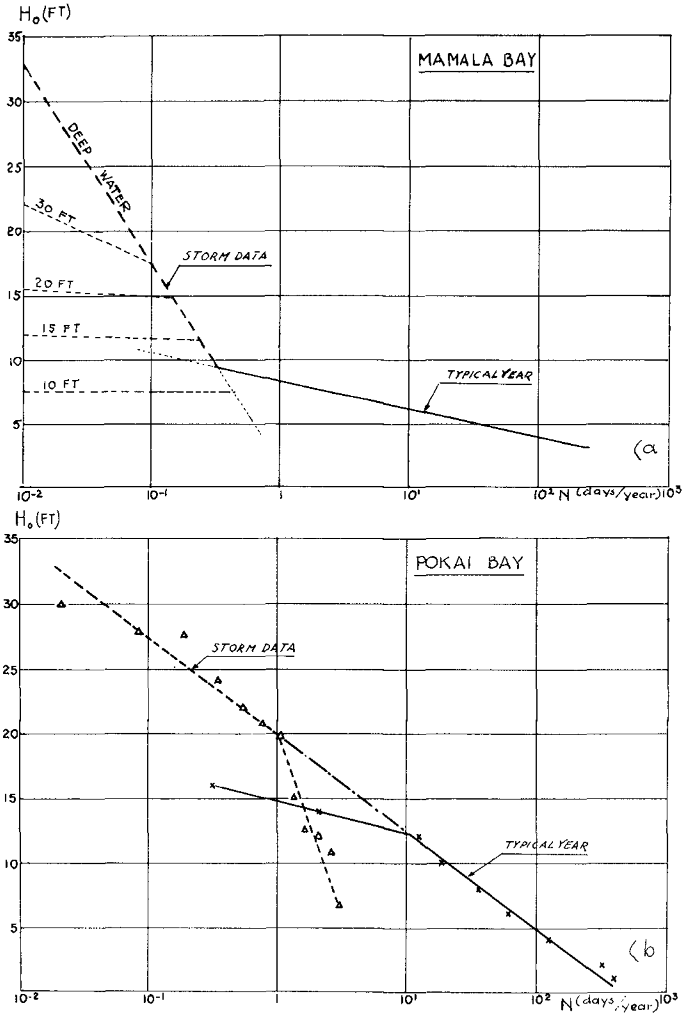

Figure 6

Frequency Diagrams for Offshore and Nearshore Waves

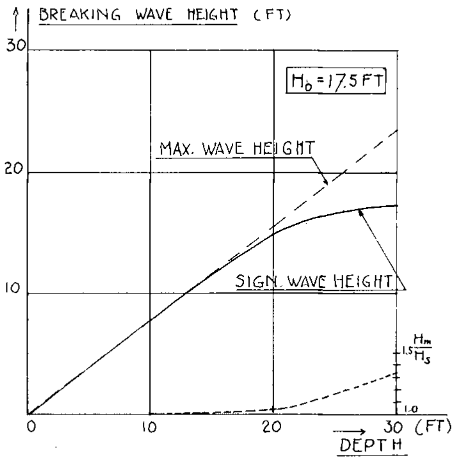

Figure 7

Significant Breaking Wave Height Versus Depth for Given Deep Water Wave Characteristics

