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SUMMARY REPORT ON STUDIES OF SAND TRANSPORTATION
BY WAVE ACTION

Errata:

FOREWORD

The following report is a summary of investigations conducted by the Department of Engineering, University of California, under contract W-49-055-Eng-2 with the Beach Erosion Board. Individual reports summarized herein and listed at the end of the report are on file in the Board's library. They are available on 30-day loan upon request.

Introduction

The purpose of this investigation was to define the more important factors involved in the littoral transportation of sand by wave action. The scope of this study was relatively broad and included both model and field studies. The model studies consisted of investigations of (a) sand movement with two dimensional wave motion, (b) influence of groins on beach stabilization, and (c) the movement of sand by waves acting at an angle to a straight beach. The field studies consisted of (a) a comprehensive analysis of all available field data to determine a generalized relationship between sediment, beach and wave characteristics, (b) the measurement of the wave characteristics and the sand accumulation at Santa Barbara Harbor in order to estimate the average rate of sand transport that might be expected from given wave conditions. Eventually, it is believed that model and field studies as conducted in this investigation will permit the coastal engineer to estimate expected rates of littoral drift at any given location on a coast exposed to wave action.

In addition to the model and field studies mentioned above, wave recorders were operated at various locations along the Pacific Coast. The recorders from these recorders were analyzed for the significant height and period, and the data then summarized in tabular form for distribution to interested agencies.

A supplementary task order to this contract was the compilation of certain data of a classified nature. Because of the classification, this material is not summarized in this report.

MODEL STUDIES OF SAND TRANSPORTATION BY WAVE ACTION

Sand Movement in Two Dimensional Wave Motion

Before the investigation described below in items B and C could be conducted, it was necessary to determine whether certain relatively fine sands would actually form a beach under laboratory conditions. Because of the economy of time in setting up such experiments and because of the flexibility permitted in varying the experimental conditions, a series of experiments were made in the one-foot wave channel located in the Fluid Mechanics Laboratory of the University of California (for complete details see the report Issue No. 5, Series 14, as listed in Part VI). The purposes of this investigation were:

a. To study the action of waves on beaches where no littoral sand transport occurs; comparing the profiles formed by normal waves (0^{o} angle) for various selected wave-steepness ratios.

b. To observe the movement of beach sand under the action of waves perpendicular to the beach with and without tides.

c. To determine whether very fine grained sands will make a beach or what minimum grain sizes could be used for forming a model beach under existing experimental conditions.

d. To determine the amount of material in suspension due to wave action on these fine sands, and the particle-size distribution throughout the channel bed.

e. To show the formation of a beach starting from an initially uniform slope to its final stable condition. Further, to show how a beach (where no littoral transport occurs) changes shape when the period is suddenly varied.

Summary

The movement of waves impinging upon the sand beach and the subsequent movement of the sand particles were observed through a glass-walled wave channel. After each beach tested had reached a stable condition, the lengths of the foreshore beach and the berm height were measured. Both of these values, for a given sand and a given wave steepness, were found to be directly proportional to the square of the wave period. More experimental data are required to establish a relationship between the berm height and the foreshore slope to both the steepness ratio and the grain diameter.

Observation showed that receding tides tend to flatten or smooth out the entire beach profile while a rising tide keeps the original beach profile intact but moves the beach position landward.

It was found that only the sand mixtures having a grain-size distribution curve similar to the natural beach sands resulted in the formation of a stable model beach. Furthermore, in contrast to this, it was found that if a sand mixture was used that had a relatively wider range of the grain sizes than that occurring in natural beach sands, the particles tended to segregate. This resulted in the beach becoming

unstable and the profile consequently being unpredictable.

A series of experiments were made to determine the amounts of material that were thrown into suspension due to the action of the waves on a beach. All of the tests indicated that the maximum concentration of suspended material occurred in the breaker region. It was also observed that the orientation of the sampling tube in the wave stream affected the measured concentration of the sand particles.

Because of the number of waves required to develop a stable condition in the model beaches for the particular wave periods used, it is questionable whether a corresponding prototype beach in nature, under the natural wave and tidal actions, would result in an equilibrium state.

The qualitative observations made on ripple formation indicate that the wave height appeared to be the controlling element in forming the size and shape of the ripple. A wave of greater amplitude, having a relatively large particle movement, gave greater ripple amplitudes and spacing than the wave heights of lower amplitudes.

Recommendations

After a review of recent literature on wave action on granular material and in view of the rather limited tests discussed above, it appears desirable that further study of two-dimensional wave action be conducted on the following problems:

a. In the light of recent investigations on wave forces on particles* a comprehensive study should be made on the forces which cause bed movement by wave action. The variables in these tests should include the wave characteristics and the specific gravity and mechanical analysis of the material.

b. The movement of sand exposed to two-dimensional wave motion and the nature of profile changes should be investigated under conditions where a tide is introduced and where the wave characteristics are changed.

c. Observations under the controlled conditions of a wave channel should be made on the nature of suspended-matter distribution in and near the surf zone. The variables should include the characteristics of both the sediment and the waves.

Influence of Groins on Beach Stabilization

Erosion of a beach occurs when the supply of sand to it is less than the rate at which the sand is transported along the beach. To control erosion groin systems often are used to promote the accretion and stabilization of beaches where the littoral drift induced by the

* Foot note shown at bottom of page 4 relates to above asterisk.

wave action is a significant factor. As part of the research program on this contract, a study was made of two types of groins: one, the sloping, impermeable groin; and second, the high, permeable groin. This investigation was intended to determine the relative influence of the high permeable groins and the sloping impermeable groins for stabilizing a beach where littoral transport occurs.

In this study a sand beach was placed at one end of a model basin. Waves were generated at the opposite end of the basin and moved toward the beach. These waves breaking along the shore induced a current which caused a littoral movement of the sand. The relative effect of a particular type of groin was determined by comparing the topography of a straight, unobstructed beach which had reached an equilibrium profile with the topography of a beach which had reached equilibrium after a groin or system of groins were installed.

The experimental program for studying the groin influence on the littoral sand movement was carried out under the following conditions:

a. with no groins in place (for establishing the base equilibrium condition);

b. with one high, permeable groin in place;

c. with a system of two high, permeable groins in place;

d. with a system of three high, permeable groins in place;

e. with a system of ten sloping, impermeable groins in place;

f. with a system of ten high, permeable groins in place;

g. introducing dyed sand particles in the bed of the beach to study currents.

Prior to placing a particular groin, or groins, in position, the littoral transport rate was determined (i.e. for the steady state conditions obtained with a specific set of wave characteristics). The sand composition was the same throughout the tests. The stable profile of the beach then became the base for evaluation of subsequent changes in the beach configuration. The effects of tide were not studied. (For complete details see the report Issue No. 6, Series No. 14, as listed in Part VI).

* O'Brien, M. P. and Morison, J. R.; The Forces Exerted by Waves on Objects; Transactions, American Geophysical Union, (In Press).

Summary

The ratio of the rate of sand transport without groins to the rate of sand transport with groins perhaps is the best criterion for evaluating the effectiveness of a particular groin system. In this series of experiments, once the equilibrium rates were established the shore line was considered to be in a stable position. The introduction of fixation works produced a rate of change peculiar to that particular type of structure. These rates in turn developed the subsequent volume changes that were computed on a percentage basis using the stable profiles of the beach without any structures in place as a reference.

A review of the experimental data for the tests made with the systems using three permeable groins indicates that where there is proper nourishment to the beach, the permeable structures have a small but effective influence on the beach. Significantly, for both sets of tests the runs made with one groin in place produced a marked scour area in the region downcoast from the structures. The tests substantiate the fact that for sand trapping purposes the permeable groins should not be used as individual units isolated along the beach but in a group, i.e., in a system of groins. Care also must be taken when placing the groins in the beach, for if they are placed further apart than their influence area, each would act as an undesirable individual unit.

With a constant feed input to the surf zone, the first set of tests made on the permeable groins showed that there was a 26 per cent deposit of sand on the beach, with the structures in place, over the base condition, with a straight unobstructed beach. The second set of tests on the permeable groins, made with a different set of wave conditions, showed only an 11 per cent beach fill. Comparison of the data on the types of fixation works tested, where the littoral current is a significant factor, showed that the impermeable groins were more effective in the accretion of sands that the permeable groins.

