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Littoral Drifts around Oahu Island in Hawaii Estimated from Wave Watch III Data
파랑 자료 Wave Watch III로부터 산출된 하와이 오아후 섬에서의 연안 표사량

Jung Lyul Lee[1] and Michelle H. Teng[2]
이정렬1, 미셸 텡2

1. INTRODUCTION

Serious beach erosion has been observed at many locations in Hawaii. For example, at one beach area in Makaha on Oahu Island, the waterline has intruded inland to just a few meters away from several apartment buildings. Sand bags have to be used to prevent the beach from further erosion in the area. Typical erosion rates in Hawaii are in the range of 15 to 30 cm/yr (0.5 to 1 ft/yr; Hwang, 1981; Sea Engineering, Inc., 1988; Makai Ocean Engineering, Inc. and Sea Engineering, Inc., 1991). Recent studies on Oahu have shown that nearly 24%, or 27.5 km (17.1 mi) of an original 115 km (71.6 mi) of sandy shoreline (1940's) has been either significantly narrowed (17.2 km; 10.7 mi) or lost (10.3 km; 6.4 mi) (Fletcher et al., 1997; Coyne et al., 1999). Nearly one-quarter of the island's beaches have been significantly degraded over the last half-century and all shorelines have been affected to some degree. At the same time, at some other locations along the coast of Oahu, for example, along the north shore and in Kailua, sand has relatively been accumulating at the beaches. As a result, stream mouths and highway bridges and culverts are partially or fully blocked by sand during dry season. The sand blockage may pose a serious threat to coastal highways and residential areas during storms as the blockage reduces the drainage capacity of the streams and highway bridges and culverts. If dredging is not done periodically, the coastal highways and other coastal structures may be flooded during the storms. Dramatic examples of coastal erosion, such as houses and roads falling into the sea, are rare in Oahu, but the impact of erosion is still very serious. In recent years, the local government agencies are very concerned of the threat to some segment of highway and residential properties near the shoreline caused by the erosion and sand accumulation. Clearly, a better understanding of and the ability to predict sediment transport are necessary for developing better coastal management plans.

The objectives of the present study are to verify the applicability of a simplified empirical approach for predicting general patterns of wave-induced sediment transport in Hawaii by applying to the Island of Oahu as a case study.

2. WAVE AND BEACH CONDITIONS AROUND THE OAHU ISLAND

Better understanding of the oceanographic situation and beach conditions around the Island of Oahu is very critical to the study of sediment transport. The ocean waves are the most significant factor influencing the shorelines and coastal beaches in Oahu compared with other factors such as stream runoff and chemical & biological processes that can be neglected (Sea Engineering, Inc., 1988). The waves concerned in our study are the wind-generated waves that play the much important role in coastal sediment transport. Other ocean waves that may also influence sediment transport include tides, storm surges and others. For this study, our focus is on sediment transport due to wind-generated waves in coastal waters.

1 성균관대학교 토목환경공학과 부교수
2 미 하와이대학 토목환경공학과 부교수

2.1 Wave Data

In estimating sediment transport around Oahu Island, the main input parameters required by the simulation models include wave height, wave direction and wave period. These wave data are usually not available in coastal waters in Hawaii due to lack of long-term monitoring programs. For open oceans, there are several buoys set up by NOAA around Hawaiian islands in the Northeastern Pacific Ocean that measure the wave height and period. Unfortunately, the wave data from these buoys do not provide the wave direction which is very important for sediment transport. The inadequate buoy data prompted us to find the necessary wave data from other sources, such as the simulated data by the Marine Modeling and Analysis Branch of the Environment Modeling Center within NOAA. This branch is a government division responsible for development of improved numerical models for weather, marine, and climate prediction and analysis. They developed several good models to simulate the global waves generated by winds, and among them, NOAA WAVE WATCH III is the most efficient program. The program provides short-term forecast as well as simulated historical wave data to the public, through its ftp server. The global wave data for the entire year of 2002 were downloaded for our study. The computational domain involved in the NWW model covers the area from latitude 78°N to 78°S and from longitude 0°W to 358.75°W. The mesh grids are generated by dividing the domain by 1degree increment in latitude direction and 1.25 degree increment in longitude direction. From the specific output station on the grid system, therefore, we can obtain the wave data such as significant wave height, wave period and dominant wave direction in three-hour interval. Table 1 shows the location coordinates of nine output stations we choose to analyze the open ocean wave data around Hawaii Islands from the NWW3 Model.

