OCEANOGRAPHIC FACTORS IN UNDERWATER DEPTH DETERMINATION BY AERIAL PHOTOGRAPHY[1]

H. R. Seiwell, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

THE wartime development of aerial photographic methods for determining depths of shallow coastal waters has opened up new practical and theoretical problems of ocean research. Based on the oceanographic requirements and techniques, aerial photo methods fall into two general groups. One group is concerned with evaluations of water depths from measurements of horizontal parallax of surface and bottom images on stereo photos, or from measurements of emulsion densities on photographs obtained from various filter combinations. The second group of methods is concerned with evaluations of depths and bottom gradients from characteristics of the photographed sea surface wave patterns.

2. It is the opinion of this writer that the second group shows greater promise of practical development. This is because of the ease and flexibility of practical operation combined with greater versatility, and because several independent checks of depth computations may be had from a single photograph. The wave pattern methods are applicable to any part of the world's coastal areas requiring only that it be possible to evaluate characteristics of surface wave patterns from aerial photographs. Uncertainty in their use lies in the fact that computations are based on somewhat uncertain theoretical interrelationships of wave properties, such as height, period, length, steepness and refraction as the surface waves advance from deep water over shallow sloping bottoms. Thus the oceanographic requirements of aerial photography tie in with the general problem of sea surface wave investigations. Like many problems of this category, the investigation ultimately reduces to one of controlled experiments and controlled observational programs.

3. The theoretical considerations forming the background of computation are drawn from classical hydrodynamics. Specifically they apply to surface waves of low steepness, that is waves whose height is less than one half per cent of the length. Thus wave velocity (C), wave length (λ) and depth (d) are related by:

$$C^2 = \frac{g\lambda}{2\pi} \tan h \frac{2\pi d}{\lambda}. \tag{1}$$

This relationship is graphed in Figure 1.

Substituting the fundamental deep water relationship of wave velocity, wave length and wave period