The retention, or holding power, of the impermeable groins is relatively large. In a particular series of tests where there was no feed material introduced, the total decrease or the amount of scour that occurred from the base reference volume (taken at the start of a test) amounted to a reduction slightly less than 20 per cent in a run that exceeded 54 hours in duration.

The experiments show that, when the beach is adequately nourished and the littoral current is an effective force, the impermeable groins rapidly accrete the sediment. The building or filling-up of the area between groins follows a very definite pattern. In general, the sand begins to move around the seaward tip of a groin and fills in the space near the downcoast side of the groin. Then the sand moves at an angle across to the next groin and fills in the upcoast face. Then the

center portion of the area becomes filled. The following sand and grains are then forced to move over the groin tops (which are now flush with the built-up sand bed) and seaward of the structures. This essentially causes the beach face to be moved seaward and, after a time, the groins are completely buried beneath the sand and the new beach is relocated further seaward. The behavior of the beach appears to be predominately dependent upon the transport rate as to whether the body of the beach face is to remain in a stabilized state or not.

In order to observe the path that the littoral current takes through the permeable groins, a dye was introduced in the breaker-to-shore region where the probable maximum littoral velocity occurs. The results were indicative of where the sand usually builds up and/or scours around the groins, as determined from the other experiments. The fact that the dye went through the first two groins in an even "fan" pattern would tend to show that the littoral current was still great enough to also carry the sand particles through the slat section. Furthermore, it would tend to indicate that should permeable groins be contemplated for a comparable prototype situation, they should be used in groups of three or more groins.

In tests made to study the bed load movement of the sand particles in the breaker region, the sand grains were observed generally to follow a definite pattern. The initial wave action first covered the grains in the bed, then the following waves uncovered the grains and moved them a short distance in both a seaward and lateral direction. Succeeding waves again covered the particles and the process began to be repeated. The cycle occurred within approximately 1 minute (60 waves for this particular test). This cyclic particle movement also has been observed in the one-foot wave channel as discussed in Section "A" above.

The Movement of Sand Transported by Wave Action Along a Straight Beach

Waves breaking at an angle to a beach generate a current that moves parallel to the beach; this is known as the littoral current. The purpose of this investigation was to study to what extent a change in wave characteristics and beach affected the rate of transportation. The experimental program began with a continuation of previous experiments on sand transport.* A wave machine and a model beach were arranged in a model basin approximately 66 ft. by 122 ft. in plan and two feet in depth. The wave machine was of the flap type in which the period of the waves could be varied by changing the speed of the driving motor, and the wave energy could be changed by adjusting the throw on crank arms connected to the wave flaps. The wave height and wave length were determined by the period and energy settings. A sand beach was molded initially to a 1/10 slope by screeding, and then allowed to develop its profile under the action of the waves. A sand trap and

*Saville, Thorndike, Jr.; Model Study of Sand Transport Along an Infinitely Straight Beach, Trans. Amer. Geoph. Union, Vol. 31, 1950 weighing device for recording the rate of littoral sand transport induced by direct wave action and by the littoral current was installed at the downbeach end. This device consisted of a metal hopper suspended on a beam which rested on a fulcrum. On one end of the beam a counterweight was attached (for zero setting), and the other end of the beam rested on a sylphon bellows which was liquid-filled and connected by tubing to a clock-driven Bourdon-type pressure recorder. The recorder was calibrated by placing known weights into the sand hopper. The efficiency of the sand trap was determined under operating conditions by feeding known weights of sand into the flow at the entrance to the unit.

To insure that all sand transported along the beach would be carried into the weighing device, it was necessary to induce a flow into the basin containing the hopper. This pumping action was necessary in order to prevent the littoral current, upon reaching the trap, from flowing seaward; since such a seaward current would oppose the waves, sand deposition would occur in this region, and thus progressively change the rate of transport into the trap. The flow from the pump was returned to the main basin through a channel of relatively large dimensions at a corresponding low velocity, so that no large scale circulation was induced in the basin. Thus, the length of beach studied approximated a section of beach of infinite length. The beach angle was varied between 10° and 50°.

Summary

The following statements summarize the experimental work made on the movement of one particular sand transported along a straight beach unobstructed by fixation works. In the prototype the sand used would correspond to pea gravel; the stable model beach corresponds to a prototype gravel beach.

a. The waves impinging upon a beach set at 30° to the wave generator developed a greater rate of sand transport than did that created by the beach set at a 10° angle.

b. In the region of flat waves (low steepness ratios) the transport rate sharply increases for small increases in the H_o/L_o ratio, until a peak value of around $H_o/L_o = 0.023$ is reached. Here, in this region, the major portion of the sand that is moved drifts along the beach as bed load, whereas in the region of steep waves (high steepness ratios, H_o/L_o exceeding 0.025) the curve of the transport rate takes on a negative, or opposite, slope when compared to the curve for the waves in the low steepness region. The slope for the transport rate curve is less steep and a small change in wave shape does not materially affect the movement of sand. In the region of steep waves the sand is moved by a combination of beach drift and that thrown up into suspension, with the latter accounting for the principal amount of transport. Most of the beach drift occurs at the toe of the beach face and the material in suspension is carried along just shoreward of the offshore bar.

c. The beaches developed by waves of low steepness had a relatively straight or smooth beach face with little separation taking place between the foreshore beach and the offshore section, whereas, for high wave steepness ratios, at least one or more offshore bars were formed and the foreshore was at a steeper angle than that being formed on the offshore bed.

d. The experiments indicate for the range of angles tested, that the transport rate is dependent upon the littoral current. Further, the maximum rate of sand transport occurred where the value of the littoral current reached a maximum value, namely at a 43° deep-water angle.

e. As was found by other experimenters, despite appreciable changes in wave characteristics there was no significant sand sorting along the beach in the longitudinal direction. However, perpendicular to the beach the larger sand particles moved inshore with the fine sediment being carried seaward.

Recommendations

In view of these exploratory experiments, which pertain to only one sand size, further investigations are desirable to determine the effect of sand size on the laws of transport. The experiments discussed in this report provide information on the most desirable size of wave tank for conducting future tests, namely a width of basin not to exceed 15 to 20 feet and a length of basin which will depend on the equilibrium slope of the finest material used in the tests. Simultaneously with such tests, if not before, a fundamental investigation should be made of the magnitude and character of the forces acting on bed particles due to wave action as recommended under Item A of Part II of this report.

FIELD STUDIES OF SAND TRANSPORTATION BY WAVE ACTION

The Relationship Between Sand Size and Beach Face Slope

Introduction - Under the sponsorship of the Office of Naval Research and the Beach Erosion Board, a University of California field party visited and repeatedly surveyed some 40 beaches on the Pacific Coast of the U. S. in the years 1944 to 1948. These beaches ranged from southern California to northern Washington and included steep and flat beaches under winter and summer conditions and in high and low surf. Details of beach conditions from the dunes to beyond the breaker zone were surveyed and noted; sand samples were taken at many points; the effect of surf conditions on each beach was recorded; and an elaborate program of breaker measurements was conducted. A total of about 500 profiles (from dunes to minus 30 feet) were made and over 600 sand samples were taken in the course of these investigations. With its irregularities, the U. S. Pacific Coast is thousands of miles long and quite probably includes most of the possible ocean beach conditions and configurations.

The scope of this report includes only sandy beaches in which sand is defined as ranging in size from 0.05 mm. to 1.0 mm (U. S. Bureau of Soils classification). Although there are a few pebbles, gravel, and cobble beaches on the coast studied, the largest material found on extensive beaches subjected to systematic sampling was 0.8 mm sand. It seems reasonable to believe that the curves can be extended smoothly upward when data on beaches composed of coarse material are available.

The importance of using standardized measurements can scarcely be overstated and other researchers are urged to consider the use of the "reference point" discussed below in future beach examinations so that data will be comparable. This report is concerned with comparing western U. S. Beaches on the basis of median sand size and beach-face slope and shows the probable limits of each. The beach face in this instance is synonomous with shoreface or foreshore. The importance of surf action in changing slopes from a profile of deposition to one of erosion is shown as are the variations in slope with exposure.

