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WAVE PATTERNS OFF SOUTHERN CALIFORNIA

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ABSTRACT

Mapping of wave trains during four flights over the ocean off southern California showed the consistent presence of a high 10-second swell from the westnorthwest, of one or two low 3- to 5-second swells from other westerly directions, and of local wind waves; occasionally a low 13-second swell from the west and southwest was also present. Islands reduce the height of swells but produce little discernable cross-swell in their lee. Maps of swells and wind waves provide information on the best courses to be followed by airplanes during ditching at sea; they may also aid in the interpretation of wave recordings at shore stations. The direction of most swells is such as to drive the sand of mainland beaches to the southeast in general, according with the known chief direction of accumulation of sand against artificial beach structures.

INTRODUCTION

Charts showing the direction of movement of ocean waves were made and used for navigational purposes by the Marshall Islanders until the end of the nineteenth century. Such charts were constructed of split palm stems arranged in a frame, on which were fixed shells to denote islands and short parallel sticks to represent swells. Examples of the charts and a summary description of them have been given by Emery, et al. (1954; 4, 5, pl. 1). Made by acute observers of nature, these charts represent a form of wave study that has not been investigated by modern man with his array of elaborate instruments. Instead, recent work on ocean waves has been directed mostly toward studies of refraction in local areas of shallow water (Munk and Traylor, 1947), of the spectrum of wave heights measured at shore stations (Munk, 1947) and computed from weather maps (Saur, et al., 1947), and of the influence of waves on natural (Munk and Sargent, 1948) or artificial (Fleming and Bates, 1951) structures.

In order to learn whether an improvement might be made over Polynesian techniques and to determine the wave pattern existing

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off southern California, the writer made wave observations aboard the University of Southern California's R/v Velero IV during cruises that were set up mainly for other purposes. Azimuths of two or more sets of wave trains were noted both visually and on a radar scope. It was soon learned, however, that wind and wave conditions in this region vary too rapidly to permit mapping of waves during the several days that are required to cover the area by ship.

Observation from an airplane was obviously required. Through the interest of the Office of Naval Research, facilities were made available by Fleet Air Wing Fourteen, Naval Air Station, North Island, San Diego. Four flights were made at three-month intervals, on 15 October 1957, 16 January, 15 April, and 15 July 1958, using the Marlin (P5M) seaplane for three flights and the Neptune (P2V) amphibious plane for one. The high degree of visibility from the latter made it ideal for the work. Excellent co-operation was provided by administrative and flight personnel. Appreciation is also due D. S. Gorsline, R. L. Dunbar, E. S. Roth, and R. E. Stevenson, students of marine geology at University of Southern California, each of whom acted as recorder on one or more flights.

**METHOD**

Flight lines totalling 720 to 910 statute miles were covered in 4 to 6 hours; differences between the four flight plans came about because of military restrictions (imposed by Point Mugu Missile Test Center) and because of a desire on the second flight to follow a closely spaced grid. Positions were obtained by radar fixes at 15- to 30-minute intervals. Since flights had to be scheduled a week or two in advance, no selection of weather was possible; however, each flight happened to occur on a day of typical weather with northwesterly winds of 10 to 20 miles per hour in all of the region except near the northwestern corner of the survey, where winds were 20 to 30 miles per hour.

After some experimentation, an elevation of 2000 feet was selected as most suitable for identifying separate wave trains; observation at lower elevations caused some confusion by too great detail, and at much higher elevations trains of small waves tended to be overlooked. Owing to low clouds, the fourth flight was made at only 400 feet.

Observation was purely visual and was found to be clearest when
wave trains were viewed away from the sun at an angle of about 45° from their crest azimuth and at a downward angle of 15 to 45°. This angle of view permitted identification of waves by the alternation of dark and light stripes at the near and far sides of wave crests produced by differences in the ratio of light coming from within the water and reflected from its surface. Cross-checks on the direction of waves were made as frequently as practicable, usually at about 10-minute intervals, by viewing at the opposite side of the airplane.

In order to simplify the work, a wooden pelorus was mounted at the observation station with its fore and aft line parallel to the airplane’s axis; the disk was turned until its indicated direction matched the airplane’s true compass heading. Each of three moveable arms pivoted at the center of the disk was set as nearly parallel to wave crests as could be judged. The error of setting, as indicated by back sights and by comparison of results obtained on different flight legs, was usually less than 10°. During flight the observer attempted to keep the arms set at all times, reading off the settings at 1- or 2-minute intervals. These settings were noted by a recorder who also made frequent estimates of the period of waves in each train by timing the passage of waves beneath patches of foam, floating kelp, or gulls resting on the water. The position of each observation point was determined by interpolation between the less frequent radar position fixes.

