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THE REFLECTING POWER OF MARITIME WORKS EXPOSED TO ACTION OF THE WAVES

by

M. Miche

This paper in the French language was published in the May-June 1951 Annals of the Highway Department, National Press (France). An English translation is on file at the Beach Erosion Board Library. An abstract of this paper with the major findings of the author is presented herewith. A translation from the Spanish of a paper by Ramon Irribarren Cavanilles and Casto Nogales Y Olano entitled "Limiting Batter (Slope) Between the Breaking and Reflection of Waves" appeared in volume 5, issue number 1 of the Bulletin dated 1 April 1951. In that paper a formula for the limiting slope of a structure exposed to wave action was evolved in terms of the wave characteristics, where slopes flatter than the limiting slope tend to give total breaking and steeper slopes tend to give total reflection of the incident wave. This paper by Mr. Miche is an extension to the work by Irribarren and Nogales in that Mr. Miche evolves relationships, useful in design, for determining the amplitude of the reflected wave for particular incident waves and types and slopes of the intercepting structures.

In the paper the author discusses the general considerations involved in determining the ability of a maritime structure to reflect sea waves. His findings are based on the conditions that the wave does not break before reaching the structure or overtop the structure after reaching it, the waves attack the structure frontally or are unaffected by refraction or diffraction, the structure is not convex or concave seaward, and that the structure has a continuous slope, or a form capable of being expressed as an equivalent slope.

The maximum value of the steepness ratio γ_o max in deep water of a wave capable of being, theoretically, totally reflected by a structure inclined at angle α with the horizontal is given by the formula:

$$\gamma_o \max = \sqrt{\frac{2\alpha}{\pi}} \times \frac{\sin^2\alpha}{\pi} \tag{1}$$

or if $\alpha \leqslant 15^\circ$ (tan α about 0.27), the formula approximates:

$$\gamma_o \max = \frac{i^{5/2}}{4} \qquad \text{(where } i = \tan\alpha \text{)} \tag{1'}$$

Figure 1 shows this relationship graphically.

The author compares results from the above formula 1 with test data obtained by Irribarren and Nogales to verify their own formula ($i = 4/T \sqrt{h/g}$) and this comparison is shown in Table 1. Comparison of columns 4 and 7 shows remarkably good agreement.