Reference Point - The necessity for standardizing beach sampling and measurement procedures became increasingly evident as data were reduced from widely separated beaches between which it was desirable to make comparisons. The apparently simple job of determining the slope of a beach from a plotted profile raised perplexing questions of how and where to make the measurement. Sand samples from a single beach differed so much in median diameter (because of different sample locations) that first attempts at correlation were failures. Eventually however, by plotting the mass of data in various ways, patterns began to take shape. This work ultimately led to a decision to standardize on a specific location so that valid comparisons could be made across time and distance. The point selected was the part of the beach face subject to wave action at mid-tide elevation--now known as the reference point. All slope measurements and sand samples referred to in this report were taken at that point. The several illustrations discussed below develop the reasons for its selection and indicate the results that may be obtained by its use. Certain advantages are claimed for this technique: (1) a line investigator with simple equipment can take measurements rapidly and easily (2) the variables being samples are those of the present time (the existing waves placed the sand sampled at the slope measured) (3) the inter-tidal beach face slope seems to be a major criterion for the potential use of the beach (4) some previous investigators have used this location and their data are usable for comparison. The reference zone may be fairly wide; it is deliberately described somewhat loosely as being the part of the beach subject to wave action at mid-tide stage since the technique would be highly impracticable if it were necessary to locate some exact elevation. Any reference point in this zone is presumed to have approximately the same characteristics. Since the backrush is only slightly below, and the uprush may be considerably above the average sea level, these measurements will be somewhat above the mid-tide level. This part of the beach seems to be the most stable and consistent results usually can be obtained there. Mid-tide refers to a level half-way between the previous high tide and the succeeding low. It is convenient to keep this dimension flexible because the inter-tidal zone on open ocean beaches may be above or below its predicted position; this is caused by piling up of water on a beach due to wave action, wind drag on the sea surface causing either higher or lower tides, and changes in sea level due to barometric pressure gradients. On steep beaches, the reference zone may be as narrow as twenty feet while on flat beaches it may be over a hundred feet wide.

Relationship Between Beach and Sediment Characteristics - A complete discussion of the analysis of the various field data appears in the report Issue No. 2, Series 14 (see Part VI). Briefly, the results of this study show the following information, (a) a generalized distribution of sand size across a beach from the dunes to an offshore depth of approximately 30 feet, (b) typical sand sizes and beach slopes of Pacific Coast beaches, (c) the changes in beach slope with erosion and deposition, (d) the variation of sand size and beach slope with the degree of protection from wave action, (e) and the relationship between sand size and slope of the beach face.

Conclusions - From the results of this comprehensive study of a large number of Pacific Coast beaches, the following conclusions appear reasonable:

1. Sandy beach-face slopes (reference zone) on U. S. Pacific Coast beaches range from 1:4 to 1:100.

2. Median diameter of beach material from the reference point on sandy beaches range upward from 0.17 mm.

3. As beaches build and erode, the slope of the beach face at the reference point will change considerably, apparently in response to the H/L factor of the waves. An eroding beach will flatten; a building beach will steepen.

4. Distribution of sand by size along a profile is predictable with reasonable accuracy if the median diameter of the sand at the reference point is known. Large grains are found at points of maximum turbulence; sizes get smaller as turbulence decreases.

5. The slope of the beach face is related to the median diameter of the sand and the amount of wave energy reaching that point. The amount of energy is a function of the refraction conditions; consequently, beaches that are protected are steeper for any given sand size than exposed beaches.

Investigation of Coastal Sand Movements; Santa Barbara, California

Introduction - Little is known about many of the factors which influence littoral transport. Basic questions have never been answered, such as: What is the relationship between the wave components height, period, steepness, angle of attack) and littoral flow of sand? To what depth of water does the sand move? What is the relationship between longshore sand movement and offshore-onshore sand movement? What is the influence of sand size and density on littoral transport? How can sand flow be estimated if all wind, wave and current data are known? A major objective of this study is to secure all possible information which may throw some light on the solution of these and other problems.

Santa Barbara is a logical site for the investigation of littoral transport on several scores:

a. Complex as the conditions are, they represent a great simplification of an open coast situation. Santa Barbara may be regarded as a large scale model in which variables are held to a minimum. Wave direction, with the exception of one or two southeasterly storms a year, is nearly always at 235° (SW). Winds are held within 180° by the high Santa Ynez range nearby; velocities greater than 15 knots are unusual and direction is reasonably constant for any given time of day. This leaves the wave characteristics (which would be the variable in a model experiment) the principal unknown.

b. Santa Barbara is unique in that it is both easy and necessary (for dredging purposes) to measure the quantity of littoral drift. It appears evident that all sand moving along the coast is trapped in a small area of the harbor and average rates of flow between surveys are easily determined.

c. Santa Barbara is similar to a large part of the coast of southern California which is highly developed and which has similar sand problems. Presumably any solutions or explanations which are usable at Santa Barbara are valid, by extension, at Ventura, Hueneme, Santa Monica and other nearly areas.

d. There is immediate economic pressure for obtaining a specific solution to the problems locally. This amounts to about $60,000 per year for dredging plus an unestimated value of inconvenience to the users of the harbor. Several changes in the shape and layout of the breakwater and harbor have been suggested by various agencies; these have not been completely evaluated as yet, partly because of a dearth of information on the movement of the sand.

e. The beaches are constant in several important respects. They seem to have a common source of sand; exposure to waves is about the same, and beach slopes are reasonably constant.

The major variables all can be measured and are controlled by the physical circumstances. The problem than, is to correlate the specific causes and effects that are measured and to attempt to arrive at a law that relates them. Of primary importance is the relationship between wave characteristics and rate of sand flow. The principal efforts were made in this direction.

Other problems which should be considered are: Where do today's flow rates stand? Are there other causes of sand movement besides wave action? Is sand sorting by size or minerals of any significance either in the fill or on the feeder beaches?

Examination of Prior Data - In order to get the necessary background for the layout of details of this program, a great deal of existing data were obtained from the sponsor and studied by University engineers. Past surveys were of great help in selecting stations for repeat surveys and study. House Document 761 was used as a handbook because of its valuable summaries of statistical data.

Three specific uses were made of these past data. (a) Times of important changes (both accretion and erosion) were selected with a view to having wave hindcasts made which would be comparable with University-obtained sand flow data. No hindcaster was available and this part of the work has been postponed for the future. (b) Rate of sand flow past a series of survey points was plotted graphically in two ways in an effort to ascertain the validity of the theory of sand waves. This theory proposes that periods of storm move large quantities of sand from the feeder beach; this sand travels as a unit for some distance along the beach until brought to rest by a period of light seas; another stormy period moves it along again. Eventually, of course, the sand unit, or sand wave, is spread too thin to be recognized. This motivating storm series might be the winter season, in which case the period of the sand wave would be one year. A limited examination indicates that this may be true and a wave length of 6000 feet may exist. Further study is required on this phenomena before definite conclusions can be made. (c) The data on harbor accretion has been reduced to graphic form, mostly to get a basis for comparison of the new data.

Surveys - Three types of location were deemed necessary to obtain an adequate picture of the sand changes in the Santa Barbara area.

a. A beach outside the "problem area" of accretion or erosion which responds only to seasonal changes. This was used to determine whether changes in the area under study are temporary (offshore-onshore) or permanent (along-shore). The location selected for this was at Arroyo Burro (Hendry's Beach). In addition to the characteristic noted above it is the mouth of an important drainage area and if any appreciable sediment had been brought down by a heavy runoff, the delta formed would have been surveyed. Two ranges on West Beach (which is believed to be stable) are expected to show the same seasonal change.

b. The harbor fill area inside the breakwater is the most critical area. Here the rate of accretion can be calculated readily. The outline and profile of the fill at the start of the surveys is known and complete outlines and profiles were made at each regular hydrographic survey. To establish a rate-of-fill, regular checks of the principal fill area were made at shorter intervals. These checks consisted of simple measurements made from fixed poles in the fill to the edge of the breakoff (which is very abrupt and makes a definite point). Slope of fill (angle of repose) remains constant and accretion was determined.

c. The erosion areas at Palm Park extending eastward to the anticipated limits of the principal erosion of the two-year cycle (between dredgings). This comprises the bulk of the surveys since the easterly limit is not known.