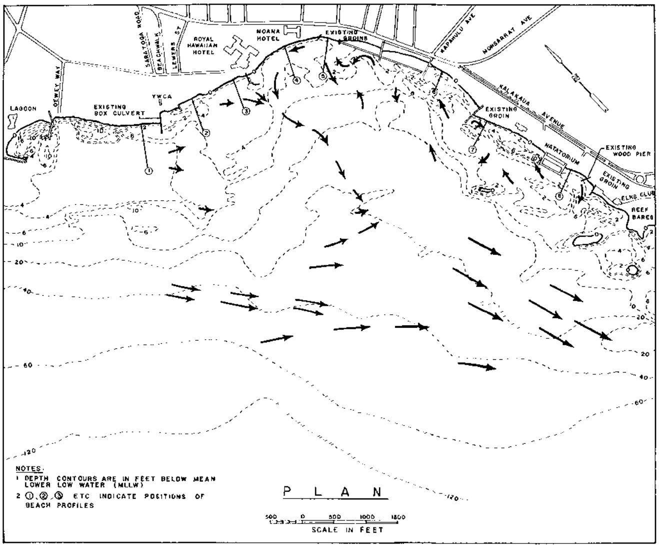

Figure 8

Waikiki Beach, Depth Contours and Circulation Pattern

Figure 9 Aerial Photograph Waikiki Beach, Showing Refraction of Waves

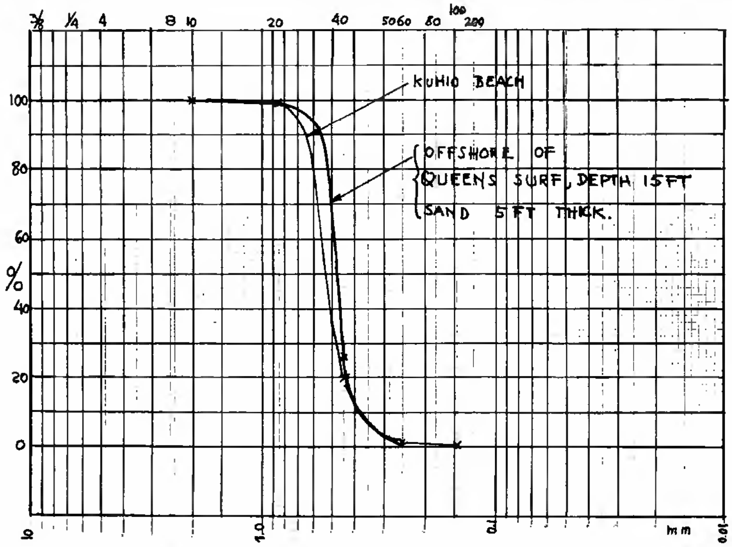

Figure 10 Sediment Characteristics for Beach and Offshore Sand at Waikiki

Realizing that for individual waves α may be larger than 0.78 and that the average depths at the measuring stations of the North Sea most likely is over 30 ft., the results suggest general agreement and therefore support the type of analysis suggested here.

Flow Measurements at Waikiki Beach

Transport of beach materials takes place under the combined action of waves and currents (Byker, ref. 6). In order to establish prevailing transport patterns, it was felt necessary to obtain a clear understanding of the prevailing current circulation. In cooperation with Dr. R. Tait of the Department of Oceanography who is involved in an analysis of environmental conditions in the Waikiki Beach area for the U.S. Army Corps of Engineers, an extensive program of current measurements was undertaken. The current measurements were taken during flood and ebb conditions both close to the shoreline and on the reef flats and in the reef channels. The methods included aerial observation of the movements of dye patches, triangulation of drogues and following of dye patches by small boats.

Without going into details, a number of preliminary conclusions came forward from the studies that have been conducted so far. Further analysis is necessary to clarify some uncertainties encountered.

Current patterns could be clearly distinguished into three groups:

1. currents associated with the tidal flow off the coast.

2. currents associated with the pattern of breaking waves (longshore currents).

3. rip currents, associated with the breaking of the (larger) waves. Where the tidal and longshore currents had principle directions parallel to the shoreline, the rip currents have directions perpendicular to the shoreline.

Regarding the nature of the above mentioned current types, the observations show the following characteristics:

Tidal Currents

Offshore currents beyond the reefs in this area are predominantly of tidal nature with reversing components parallel to the coastline. On the reefs the currents are considerably smaller than in deep water; their maximum values are of the order of 0.1-0.2 m/sec.

Flow measurements on the offshore reef areas show that in the eastern part of the study area the currents are persistently in easterly direction, both during flood and ebb periods, suggesting the existence of a large eddy during predominantly westerly flow in deep water.

In the western part of the study area currents of varying strength and direction were observed. The nature of these variations is not completely understood at this time and needs further investigation. The general circulation is shown in fig. 8.

Longshore Currents

The direction of the longshore currents inside the breaker zone and close to the beach is consistent with direction of breaking waves near the beach. They are usually small (of the order of 0.05 m/sec.) which is in agreement with the usually low wave heights near the beach. They do not reverse with the tide, but they may have a component perpendicular to the beach in the vicinity of a groin or other coastal structure. These currents are responsible for the longshore and transport, which has a predominant westerly direction eastward of the Royal Hawaiian Hotel (fig. 8). Reference is also made to fig. 9, showing the pattern of breaking waves in the Waikiki Beach offshore area.