About 50 photographs of waves were made during each flight with an aerial camera in order to check and illustrate typical patterns. Photography, however, was found to be a poor method for making the primary observations because of the small area included in each picture, the uncertainty of orientation and interpretation of the pictures, and the need of observation for several minutes before certain identification could be made of trains of smaller waves.

RESULTS

Maps of the wave patterns compiled after each of the four flights (Figs. 1 to 4) are similar in many respects. All show the predominant swell from the North Pacific storm area proceeding east-southeasterly throughout the area, with little directional control exerted by islands. Its period averaged about 10 seconds. One or two other swells, usually having 3- to 5-second periods and moving easterly
Figure 1. Survey of 15 October 1957. Flown aboard P5M at 1500 and 2000 feet. Circles show positions of observation points along flight lines. The spacing of swell and wind wave lines is arbitrary and carries no implication regarding wave lengths.

or northeasterly, probably originated from storms in the central Pacific Ocean. A long low swell, possibly from a storm center in the southern hemisphere, was detected in the southwestern part of the area during the July survey; and it may have been present in areas of low waves in the eastern part of the area during the April survey. Because of its length and lowness, it was easily obscured by accompanying shorter and higher swells. Each survey also showed the presence of a wind wave, usually of about 1.5-second period, moving southerly and following the typical wind stream lines of the region. Long narrow parallel streaks were observed to be perpendicular to the crests of wind waves in areas of high wind velocity near the northwestern part of the surveys. Both smaller swells and wind waves are influenced by islands, mostly in the form of gaps in the lee of islands.

Refraction by shallow water was noted only near the shores of the mainland and islands. Cross-swells in the lee of islands were
not detectable over large areas. Reflection of waves was even less important. In these respects, the islands off southern California appear to have less effect on waves than do islands of the tropics. Perhaps the effects of the latter islands, as observed by the Marshall Islanders and others, result from the relative simplicity of wave patterns in the belts of trade winds compared with the complexity of patterns off southern California where they are developed by several separate storm centers and by local winds.
Significance

Knowledge of the pattern of wave trains off southern California has several practical applications. Waves off Point Conception at the northwestern limit of the surveys are notoriously high compared with their progressively lower height farther southeast. This is not merely the result of the known diminution of wind velocity southeastward, because at least the 10-second swell is too long to have a local origin. Instead, the southeastward decrease in swell height must be due partly to protection offered by the islands which reflect much of the wave energy. The changing relationship of the various wave trains in the region must also produce changes in the character of wave recordings made at various places along the coast and for different times at the same site.

Ditching tests for airplanes at sea have shown that the best landing direction is parallel to the wave crests and troughs (Anonymous, 1953). As a result, a 30° or 210° true course is generally considered best for ditching in this region, because it is parallel to the
large main swell. However, a secondary swell from the west or southwest forms a crossing pattern that might damage an airplane landing along the main swell. If time permitted, an easier landing might be made on the lee side of the large islands that prevent access of some secondary swells.

The main swell from the westnorthwest is the one that contains the most energy. As it drives along the coast it is refracted so that it approaches nearly directly shoreward. Since at least a small angle remains, the wave, after breaking, drives ashore in such a direction as to carry some sand southeastward. The general southeastward movement of beach sand, locally contrary to the direction of offshore currents, is attested by the accumulation of as much as 280,000 yd$^3$/year behind breakwaters and against groins of sandy beaches (Johnson, 1956). During times when storm waves approach from the south or when the long swell comes from the southern hemisphere, the drift may be reversed locally (Shepard, 1950), but the prevalence of the main swell requires a net southeastward movement of sand along the mainland shore.
REFERENCES

ANONYMOUS

EMERY, K. O., J. I. TRACEY, JR., and H. S. LADD

FLEMING, R. H. and C. C. BATES

JOHNSON, J. W.

MUNK, W. H.

MUNK, W. H. AND M. C. SARGENT

MUNK, W. H. AND M. A. TRAYLOR

SAUR JR., J. F. T., E. R. ANDERSON, W. V. BURT, AND W. THOMPSON

SHEPARD, F. P.