Wave Recorders - Pressure type wave recorders were installed at Santa Barbara, Elwood, and Pt. Arguello. The Santa Barbara unit was installed in 30 feet of water off the west end of the breakwater, with the recording unit being located in the harbormaster's office. As a means of checking wave characteristics and to generally assume continuity of the wave record, a Beach Erosion Board step-resistance gage and a Mark IX underwater pressure unit were installed on the Signal Oil and Gas Company pier at Elwood. Unexplained corrosion of the contact points of the step-resistance gage prevented this gage from yielding records; hence, it was removed from the pier.

The Elwood-Santa Barbara wave meters record highly refracted waves just before they break on the channel shore. To get at more basic wave information, it was decided to re-activate the Pt. Arguello recording station so that unrefracted ocean waves could be compared both with the channel waves and the deep-sea conditions as estimated by forecasts.

Wind Recorders - A "Dynes" type wind velocity and direction recorder was installed at the harbormaster's office at the start of the study. This instrument is basically a recording pitot tube - weather vane arrangement. Its purpose is to keep track of influence due to winds which might act to lower or reinforce arriving waves or generate currents, and to allow appraisal of sand movements due to wind. In the event that channel storms appear to be an important factor in the sand movement, this would be a great aid in hindcasting local wave conditions due to winds not shown on small scale meteorological maps. This instrument has worked satisfactorily from the beginning and the winds appear to follow a regular pattern with storm conditions rarely arising.

Summary - A summary of the work accomplished in the Santa Barbara study is presented in the report Issue 8, Series 14 (see Part VI). As indicated in this report most of the effort to date has been directed toward installing equipment, instituting a program of measurement, and obtaining data. Additional data should be obtained, however, in order that usable, valid conclusions be reached. It can be said that the work is now thoroughly organized; personnel are familiar with the area and its problems, waves and winds are being recorded, and inexpensive program of measuring sand flow rates is underway, and enough data have been obtained to determine the best course for future investigations. These results are somewhat intangible but probably are most valuable if the work is continued, Suggestions are made below for a continuing program. The emphasis needs to be on the solution of general coastal problems and the relation of the physical aspects of the ocean to the works of man on its shores. Data from the field has been analyzed and reduced to usable form and made graphical. The analytical part of the work should be done concurrently with the collection of additional data. When the statistics are considered in the light of personal impression, which is sometimes impossible to record, they will have much greater meaning.

Recommendations - Various references have been made to the value of having a continuing program of data collection and study. These are now briefly reviewed. It is emphasized that the value of much of this information lies in its continuity and even short gaps may make the record of limited value.

a. The wave recorders in Santa Barbara channel and on the open coast should be maintained.

b. Surveys of the perimeter of the fill should be made twice monthly with full surveys at four to six month intervals so there are flow rates of sand for short periods of time for correlation with wave action.

Both of these programs should be carried forward concurrently until at least a full year of record is obtained. This is particularly important if the dredging is to be delayed a year at a time that appears to be a maximum in sand flow. This should be started as soon as possible so that there will be no break in the record between the end of the present investigation (January 1, 1951) and the start of any additional one.

c. The movements of the sand before it reaches the harbor should be studied with a view to determining its primary source and the route and means by which it is moved into the critical area. It is particularly desirable to know whether an appreciable amount of the sand comes from beyond Point Conception. A study of mineral content of the sand and a petrological study of the rocks being moved would be of value in tracing the source. Roundness and sphericity ratios between the quartz and Feldspar might help determine the distance the detritus travels.

d. Considerable time needs to be spent in investigating the basic causes of sand movement. Present and past data need to be considered in the light of detailed observation of a large area of beach.

e. Waves need to be hindcast for the several stated periods so that past sand flow data will be comparable on a cause-and-effect basis with waves.

f. Other surveys which would be of value are (1) check surveys on the various profiles under study, especially at the feeder beach, (2) surveys of beaches much further to the west (near Pt. Conception), (3) pump probings to determine thickness of sand at westerly beaches which may be a major source of sand supply.

g. The nature of the bottom off Point Arguello and the possibility that sand is moving around the point in 60 feet of water should be explored.

WAVE RECORDERS AND WAVE DATA

For the past few years a number of wave recorders have been installed and operated along the Pacific Coast more or less continuously by various institutions and government agencies. The University of California, Berkeley, in cooperation with the U. S. Navy, instituted a program of wave recording at Several points along the Pacific Coast in 1947. Charts from these records have been analyzed for the significant wave height and the wave period. Wave direction also was determined in some instances from synoptic weather charts by the wave forecasting method. These various data were summarized in tabular form and distributed to various individuals, commercial concerns, and government agencies that were interested in this type of information. In a limited number of cases summaries of wave data have been published. (1) (2)

As part of this contract with the Beach Erosion Board the various wave recorders previously installed in cooperation with the Navy were maintained in operation and the records analyzed for the significant height and period. Because of the limited funds available for this phase of the study no purchase of recording equipment, cable, and offshore pressure elements was possible; hence, as an offshore unit became inoperative and required replacement the station was discontinued.

Stations that once were in operation included Heceta Head, Oregon; Pt. Pinos, California; Pt. Sur, California; Pt. Arguello, California; and Santa Barbara, California. A summary of dates for which wave data

(1) An Analysis of Data from Recorders on the Pacific Coast of the U.S. by R. L. Wiegel, Trans. Amer. Geoph. Union, Vol. 30, No. 5, 1949
(2) Southern Swell Observed at Oceanside, California from May through September, 1949, by R. L. Wiegel and H. L. Kimberley; Trans. Amer. Geoph. Union (in press).

are available at these and other Pacific Coast stations is presented in the report Issue No. 4, Series No. 14 (see Part VI).

Recommendations - It is highly desirable that certain key wave recording stations along the entire Pacific Coast be maintained in continuous operation to provide (a) statistical wave data for design purposes, (b) data for checking wave hindcasts which might be desired for intermediate localities, and (c) data for the development of storm tracking techniques and other investigations of both peacetime and wartime importance.

The most expensive part of wave recording installations is the armored submarine cable. Fortunately, the cables at the inactive California stations are still usable. The cable at Heceta Head, Oregon, probably is no longer usable; however, a supply of cable for this installation is in storage at Astoria, Oregon.

CLASSIFIED RESEARCH

Because of the classification of the research work completed under this task, no summary of the material is presented in this report. It should be mentioned, however, that the funds expended in this investigation were greater than originally anticipated; consequently, the scope of the investigations reported above and conducted under this contract was of necessity reduced.

LIST OF REPORTS

Institute of Engineering Research
(Series No. 14)

No. 1 - (Classified Research) - 3 Vols.

No. 2 - The Relationship Between Sand Size and Beach Face Slope: W. N. Bascom, April 1951

No. 3 - Initial Surveys and Instrumentation; Sand Transport Study, Santa Barbara, California, W. N. Bascom.

No. 4 - Wave Records on the Pacific Coast of the United States: J. W. Johnson, September 1950.

No. 5 - Sand Studies in Two Dimensional Wave Motion: E. A. Shay and J. W. Johnson, November 1950.

No. 6 - Influence of Groins on Beach Stabilization: E. A. Shay and J. W. Johnson, January 1951.

No. 7 - Model Studies on the Movement of Sand Transported by Wave Action Along a Straight Beach: E. A. Shay and J. W. Johnson, February 1951.

No. 8 - Investigation of Coastal Sand Movements Near Santa Barbara, California; W. N. Bascom, January 1951, Two parts.

No. 9 - Final Report on Sand Transportation by Wave Action: May 1951.

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ANNOUNCEMENT OF PUBLICATION

The Beach Erosion Board announces the publication of its Technical Memorandum No. 25, "The Slope of Lake Surfaces Under Variable Wind Stresses" and Technical Memorandum No. 26, "Sand Movement on the Shallow Inter-Canyon Shelf At La Jolla, California." Copies are being mailed to those individuals and institutions on the mailing list for technical publications.

A limited number of copies are available for distribution upon request to the President, Beach Erosion Board, Corps of Engineers, 5201 Little Falls Road, N. W., Washington 16, D. C.