$$C = \frac{\lambda}{T} \tag{2}$$

in (1) we obtain

$$T^2 = \frac{2\pi\lambda}{g} \cot h \frac{2\pi d}{\lambda}. \tag{3}$$

[1] **Contribution No. 379 from the Woods Hole Oceanographic Institution.**

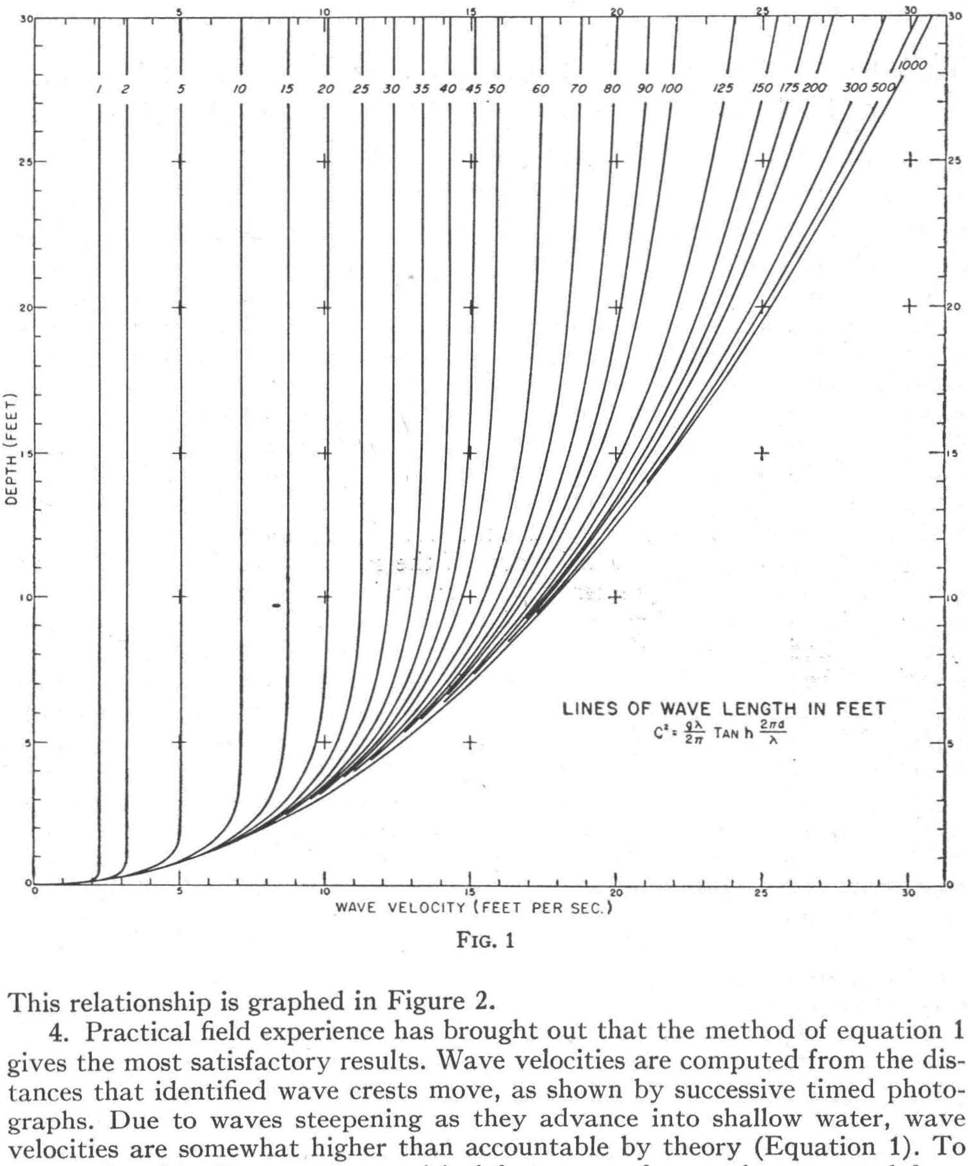

FIG. 1

This relationship is graphed in Figure 2.

4. Practical field experience has brought out that the method of equation 1 gives the most satisfactory results. Wave velocities are computed from the distances that identified wave crests move, as shown by successive timed photographs. Due to waves steepening as they advance into shallow water, wave velocities are somewhat higher than accountable by theory (Equation 1). To correct for this discrepancy, empirical factors are frequently computed from observations.

5. The analyses of differences between depths computed by the wave velocity method and by direct soundings from surface craft, show that occasionally the above theoretical relationship fails and large errors may result. Since it is these occasional large errors which in practice may be disastrous, a thorough investigation of shallow water wave properties in relation to sea surface roughness and sea bottom gradients is essential to placing the method on a practical working basis.

6. As an example of discrepancies between depths observed and depths computed by the wave velocity method, results of a series of experiments from Oahu are briefly considered. In these experiments, surface craft sounding profiles were made at right angles to the beach and were marked so as to be identified on

aerial photographs. Depth computations by the wave velocity method were made to coincide with the sounding profiles. The results of six such experiments are illustrated by Figure 3.

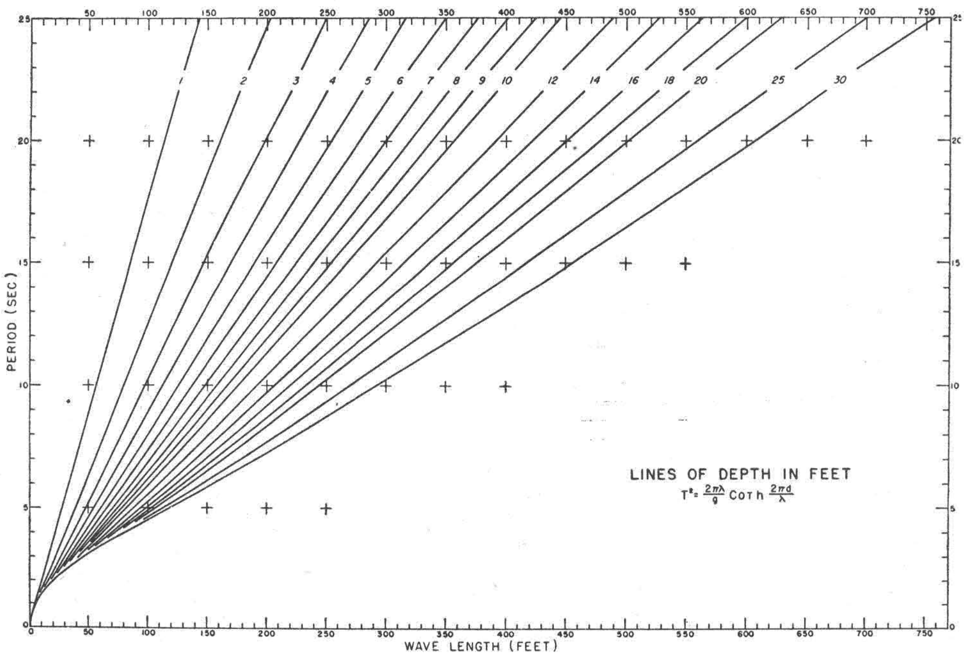

FIG. 2. Results from an experimental program investigating aerial photographic methods of underwater depth determination, undertaken by 6211 Beach Intelligence Unit, Pacific Ocean Areas, 1945.