Rip Currents

During conditions of heavy southerly swell a large rip was observed off the Royal Hawaiian Hotel, and a smaller (and shorter) rip west of the Kapahulu groin off the offshore breakwater.

Recent theoretical studies on rip currents (ref. 7, 8) indicate that the occurrence of rip currents can be associated with the phenomenon of edge waves. The latter are long period, low amplitude waves that travel in a direction parallel to the shoreline. They may be progressive waves or standing waves.

The general topography of the offshore area at Waikiki Beach (Mamala Bay) suggests that standing edge waves of a certain type could be a contributing factor to the rip current pattern. Further studies will be required to clarify this matter.

Observations of Beach Profiles

In order to study the stability of the beach in the Waikiki area, profiles have been measured at regular time intervals. Where differences between successive measurements are minimum, the beach has its highest degree of stability. Differences in stability characteristics may be observed by comparing the profiles at Stations 4, 3 and 2 of fig. 8. The maximum and minimum profiles over a period of about one-half year are presented in fig. 11. Profile No. 4 which is situated in the zone of predominantly westerly drift, is relatively stable; Profiles No. 3 and 2 are situated westward of the prevailing rip and show a higher degree of instability. The offshore reefs are relatively flat; material is moved from the beaches onto the reefs where it fills holes and channels.