2.2 Wave Data Analysis

For each station and every month, wave data with three-hour interval have been analyzed by applying four typical methods, namely, monthly mean, probability, joint probability and spectrum analyses. The detailed analysis on the data can be found in Appendix A of Liu (2003). A sample of the joint distribution of the wave data for May 2002 is shown in Fig. 1.

Table 1. Location of nine stations.

Station No.	Latitude	Longitude
1	25°N	197.5°W
2	25°N	202.5°W
3	25°N	207.5°W
4	20°N	197.5°W
5	20°N	202.5°W
6	20°N	207.5°W
7	15°N	197.5°W
8	15°N	202.5°W
9	15°N	207.5°W

Through the analysis, a seasonal trend is observed at Stations 1-2-3-4-5-6 posed around Oahu Island, while at the lower latitude Stations 7-8-9, no major variation is observed throughout the year. As shown in Fig. 2, from May to September (dry/summer season), H_s and wave direction are roughly in the same value range, and for the rest of the months (wet/winter season), they are in another value range. The difference in the value range is very distinct. However, April seems to be a transitional period between the two different seasons since H_s and direction values are between the two value ranges. There is no sharp variance for wave period T_s. For stations 7, 8, and 9, seasonal variation is not observed. These locations have the same latitude of N15° and closer to the equator.

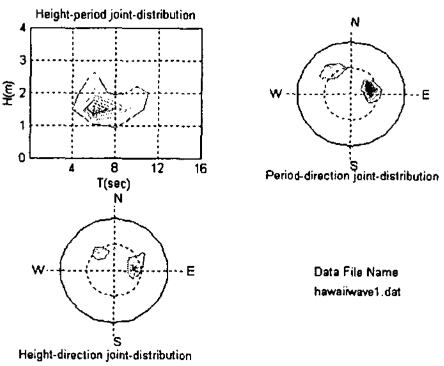

Fig. 1. Joint distributions for data of May, 2004

2.3 Comparison of NOAA Simulated Wave Data with Buoy Data

In order to examine the validity of the simulated wave data adopted in our sediment transport model, field data of three buoy stations near Hawaii are also studied. Historical buoy data can