7. Comparison of computed and observed values of Figure 3 shows that computed depths were usually greater. The discrepancy, however, is not as great as expected from first observation, due to the aerial sounded gradients being drawn from point to point determination; and the few large discrepancies are not the usual rule. However, it is these occasional large departures which greatly decrease the reliability of the method. They are not completely a result of erroneous photo interpretation, and photo measurements were checked after the first drawing of the profiles. They arise from a number of causes, and the possibility must not be excluded that reflections may play a significant role. The point is that they are not accountable by present theory. In the example, the most usually occurring depth discrepancy is of the order of two to three feet, excluding the occasional large departures, of profiles A and B in Figure 3.

8. A second method of aerial photo depth computation involves the period-wave length relation of equation 3. It has the advantage of requiring but a single aerial photograph and thus eliminates errors induced by the intervalometer. On the other hand, to apply the method, it is required that the aerial photograph cover offshore waters to a depth exceeding one half the length of the existing surface waves. It also involves the assumption that wave period remains constant as wave lengths and wave velocities diminish with their inshore progression.

9. Experiences during the recent war indicated that application of the

period-wave length relationship was less satisfactory than that relating wave velocity and length. In general, it was used only when intervalometer equipment for obtaining timed photographs was not available. The method appears to offer good possibilities which have as yet not been investigated.

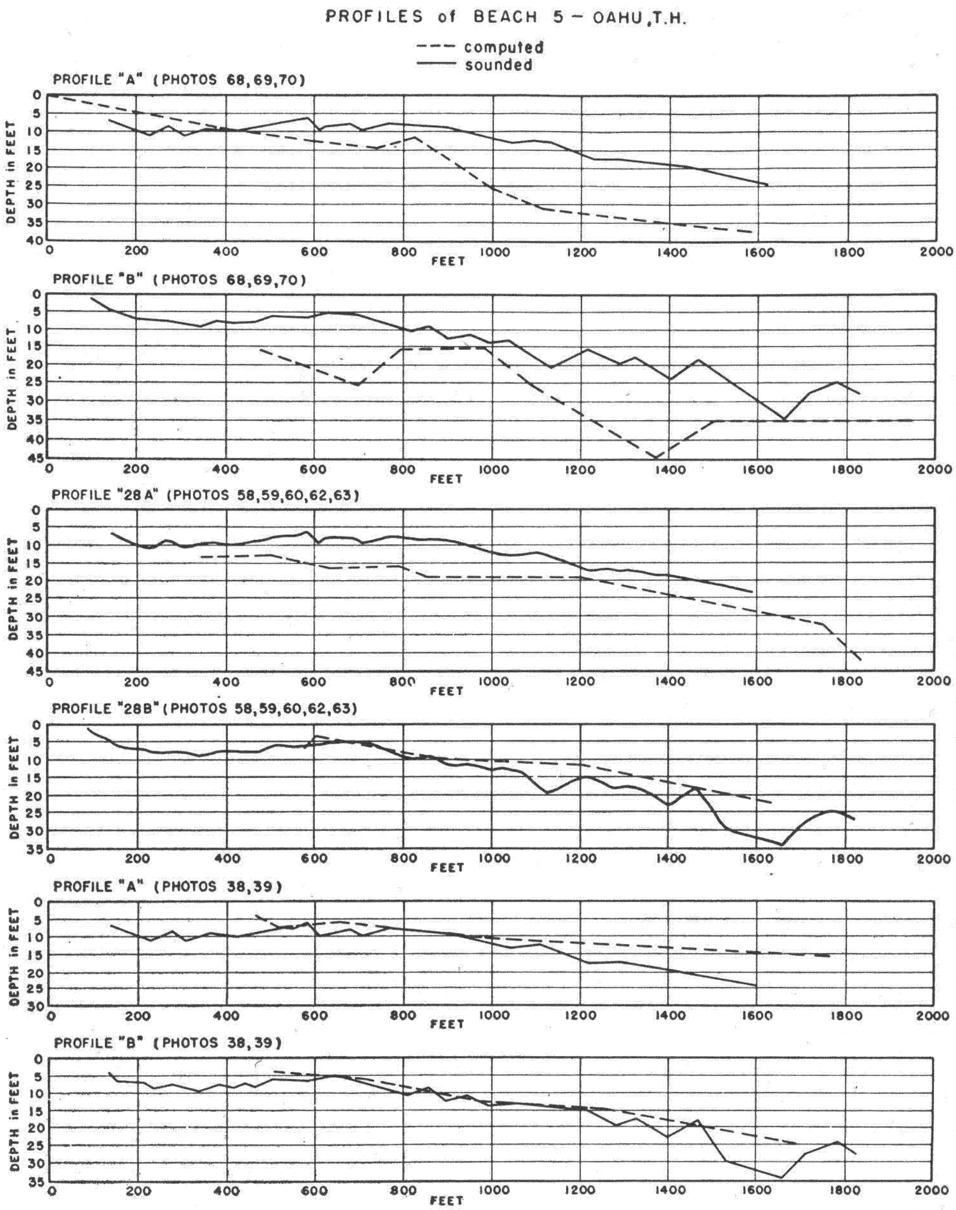

FIG. 3

10. The third application of shallow wave theory to depth computations from aerial photographs makes use of the refraction patterns of surface waves as they move from deep to shallow water. This occurs when deep water wave fronts make an appreciable angle of incidence with the shore line. As waves ad-