DISCUSSION

A METHOD FOR DRAWING ORTHOGONALS SEAWARD FROM SHORE

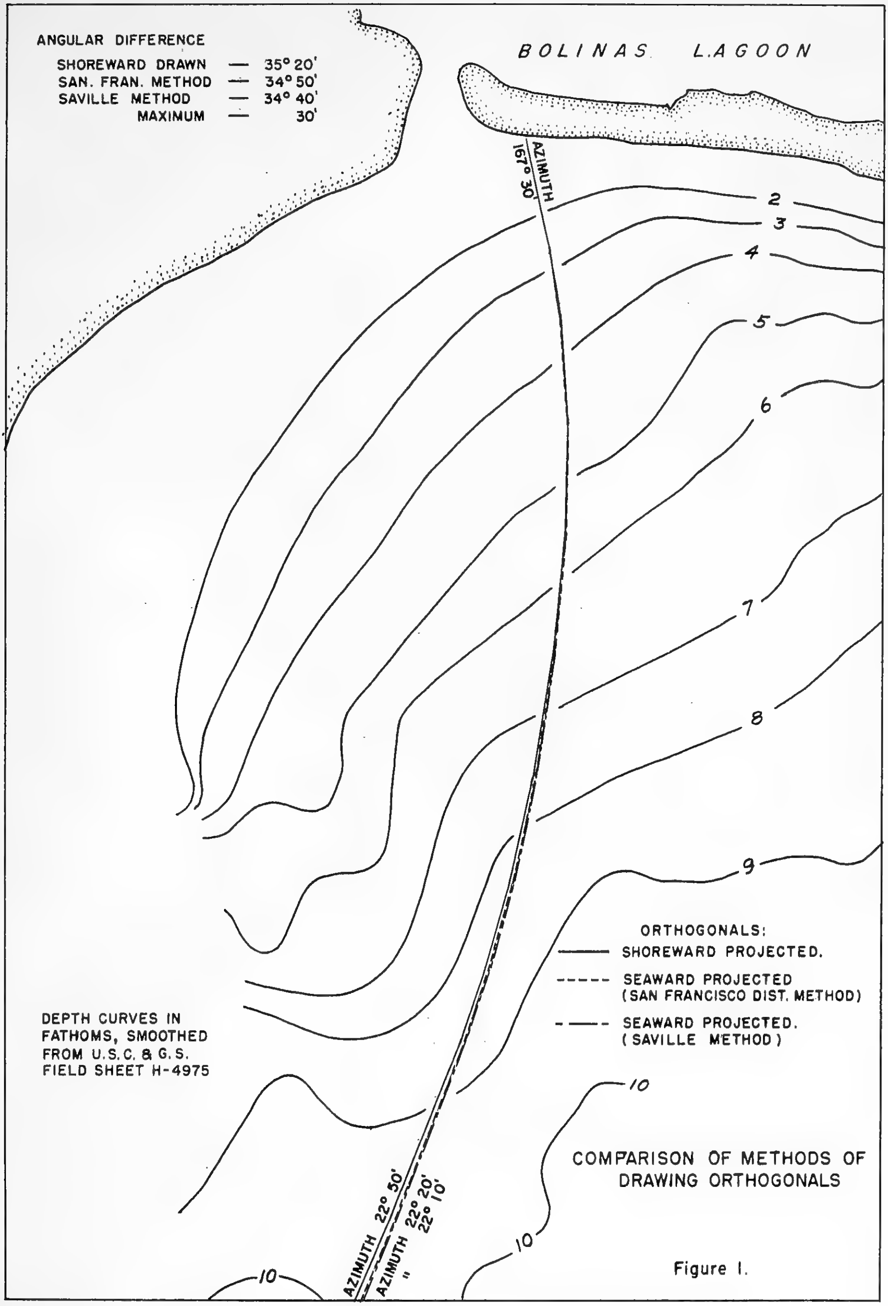
The Bulletin is always glad to receive discussion of its articles, and is pleased to present the following discussion of Mr. Saville's article "A Method for Drawing Orthogonals Seaward from Shore" which appeared in the October 1951 issue of the Bulletin. The discussion is by Mr. Kenneth Kaplan of the San Francisco District, Corps of Engineers.

In 1949 and 1950 this office was engaged in a general study of possible small-craft harbors on the northern California coast. This study required the drawing of many refraction diagrams, and for convenience, many refraction fans. The first attempts at drawing these fans were made merely by reversing Isaac's orthogonal technique; that is using for $\Delta\alpha$ that value determined from the standard nomograph with the calculated $\Delta L/L_{av.}$ value and a value for angle designated by the author as α' . This method, quite naturally, was found to be highly inaccurate for any situation in which the $\Delta\alpha$ was relatively large.

Accordingly, Mr. R. W. Lowe, formerly of this office, developed, in late 1949, a method which essentially consists of taking the first approximation of a successive approximation series for the determination of $\Delta\alpha$. The angle between the level line between contours and the normal to a seaward projected orthogonal is measured (call it α') and a value (say) $\Delta\alpha'$ is determined from Isaac's nomograph with this and the correct $\Delta L/L_{av.}$ value. These two values α' & $\Delta\alpha'$ are added to find the approximate value of α , which in turn is used to find the approximately correct $\Delta\alpha$. The method is simple, requires the use of no protractors (the drafting machine's two arms are ideal), and permits the drawing of orthogonals well within the accuracy desired.

The method the author presents is, of course, a refinement of the above but, since it makes necessary the use of additional protractors, I believe the refinement introduced is unwarranted. For the construction of a fan diagram either method will give approximately the same results, and the simpler one is to be preferred. In addition, an orthogonal constructed by use of either method cannot safely be used as a true orthogonal but merely as an indication of the correct deep-water position and direction of approach.

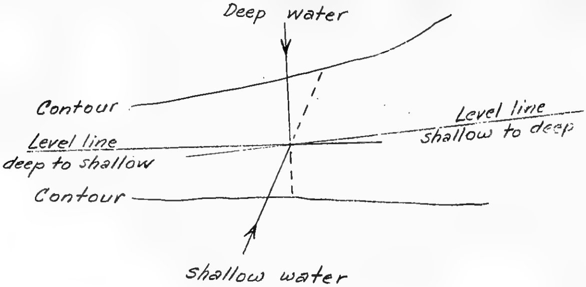
This last statement needs some amplification. A level line between two contours is established by averaging the angles between a projected orthogonal and the two contours. (See Johnson, O'Brien and Isaacs, H. O. Publication No. 605, page 26, step 6). Reference to the following figure shows that a level line so determined with a shoreward projected orthogonal may well differ from one determined with a seaward projected



ANGULAR DIFFERENCE
SHOREWARD DRAWN — 35° 20'
SAN. FRAN. METHOD — 34° 50'
SAVILLE METHOD — 34° 40'
MAXIMUM — 30'
BOLINAS LAGOON
AZIMUTH 167° 30'
2
3
4
5
6
7
8
9
10
10
10
ORTHOGONALS:
SHOREWARD PROJECTED.
SEAWARD PROJECTED (SAN FRANCISCO DIST. METHOD)
SEAWARD PROJECTED. (SAVILLE METHOD)
DEPTH CURVES IN FATHOMS, SMOOTHED FROM U.S.C. & G.S. FIELD SHEET H-4975
AZIMUTH 22° 50'
AZIMUTH 22° 20'
" 22° 10'
COMPARISON OF METHODS OF DRAWING ORTHOGONALS

Figure I.

orthogonal. The figure is exaggerated to be sure, but since the determination of an angle of turning depends on the "accurate" determination of the direction of a level line, it can be seen that a seaward projected orthogonal need not coincide with one projected shoreward over the same underwater topography. Since this is so, it would seem that the simpler method of constructing a seaward orthogonal is to be preferred.



It might be pointed out that the means prescribed in H. O. Publ. No. 605 for the determination of a level line is the one major weakness of the orthogonal method as presented in that paper. Assumption 5 on page 19 requires that a level line (make) "....equal angles with the adjacent contours ...", that is, that its direction is to be determined by a normal to a line representing the gradient between contours. An orthogonal projected rarely coincides with this direction of shortest distance between contours.

Figure 1 is a drawing comparing the accuracy of the two methods of seaward orthogonal projection with a standard shoreward projection. It was constructed by first drawing a standard orthogonal, and with the shallow water position and direction so determined constructing the two seaward projected orthogonals. The total angle of turning is indicated by the azimuths given at the seaward and shoreward ends of the orthogonals.