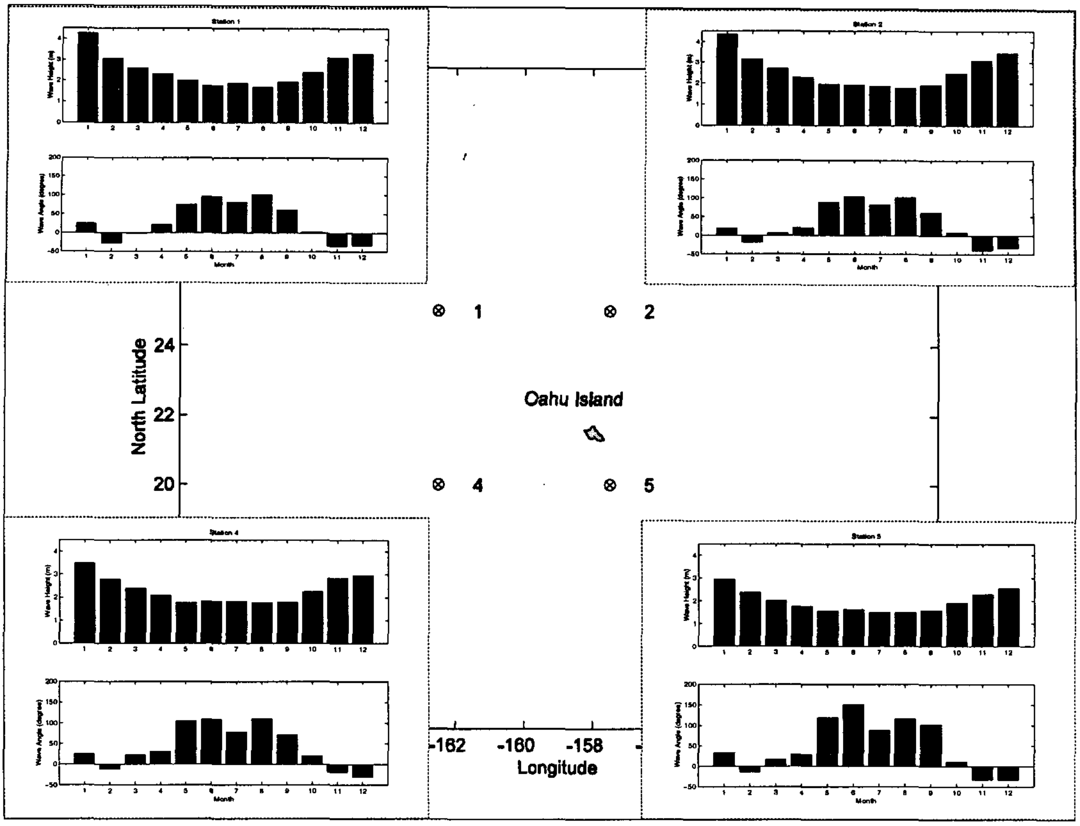

Fig. 2. Monthly variations of wave heights and wave directions (measured from N) at four stations around Oahu Island

be downloaded from the NOAA official website, and thereafter hourly significant wave height and dominant wave period can be extracted from the original recorded data. After that, mean, probability, joint-probability and spectrum analyses are applied to obtain the monthly wave parameters at these three buoy stations. For the convenience of comparison, the corresponding simulated data at the same locations are extracted and analyzed from the NWW3 model. We found that the simulated data and recorded data were in an excellent agreement with each other at all the three buoy locations. The maximum variation is about ten percent of the field data which is acceptable in engineering application. One example is shown in Figure 3.

2.4 Oahu Shoreline Features

Sea Engineering, Inc. (1989) has conducted a thorough shoreline study around the entire Oahu Island. For each beach, detailed conditions were carefully studied through measurement and observations. The basic methodology applied in this study is the comparison of the historical aerial photographs and the updated one taken in 1988 as well as the field survey and observation. The emphasis of this particular study was the long-term beach changes and the potential of sand erosion or accretion, and the result can serve as a good reference for comparison with our present simulated results on sediment transport. The table attached in Appendix B of Liu (2003) lists the beach information summarized from the report *Oahu Shoreline Study, Part1 and Part 2* prepared by Sea Engineering, Inc. (1989). We noticed that several important beaches (Kaneohe Bay, Waikiki Beach and Ala Moana Beach) were not covered in the study by Sea Engineering, Inc. due to two main reasons: either the beach is under military control or it is a well-known beach and had already been well studied by other research teams.

3. EMPIRICAL PREDICTION OF LITTORAL SEDIMENT TRANSPORT AROUND OAHU ISLAND

3.1 Empirical Formulas of Littoral Sediment Transport

A study on littoral sediment transport usually aims to estimate the net long-shore transport rate of sediment based on the waves and currents that cause the transport. This type of study was initially motivated by the problem of blocking of natural sand movement by the construction of jetties or other coastal structures.