vance inshore, bending occurs as the crest velocity diminishes according to the ratio of water depth to wave length. Thus, in the case of a straight shore line, with offshore parallel bottom contours, the angle the deep water wave crests makes with the shore line (α_0) is related to the angle at depth, d, (α) by

$$\sin \alpha = \sin \alpha_0 \frac{C}{C_0} \tag{4}$$

where C_0 is the deep water wave velocity, and C the velocity, where d is less than one half the wave length. For this relationship, it is assumed that velocities of the wave crests depend only upon the water depth under the crest; that the wave crests advance perpendicular, and that energy does not flow laterally along the crest.

11. On the basis of a constant wave period we have from 4:

$$\sin \alpha = \sin \alpha_0 \frac{C}{C_0} = \sin \alpha_0 \frac{\lambda}{\lambda_0} = \sin \alpha_0 \tan\text{h} \frac{2\pi d}{\lambda} \cdot \tag{5}$$

For convenience we use

$$\frac{C}{C_0} = f\left(\frac{d}{\lambda_0}\right) \tag{6}$$

where the velocity ratio is related to the ratio of depth to deep water length, obtained as a numerical solution of the above. Hence, for practical use

$$\sin \alpha = \sin \alpha_0 f\left(\frac{d}{\lambda_0}\right) \tag{7}$$

α, α_0, λ_0 are read directly from the photographs. This method appears to be the least accurate of the three, although its possibilities have not been developed.

12. The adaption of geophysical field methods to the air needs no elaboration. In the case of Oceanography, air borne methods offer unlimited possibilities for obtaining critical data not heretofore possible except by tedious and expensive field programs. The problem now is to systematically investigate and record interrelationships of relevant oceanographic situations with the object of ultimately analyzing bathymetric situations of coastal areas from a minimum number of aerial photos. In this manner we reduce expensive and painstaking field programs to the more economical laboratory procedures. This is in addition to their military use during the next emergency. Thus the development of aerial photographic methods for determining underwater depths of coastal waters is one of the outstanding practical applications of oceanography. Future progress will require coordination of effort between the research oceanographer, the aerial photographic technician and the reconnaissance pilot, and in this manner research plans will be formulated along lines most suitable to produce useful results.

13. The application of physical oceanographic research to the aerial photo depth determination will now follow the same pattern as that for other oceanographic applications. Knowledge of the state of the sea surface, obtained from great masses of random observations have revealed that the general pattern conforms to the broad theoretical considerations of classical hydrodynamics. Nothing further is to be gained from analyses of the random and not too precise observations of the sea surface. Further progress in this direction, as in other applications of physical oceanography, depends on formulating and undertaking

systematic programs of controlled experiment or controlled observation. That is, field experiments and observations, aimed at the solution of specific problems and for which the analytical methods of reduction have been decided previous to their initiation.

14. In our specific case, we wish to obtain systematic experimental and observational data of highest possible accuracy and in such a fashion that the data lend themselves to the extraction of characterizing parameters. These parameters, representing the dynamic situations, permit numerical interrelationships to be established between the characteristics of deep water surface waves as they move in over sloping beaches. In this manner we do not exclude the possibility that the present observed discrepancies may be accountable by development of additional theory. We have reached the stage where this is now possible. Adequate instrumentation is available and the statistical procedures for reduction are known. It remains now to formulate the problems in exact terms and to undertake the specific experimental and observational programs.

NEWS NOTES

NEW AIR SURVEY COMPANY

Photographic Survey Co. Ltd. of Toronto, Canada—a Sustaining Member of this Society—has recently announced that a new air survey company, in association with Photographic Survey Co. Ltd., has recently been formed. This is Photographic Surveys (Western) Limited and the address is Vancouver International Airport, Vancouver, A.M.F., B. C. It is stated that the new company is fully equipped for air photography, planimetric and topographic mapping.

BT-13 USED FOR AERIAL MAPPING

The Davis Aerial Photographic Service of Houma, Louisiana reports that after considerable experimental work they have finally obtained CAA approval of alteration plans for converting the BT for vertical photographic mapping. And, that the plane is working out very satisfactory for both vertical and high oblique work.

It is claimed that no rerouting of control cables is necessary, and that the control changes can be built outside the airplane and installed within a few hours.