* * * * *

Author's Comments:

It is interesting to note the similarity in the two methods of solution to the problem of drawing orthogonals seaward from shore. The use of the new protractor represents a logical extension of Mr. Lowe's method, and since it substitutes a mechanical determination of the angle change for a mathematical computation, would seem to be preferable. Both methods, as indicated in Mr. Kaplan's figure, give almost identical results.

It might also be noted that, in actual practice, the direction of level bottom is usually determined by mentally interpolating an extra contour midway between the two contours being considered, and taking the direction of level bottom as a line tangent to this contour at its intersection with the orthogonal. It is thought that this method gives a more accurate determination than that given in H. O. Publ. No. 605 and referred to by Mr. Kaplan, and, in addition, has the advantage of giving the same direction for level bottom regardless of which direction the orthogonal is being drawn in.

ON THE EXPANSION OF SEA WAVES DUE TO THE EFFECT OF WIND
(based on measurements in shallow tidal waters)

by

Hans Ulrich Roll

This paper appeared in the German publication "Deutsche Hydrographische Zeitschrift", Vol. 2, No. 6, 1949. An English translation is on file at the Beach Erosion Board Library. An abstract of which is presented herewith.

Recent wave and wind measurements made in the tidal waters of the "Neuwerk Shallows" in the North Sea at the mouth of the Elbe River are described and are compared with the theoretical results based on the methods employed by Sverdrup and Munk. Most wave measurements were made where the wave length-water depth ratio was slightly greater than 2, the accepted transition value between deep and shallow water wave theory. However, in slightly over 80 per cent of the cases, the maximum deviations of wave height and velocity from the deep water values were only 7 per cent for the wave height and 4 per cent for the velocity, so for at least 80 per cent of the cases it should be expected that the relationship between wave velocity and length would be satisfactorily expressed by $C = \sqrt{gL/2\pi}$ as used by Sverdrup and Munk. The wave velocity measurements have been adjusted where necessary for the effect of tidal currents.

The adjusted values of wave velocity and the measured values of wave length follow the curve of the theoretical relationship ($C=\sqrt{\frac{gL}{2\pi}\frac{Q_W-Q_L}{Q_W+Q_L}+\frac{2\pi\gamma}{L(Q_W+Q_L)}}$) relatively well (shown in Figure 1) except that the main body of plotted points lies below the curve, indicating that the theory seems to represent the upper limit of the measured values rather than their average. As shown in Figure 2 the author relates this negative deviation of measured ~~theatrical~~ wave → from theoretical velocities as computed from the LaPlace formula $C=\sqrt{\frac{gL}{2\pi}\tanh\frac{2\pi h}{L}}$ to the wave steepness and wind velocity. Empirically it is indicated that this negative deviation becomes larger as the waves become steeper with a fixed wave length, and becomes smaller with an increase in wind velocity.

The empirical relation between wave steepness and wave age as developed by Sverdrup and Munk is compared with the measured values at Neuwerk, and is shown in Figure 3. The author suggests that it appears problematical that this relatively wide dispersion of plotted

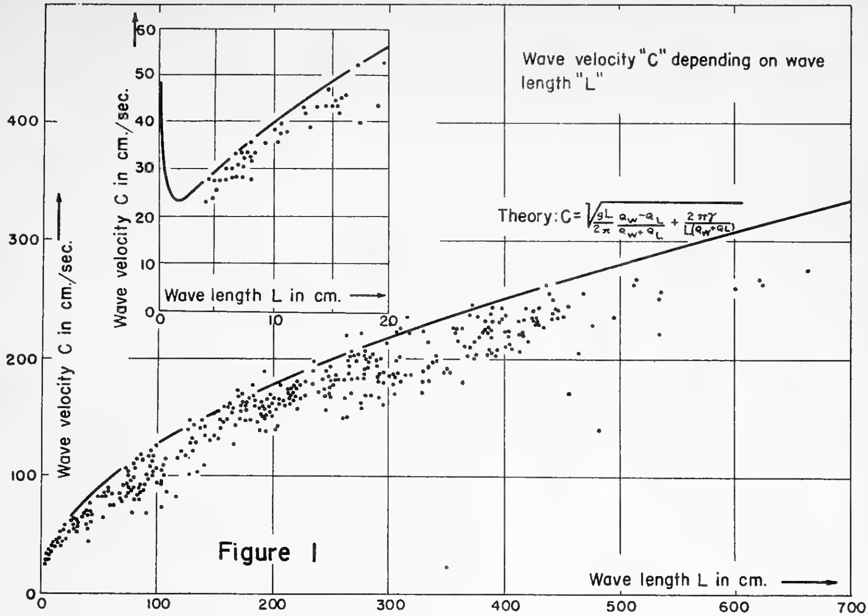


Figure 1

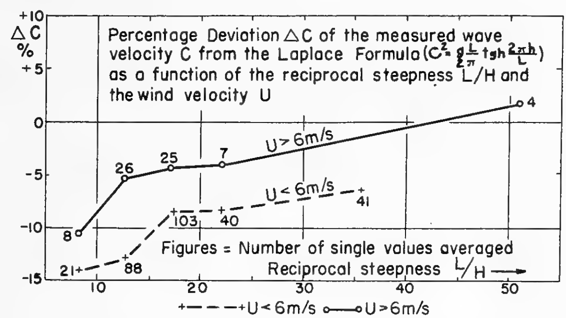


Figure 2

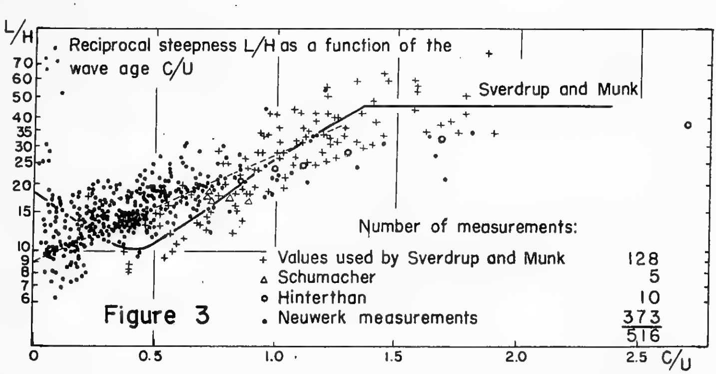
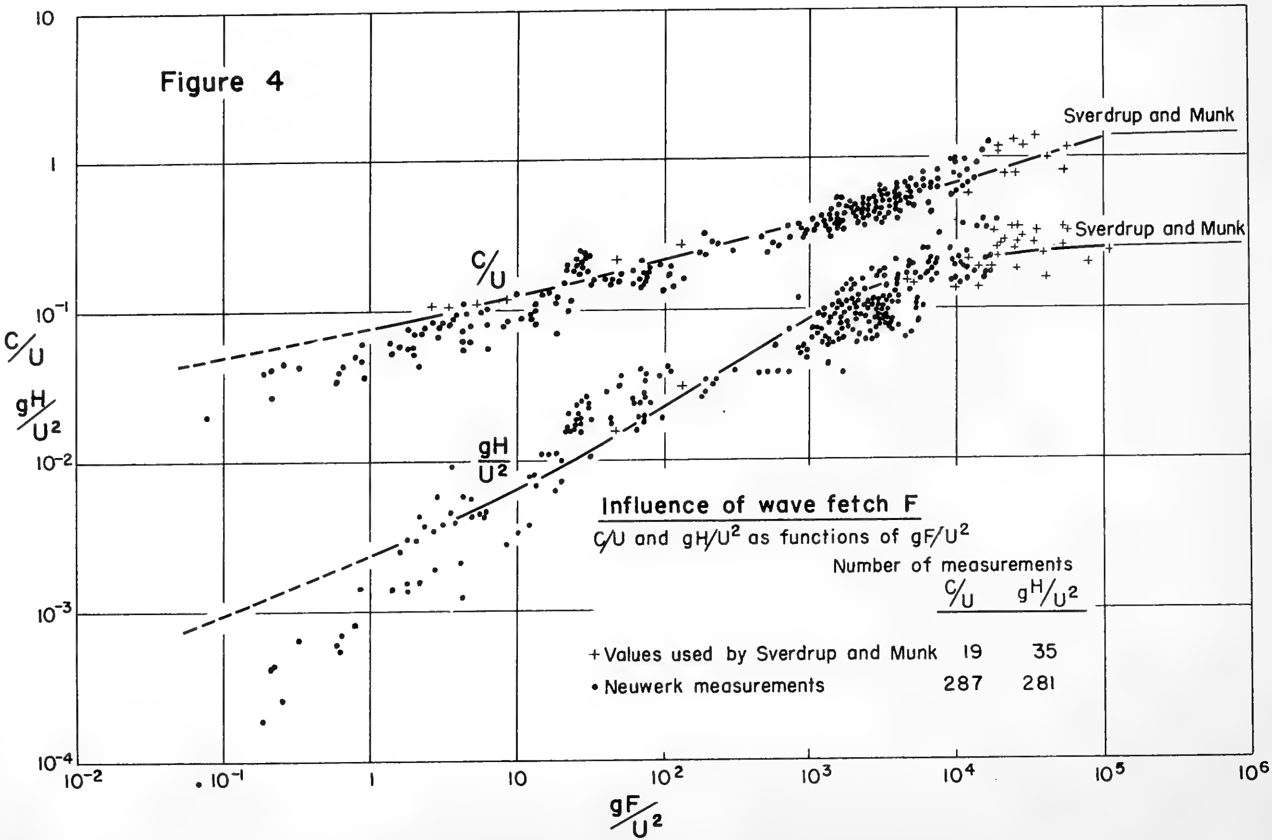