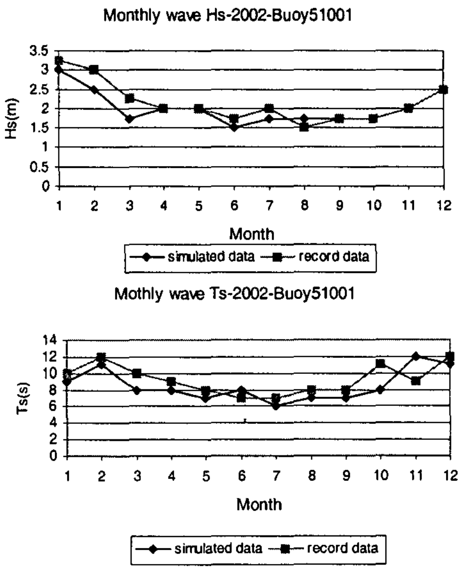

Fig. 3. Comparison between NNW3 St. 1 and Buoy St. 51001 (longitude: 162.3W, Latitude: 23.4N, water depth: 3305.3m)

Over the years, many scientists and engineers have contributed to this research area. For example, Komar and Inman (1970) has tested and verified a set of empirical equations for estimating the long-shore sediment transport by relating the wave energy along shoreline and in the wave-breaking zone. This set of empirical equations are still widely used in coastal engineering worldwide:

$$Q_l(\beta) = C'\frac{g^{0.6} H_0^{2.4} T^{0.2} \cos^{1.2}\beta \sin\beta}{16(4\pi)^{0.2}\chi^{0.4}} \quad (1)$$

where H_o is the deep ocean wave height, T is the wave period, • is the ratio factor of breaking wave height to breaking water depth, and $\beta = \theta_o - \alpha - \pi/2$ where α is the angle of shoreline orientation and θ_o is the angle of incident deep water wave clockwise measured from the north, respectively as shown below.

3.2 Longshore Sediment Transport Pattern around Oahu Island

The entire Oahu shoreline is divided into hundreds of straight segments each of which has a certain shoreline orientation. Then the net littoral sediment transport rate during a certain period can be estimated by summing contributions of many waves of varying height originating from many directions. The resolution of the shoreline data and the accuracy of the wave data are very important in this simulation.

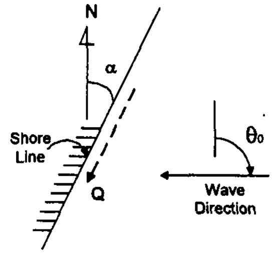

Fig. 4. Definition sketch of angles

There are three sets of data needed to be input into the model: Oahu shoreline data, wave parameter and empirical parameters related to sand sediment properties having influences on the long-shore sediment. The data of Oahu shorelines were obtained from the Marine Data Archives Office (SOEST, University of Hawaii at Manoa) with the resolution of 100 meters. A total of 206 data points were extracted from the bathymetric data by applying the software package SMS. We would like to emphasize that this part of our study on the prediction of the littoral sediment transport around Oahu Island is for a quick and rough estimate of the large-scale transport pattern around the island rather than a detailed study in a small area. For the convenience of display, some modifications were made to the Oahu shoreline. For example, the shoreline of the Pearl Harbor area is smoothened out as if no harbor existed there. This will not affect the prediction of the large scaled sediment transport patterns around Oahu (see Fig. 5).

Input wave data were described in the previous section. Wave data from four stations are selected as input in this simulation. These stations are Stations 1, 2, 4 and 5.

Though a single value for K of 0.70 was suggested by Komar and Inman (1970) and Komar (1977), many other studies shown that the K value may depend on the specific features of the study sites. However, the variations in K are not easy to determine. In this study, we adopted the K value of 0.70 as originally suggested by Komar and Inman (1970). The computational results are displayed graphically for the convenience of analysis and