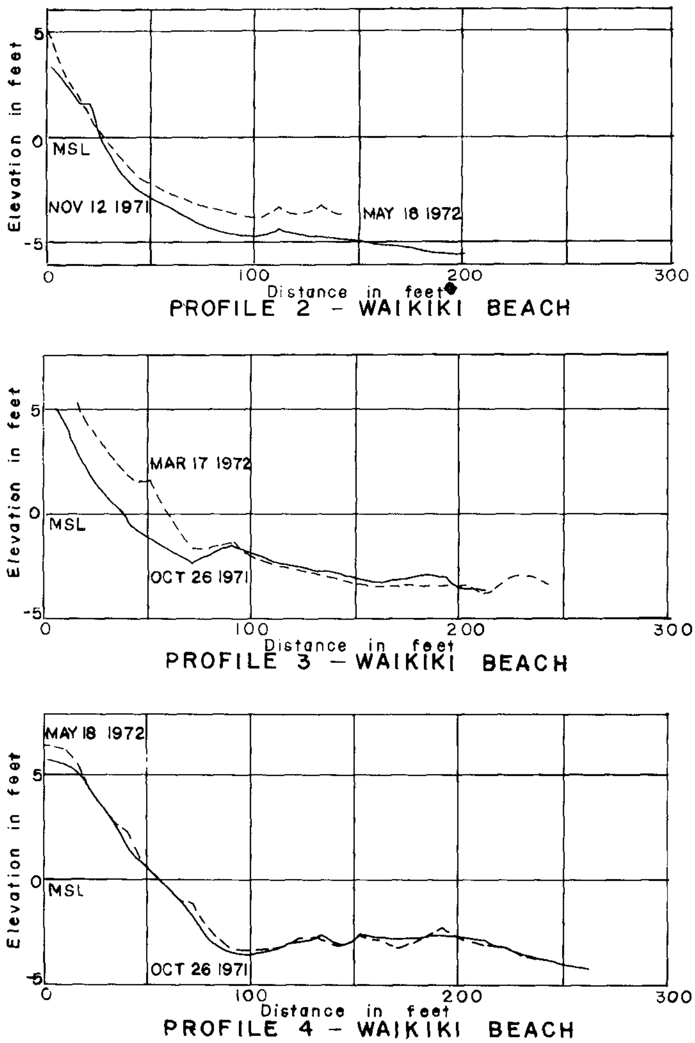

Figure 11

Characteristic Beach Profiles, Waikiki

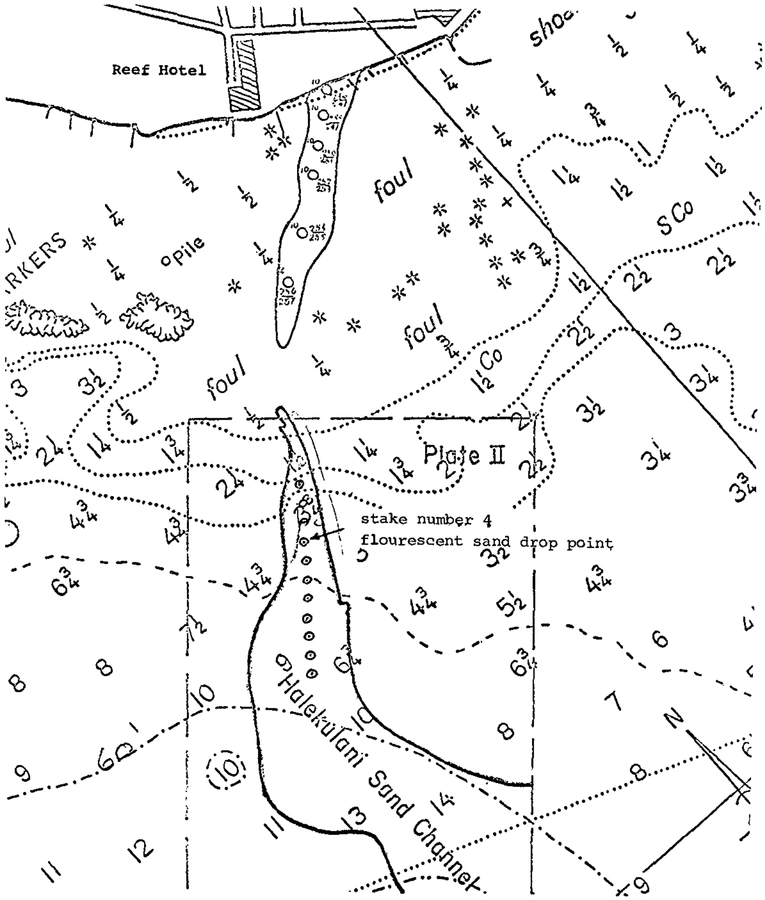

Figure 12

Stations for Measurement of Sand Transport in Halekulani Channel

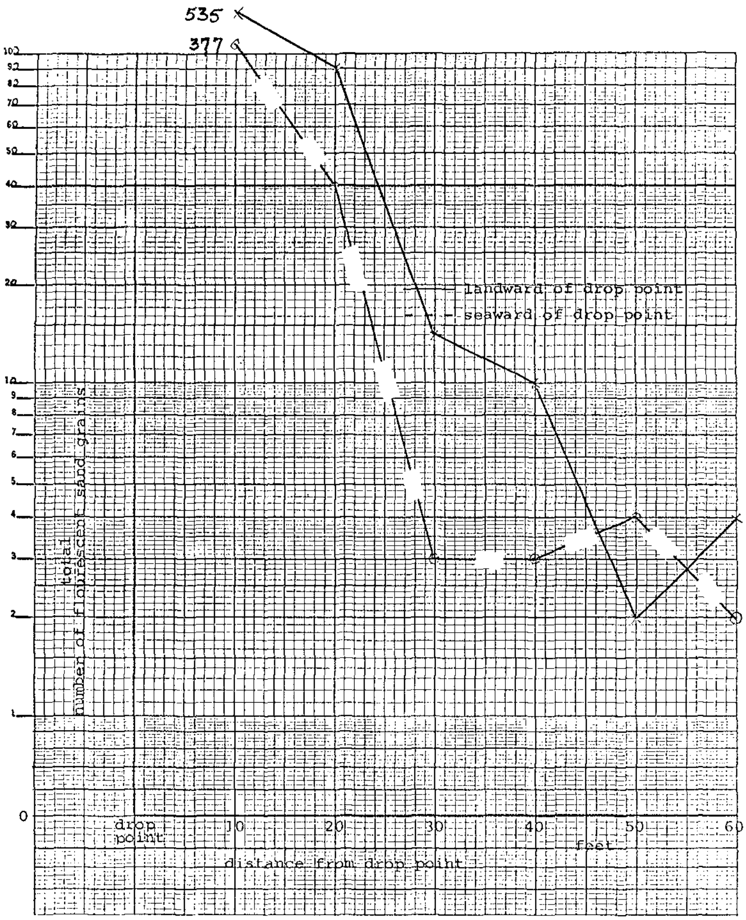

Figure 13

Tracer Counts for Transport of Sand in Halekulani Channel

It may be expected that the material found on the reefs will be of the same characteristics as the material on the beach. Analysis of beach and reef sand by Fred Casciano, as presented in fig. 10, confirms that beach and reef sand is basically of the same grain-size distribution characteristics.