Figure 3

Figure 4


Sverdrup and Munk
Sverdrup and Munk
C/U
gH/U²
Influence of wave fetch F
C/U and gH/U² as functions of gF/U²
Number of measurements
C/U gH/U²
+ Values used by Sverdrup and Munk 19 35
• Neuwerk measurements 287 281
gF/U²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻²
10⁻¹
1
10
10²
10³
10⁴
10⁵
10⁶

points can be represented by a curve, but if it is attempted "it might be expedient to depart from the curve given by Sverdrup and Munk somewhat in the manner indicated by the dashed line in Figure 3." He states further that a very considerable increase in steepness is assumed with the youngest waves immediately after their formation, then their steepness very quickly approaches the relation as shown by the dashed line in Figure 3, and that the relationship between steepness and wave age is not yet completely explained.

The influence of the fetch on wave height and wave age as developed by Sverdrup and Munk is compared with that indicated by the Neuwerk wave measurements in Figure 4, and generally speaking, agreement may be regarded as satisfactory. Differences that are apparent are believed by the author to be not wholly the result of inaccurracies in measurement, but probably are due more to the minor descrepancies previously shown between theory and measured values. However, the author regards the results of the Neuwerk wave and wind measurements as a verification of the Sverdrup-Munk theory on the growth of sea waves due to the influence of the wind.

THE GENERATION OF WATER WAVES BY WIND

by

Gerhard Neumann

This paper appeared in the German publication "Deutsche Hydrographische Zeitschrift", Vol. 2, No. 5, 1949. An English translation is on file at the Beach Erosion Board Library. An abstract of which is presented herewith. The author is currently a visiting professor to the staff at New York University

Classical considerations of wave formation by others have been investigated by the author, and a new treatment of this problem is presented. Theory is presented for computing the length and amplitude of initial waves generated by incident winds of different velocities, which is valid until the initial waves attain a steepness where they are no longer stable and turbulence occurs. The energy supplied by the wind to the water surface is computed, assuming dynamic equilibrium of the effective shearing stress of the wind and resistance to this stress offered by the water surface. An empirical relationship between the effective shearing stress of the wind and the wind velocity has been determined. Surface resistance has been considered as the resistance due to pressure differences for both capillary and gravity waves, and that due to frictional stresses. Values of a "resistance coefficient" have been computed for different values of wind velocity, and this coefficient is indicated empirically to be simply proportional to the wave steepness. The energy dissipated by the wave motion is considered for a water layer of finite depth, and is computed as that consumed by inner friction in the water and that dissipated through bottom friction. For the generated wave to be propagated and maintained, it is necessary that the energy transmitted to the wave by the wind be greater than that dissipated by the wave motion. From this consideration, equation 18 below is obtained.

$$\frac{1}{4}\frac{\rho'}{\rho} s \frac{(v_m-\sigma)^2}{\chi \nu \sigma} \operatorname{tgh}(\chi h) \geqq a\chi + \frac{a}{2\nu}\sqrt{\frac{\chi\sigma\nu}{2}}\,\frac{1}{\sinh(2\chi h)} \qquad (18)$$

where:

ρ' = density of air
ρ = density of water
s = screening coefficient
v_m = wind velocity
σ = wave transmission velocity
ν = kinematic viscosity
χ = wave no. = $2\pi/\lambda$
h = water depth
a = wave amplitude

It follows that there is a lower limit of wind velocity below which waves will not be generated. The change in the wave amplitude with time is computed from a consideration of the difference of the energy supplied and that dissipated by the wave with respect to time, and can be expressed in the following form:

$$\frac{da}{dt} = \frac{s}{2}\frac{\rho'}{\rho}\frac{(v-\sigma)^2}{\sigma} tgh(\chi h) - \left(2\nu\chi^2 + \chi\frac{\sqrt{1/2\,\chi\sigma\nu}}{\sinh(2\chi h)}\right)a \qquad (20)$$

Integration of equation 20 gives:

$$t = \frac{1}{C_2}\ln\frac{C_1 - C_2 a'}{C_1 - C_2 a} \qquad (21)$$

where a' is the wave amplitude at the beginning of the time interval and $C_1 = \frac{s}{2}\frac{\rho'}{\rho}\frac{(v-\sigma)^2}{\sigma}$, and $C_2 = 2\nu\chi^2 + \chi\frac{\sqrt{1/2\,\chi\sigma\nu}}{\sinh(2\chi h)}$.

Experimentally it has been shown that there is a definite maximum wave amplitude for a given wind velocity which cannot be exceeded regardless of the duration of the wind velocity.

The author deduces that any wind with a velocity greater than 69.5 cm. per second is capable of generating waves, and the combined effect of capillarity and gravity produces two separate wave trains. Table I gives the computed values of the length and height of waves of maximum steepness that can be generated in depths greater than the wave length, by winds with velocities from 70 to 122.7 cm. per second.

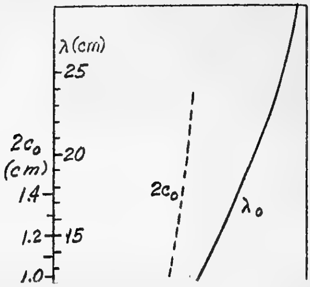
TABLE I

v_m (cm/sec)	70		80		90		100	
λ_o (cm)	2.05	1.45	3.71	0.80	5.19	0.57	6.68	0.44
σ (cm/sec)	23.3		26.9		30.0		33.2	
a_o/λ_o	0.00782	0.00591	0.01590	0.00343	0.0254	0.00279	0.0366	~~0.0241~~ 0.00241
$2a_o = H$ (cm)	0.032	0.017	0.118	0.0055	0.264	0.0032	0.49	0.0022

v_m (cm/sec)	122.7	
λ_o (cm)	10.46	0.28
σ (cm/sec)	41.2	
a_o/λ_o	0.069	0.00184
$2a_o = H$ (cm)	1.444	0.0010

With an increasing wind velocity, the shorter, capillary waves decrease rapidly in contrast with the increasing gravity waves, until with wind velocities of about 90 to 100 cm per second they practically disappear. It is indicated that waves with the maximum stable steepness ratio (height to length) of 1 to 7 are attained with a wind velocity of about 122.7 cm. per second. The plot in Figure itial waves with th Tables II a and b g puted time required itial wave to "matu... or to grow to a stationary condition, for wind velocities of 80 and 122.7 cm. per second.

The 3rd sentence should read; "The plot in Figure 1 shows graphically the variation of the wave length and stationary height for initial waves with the wind velocity."



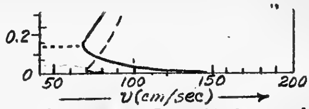


Figure 1 - Wave length λ_0 and wave height $2\ a_0$ with stationary initial waves in their dependency on the wind velocity v.