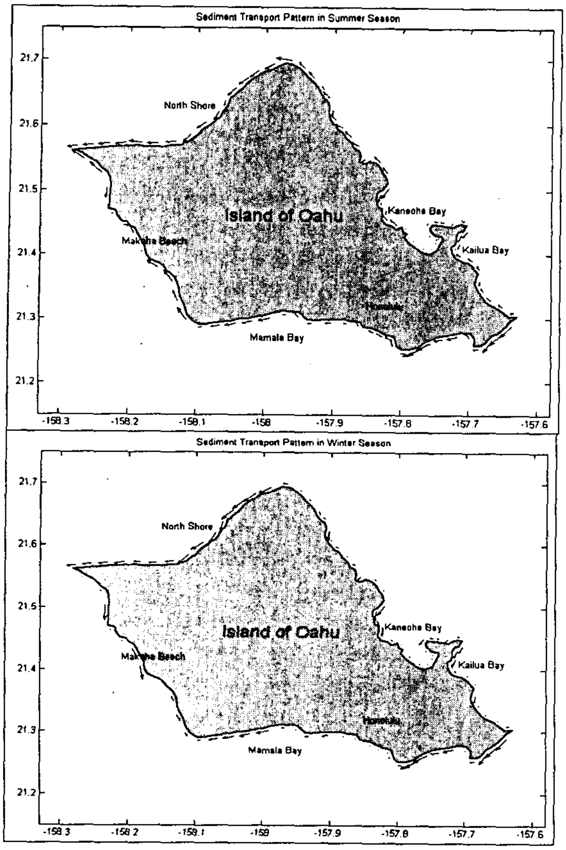

Fig. 5. Potential sediment transport patterns around Oahu Island (a) dry (summer) season, (b) wet (winter) season

comparison. The arrows show the sediment transport direction and the length of the arrows indicate the magnitude of the transport rate.

The information on actual coastal sediment transport conditions was obtained mainly from three sources: the field observation from the City and County of Honolulu Road Division, the report "Oahu shoreline study" prepared by Sea Engineering Inc. and other field observations. The City and County's road division is responsible for monitoring and cleaning accumulated sand for stream mouths around Oahu. The city engineers have many years of practical experiences with the sand transport directions at many locations. We compared our simulation with their observations, and good agreement was found in the comparison: according to Road Division's engineering manager Mr. Kalani Joseph (interviewed March 5, 2003), obvious seasonal variations have been noticed every year. The winter and summer current directions can be very different. For the winter season, for most of the locations (e.g. Kailua, Kaneohe, Makaha), the simulation results are consistent with the observations of the coastal current directions; for the summer season, it is a little difficult to judge because according to the observations, the summer current directions are not as clearly defined as the winter patterns. However, for the area around the stream mouths in Kailua, the simulation results had a very good agreement with the observations.

Another area attracting our attention is Makaha area located in the western part. At some locations around there, erosion is very serious. Our simulation result in this area shows the very reasonable prediction why this can be happening. As shown in Fig. 2, the sands transport from that area to upward coastline in the summer season, while in winter season, with the direction changed, the sands still move away from the area but to downward coastline. As the result of continuously diverging transport in such a pattern, it is not surprising to find that the terrible erosion would occur at this location. However, these simulation results are only valid for the short period corresponding to the given wave information.

5. CONCLUSION

In this study, the coarse-scale sediment transport pattern along the entire coasts of Oahu Island was estimated based on simplified empirical formulas. For wave conditions, the open ocean wave data were first extracted from the numerical simulation results of NOAA WAVE WATCH III. Then statistical analysis was performed on these data in order to determine the seasonal variations and to calculate the significant wave height, period and direction for each month and season. From the data analysis, two distinct seasons were identified for wave variations in Hawaii: summer season of April to September, and winter season from October to March. During each season, the wave conditions are relatively constant. The beach conditions around Oahu were obtained from different sources through literature search and interview with local engineers.

Our study results for sediment transport patterns around Oahu were compared with qualitative field observations, and showed promising agreements with the observed. This provides a preliminary validation of the empirical formula employed for predicting sediment transport in Hawaii. Since quantitative field data on volumetric or shoreline change rates are very limited in Hawaii, the results could not be compared in more detailed description. More research is needed to further verify the models in the future. These future studies may include conducting field study to measure sediment transport rate, applying the models to more coastal areas in Hawaii, and developing multi-layered grid system to provide better connection between the open ocean conditions and the simulation in coastal region.

ACKNOWLEDGMENTS

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