Measurements of Material Transport

Both aerial photographs and bathymetric charts indicate the presence of two sand channels in the Waikiki Beach area, they appear to be the remnants of previous river mouths. The western most channel is called the Halekulani channel; it is located offshore of the Halekulani Hotel.

In earlier studies for the improvement of Waikiki Beach, it was felt that this channel could possibly function as a drain to the littoral drift, allowing sand to pass seaward from the beach.

To investigate this possibility a program of sand tracing was developed by Fred Casciano and David Kern (ref. 9). Stations in the Halekulani channel were marked by iron bars, 100 ft. apart, as indicated in fig. 12. Rhodamine B dye was used as tracer; sand from the channel was dried after which the grains were colored with the dye. An initial deposit of 362 lbs. of colored sand was made at Station 4 and observations were made to study the movement of the colored sand. On both sides of Station No. 4, a grid system of bars, 10 ft. apart was installed for detailed observations around Station No. 4. The observations consisted of the collection of surface samples by divers with the use of bottle caps, provided with a substance to let the surface grains stick to the cap. From January 23, 1970 two days after the fluorescent sand was deposited in the channel, to May 22, 1970, 13 sets of surface cap samples were taken, each on a different day. The time between successive sampling days ranged between two days in the beginning of the study and two weeks near the end. In addition to the collection of surface samples sand cores were taken at the end of the study period. At each station the number of colored grains was counted, using ultra-violet long wave light.

Assuming the number of grains counted in a surface sample to be a measure of the total sand movement the count at the stations on the seaward side and on the landward side of the deposition point indicates whether there is a resultant shoreward or landward movement of the bottom sand in the channel.

Figure 13 shows the total count at all stations in the channels. This result and the results of individual counts during each of the observations indicate a resultant sand transport in shoreward direction in the channel during the period of observation. The results of sand cores confirmed the results of the surface sampling.

An additional observation was made that gave further weight to the conclusion of resultant landward transport: at each station the height of the bar over the (average) bottom was measured during each observation. At the most landward station an increased elevation of the bottom of about 0.1 meter was observed; at the other stations, the elevation of the bottom did not change significantly.

One may ask whether the period of observation (4 months) is long enough to justify a general conclusion in the same direction. This question is partly answered by the results of the flow measurement. During the large southern swell, observed in March 1972, and also during other periods of observations no indications were found that the Halekulani channel was functioning as a rip channel; on the contrary the currents under most conditions seemed to move parallel to shoreline, possibly with a very small shoreward component. The conclusion regarding a net material transport in the Halekulani channel in a shoreward direction therefore seems to have a general significance.

CONCLUSIONS

Hawaii's beaches are of great economical and social value, and therefore worthy of careful preservation. Past actions of man have often been hap-hazardous or detrimental, because a thorough understanding of the dynamic nature of beach systems was lacking. The present study undertaken at the University of Hawaii to obtain detailed insight into the processes at work will be useful in guiding future planning and development for Hawaiian beaches. The study at Waikiki Beach has provided a better insight into the mechanics of water and sediment motion in this area:

-- It has shown that tidal currents, littoral current and rip currents contribute to the sediment motion and the formation of the littoral cell.

-- It has provided insight into the behavior and direction of the littoral drift and has given further evidence to the supposition that the Halekulani channel does not function as a drain, but rather could have a net transport in shoreward direction.

-- A main rip current was found to exist off the Royal Hawaiian Hotel at Waikiki, by which relatively large amounts of material are moved in offshore direction.

-- In the study of beach processes at Waikiki, the use of aerial photography has been of great value.

The findings of studies of this type will be valuable in further engineering of coastal protection works and will be of general use in understanding the prevalent coastal processes.

ACKNOWLEDGEMENTS

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