Further computation has been made by the author for the generation of waves by winds over shallow water layers, or where the wave length is greater than the water depth. It is significantly shown that as the water depth ~~because~~ decrease for a given wind velocity the length of the initial waves becomes shorter, and the wind velocity necessary for the generation of clearly recognizable wave trains becomes greater. The time required for "mature" waves to be generated in shallow water depths is essentially less than that required for greater depths. Table III gives, for several water depths, the lengths of initial waves with a steepness (amplitude divided by wave length) of 0.07, and also the wind velocities required to generate these waves.

TABLE II a

1) Principal Wave (λ_0 = 3.71 cm.)

a cm.	0	0.01	0.02	0.03	0.04	0.05	0.055
t sec.	0	1.7	4.0	6.9	11.1	18.6	26.7

2) Secondary Wave (λ'_0 = 0.80 cm.)

a cm	0	0.0005	0.0010	0.0020	0.0027
t sec.	0	0.09	0.205	0.59	1.86

TABLE II b

a cm.	0	0.1	0.2	0.3	0.4	0.5
t sec.	0	11.4	24.9	41.1	62.5	91.5

a cm.	0.6	0.7
t sec.	138	272

TABLE III

h (cm)	λ_o cm.	v_m cm/sec
0,5	1,85	204
1,0	2,75	160
2,0	4,45	135
3,0	6,10	130
5,0	8,5	125
7,0	9,8	123,2
10,0	10,3	123,1
∞	10,5	123,0

Table IV indicates, for a water depth of 1 cm and wind velocity of 160 cm. per second, the time required for the initial wave of steepest form (λ_o = 2.75 cm.) to approach the stationary amplitude.

TABLE IV

a cm.	0	0,01	0,05	0,08	0,10	0,12	0,14	0,19
t sec.	0	0,27	1,36	2,16	2,93	3,86	5,08	12,3

BEACH EROSION STUDIES

The principal types of beach erosion control studies of specific localities are the following:

a. Cooperative studies (authorization by the Chief of Engineers in accordance with Section 2, River and Harbor Act approved 3 July 1930).

b. Preliminary examination and surveys (Congressional authorization by reference to locality by name).

c. Reports on shore line changes which may result from improvements of the entrances at the mouths of rivers and inlets (Section 5, Public Law No. 409, 74th Congress).

d. Reports on shore protection of Federal property (authorization by the Chief of Engineers).

Of these types of studies, cooperative beach erosion studies are the type most frequently made when a community desires investigation of its particular problem. As these studies have greater general interest, information concerning studies of specific localities contained in these quarterly bulletins will be confined to cooperative studies. Information about other types of studies can be obtained upon inquiry to this office.

Cooperative studies of beach erosion are studies made by the Corps of Engineers in cooperation with appropriate agencies of the various States by authority of Section 2, of the River and Harbor Act approved 3 July 1930. By executive ruling the cost of these studies is divided equally between the United States and the cooperating agency. Information concerning the initiation of the cooperative study may be obtained from any District Engineer of the Corps of Engineers. After a report on a cooperative study has been transmitted to Congress, a summary thereof is included in the next issue of this bulletin. A list of authorized cooperative studies follows:

AUTHORIZED COOPERATIVE BEACH EROSION STUDIES

NEW HAMPSHIRE

HAMPTON BEACH. Cooperative Agency: New Hampshire Shore and Beach Preservation and Development Commission.

Problem: To determine the best method of preventing further erosion and of stabilizing and restoring the beaches, also to determine the extent of Federal aid in any proposed plans of protection and improvement.

MASSACHUSETTS

PEMBERTON POINT TO GURNET POINT. Cooperating Agency: Department of Public Works, Commonwealth of Massachusetts.

Problem: To determine the best methods of shore protection prevention of further erosion and improvement of beaches, and specifically to develop plans for protection of Crescent Beach, The Glades, North Scituate Beach and Brant Rock.

STATE OF CONNECTICUT. Cooperating Agency: State of Connecticut (Acting through the Flood Control and Water Policy Commission).

Problem: To determine the most suitable methods of stabilizing and improving the shore line. Sections of the coast are being studied in order of priority as requested by the cooperating agency until the entire coast has been included.

NEW YORK

JONES BEACH. Cooperating Agency. Long Island State Parks Commission

Problem: To determine behavior of the shore during a 12-month cycle, including study of littoral drift, wave refraction and movement of artificial sand supply between Fire Island and Jones Inlets.

NEW JERSEY

OCEAN CITY. Cooperating Agency: City of Ocean City

Problem: To determine the causes of erosion or accretion and the effect of previously constructed groins and structures, and to recommend remedial measures to prevent further erosion and to restore the beaches.

STATE OF NEW JERSEY. Cooperating Agency: Department of Conservation and Economic Development.

Problem: To determine the best method of preventing further erosion and stabilizing and restoring the beaches, to recommend remedial measures, and to formulate a comprehensive plan for beach preservation of or coastal protection.

VIRGINIA

VIRGINIA BEACH. Cooperating Agency: Town of Virginia Beach.

Problem: To determine the methods for the imrpovement and protection of the beach and existing concrete sea wall.

FLORIDA

PINELLAS COUNTY. Cooperating Agency: Board of County Commissioners.

Problem: To determine the best methods of preventing further recession of the gulf shore line, stabilizing the gulf shores of certain passes, and widening certain beaches within the study area.

LOUISIANA

LAKE PONTCHARTRAIN. Cooperating Agency: Board of Levee Commissioners, Orleans Levee District.

Problem: To determine the best method of effecting necessary repairs to the existing sea wall and the desirability of building an artificial beach to provide protection to the wall and also to provide additional recreational beach area.

TEXAS

GALVESTON COUNTY. Cooperating Agency: County Commissioners Court of Galveston County.

Problem: To determine the best method of providing a permanent beach and the necessity for further protection or extending the sea wall within the area bounded by the Galveston South Jetty and Eight Mile Road.

To determine the most practicable and economical method of preventing or retarding bank recession on the shore of Galveston Bay between April Fool Point and Kemah.

CALIFORNIA

STATE OF CALIFORNIA. Cooperating Agency. Division of Beaches and Parks, State of California.

Problem: To conduct a study of the problems of beach erosion and shore protection along the entire coast of California. The current study covers the Santa Cruz area.

WISCONSIN

RACINE COUNTY. Cooperating Agency: Racine County.

Problem: To prevent erosion by waves and currents, and to determine the most suitable methods for protection, restoration and development of beaches.

KENOSHA. Cooperating Agency: City of Kenosha.

Problem: To determine the best method of shore protection and beach erosion control.

OHIO

STATE OF OHIO. Cooperating Agency: State of Ohio (Acting through the Superintendent of Public Works).

Problem: To determine the best method of preventing further erosion of and stabilizing existing beaches, of restoring and creating new beaches, and appropriate locations for the development of recreational facilities by the State along the Lake Erie shore line. Sections of the coast are being studied in order of priority as requested by the cooperating agency until the entire coast has been included.

TERRITORY OF HAWAII

WAIKIKI BEACH
WAIMEA & HANAPEPE, KAUAI. Cooperating Agency: Board of Harbor Commissioners, Territory of Hawaii.

Problem: To determine the most suitable method of preventing erosion, and of increasing the usable recreational beach area, and to determine the extent of Federal aid in effecting the desired improvement.

BEACH EROSION LITERATURE

The first national conference on Coastal Engineering, sponsored by the Department of Engineering and the Division of Engineering Extension of the University of California, was held at Long Beach, California, in October 1950. The Proceedings of the conference, published by the Council on Wave Research, may be ordered from Professor J. W. Johnson, Waves Council, 245 Hesse Hall, University of California, Berkeley 4, California. A second conference was held in Houston, Texas, in November 1951, the Proceedings of which will probably be published at a later date.

The contents of the Proceedings of the first conference are as follows:

Part I
Basic Principles of Wave Motion

Part 2
Basic Design Data

Part 3
Coastal Sediment Problems

Part 4
SITE CRITERIA AND THE DESIGN AND CONSTRUCTION OF COASTAL WORKS

Part 5
Case Histories of Coastal Projects