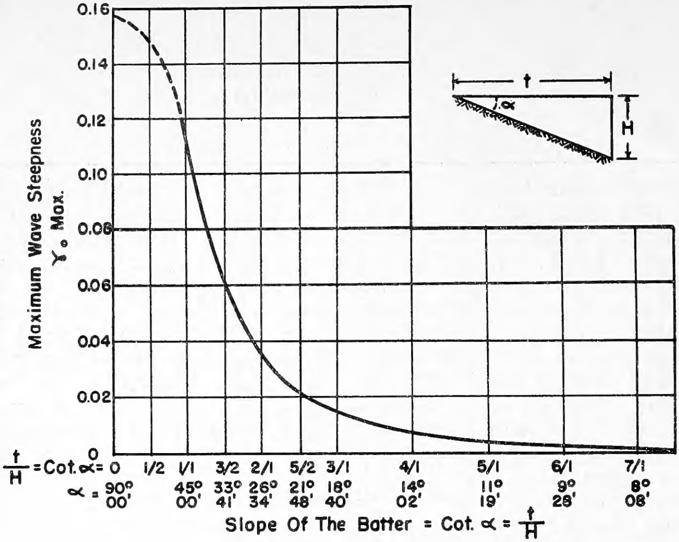


FIG. 1. THEORETICAL MAXIMUM STEEPNESS RATIO OF A WAVE CAPABLE OF BEING TOTALLY REFLECTED BY A BATTER

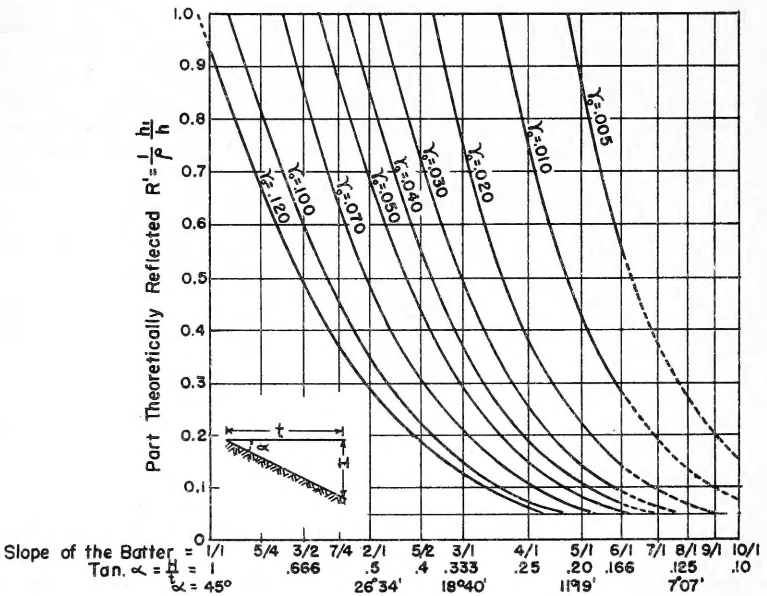


FIG. 2. REFLECTING POWER OF A BATTER WITH SLOPE $\frac{t}{H}$ DEPENDENT ON THE WAVE STEEPNESS RATIO IN DEEP WATER γ_o

TABLE 1

Characteristics of Waves		Measurement of Slopes ($i = Tg\alpha$).			Computed Slopes Irribarren Formula	Slopes Deduced from Formula 1
2h (cm.) 1	2T (sec.) 2	Total breaking 3	Total Reflection 4	Average 5	$i = \frac{4}{T}\sqrt{h/g}$ 6	$i = Tg\alpha$ 7
5.5	0.66	0.42	0.86	0.64	0.66	0.80
4.5	0.92	0.29	0.59	0.44	0.42	0.50
4.5	1.00	0.33	0.49	0.41	0.38	0.46

The reflecting power (R) of the maritime works is defined as the ratio between the amplitudes of the reflected and incident swells or $2h_1/2h$; $R = h_1/h$. From equation 1 the author deduces that theoretically the reflecting power (R') would have the following value:

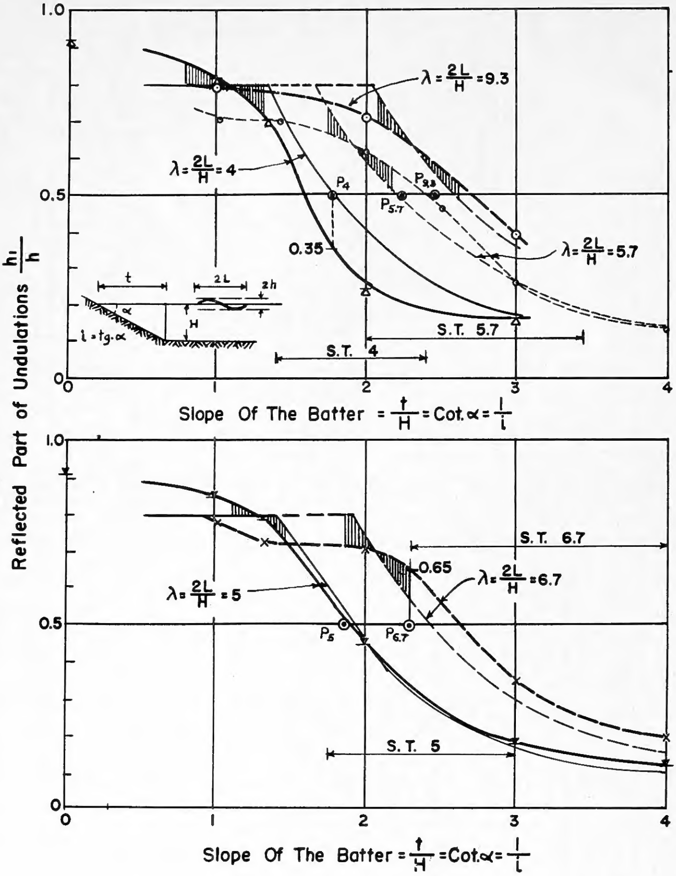
$$R' = \frac{\gamma_o \text{ max (from equation 1)}}{\gamma_o \text{ (actual)}} \quad \text{, where } R' < 1 \tag{2}$$

Then also the portion of the reflected wave energy is reduced due to the turbulence produced in the orbital movement at contact with the active part of the slope (that portion of the slope between one wave height 2h above the mean water level and one wave height below). A coefficient ρ for "intrinsic" reflection of the structure is introduced in equation 2 such that:

$$R = h_1/h = \rho R' \tag{3}$$

Figure 2 shows graphically the theoretical reflecting power (R') plotted against the parameters of slope and deep water steepness ratio of the incident wave. Multiplication of the ordinate (R') by the coefficient ρ yields the reflecting power (R) of the slope for a wave of particular steepness.

The author applies data from experimental tests made at the Laboratory of Delft by Schoemaker and Thijsse to verify his theory outlined above. Comparison of experimental measurement and application of equations 2 and 3 are shown in Figures 3 and 4 for smooth structures with continuous slopes and in Figure 5 for discontinuous slopes. It is noted that values of the "intrinsic" coefficient of reflection ρ of 0.8 and 0.7 respectively were used for this comparison. For the case of the discontinuous slopes with the vertical face at the toe (tests b) the reflected wave appears reduced



FIGS. 3 AND 4

REFLECTION OF SWELL ON BATTERS OF CONSTANT SLOPE

TESTS a

Note: 1. Experimental points corresponding to the same wave length-water depth ratio are connected by continuous curves.

2. Comparative curves with the angular point were figured from equations 2 and 3 utilizing an "intrinsic" reflection coefficient $\rho = 0.8$

3. Points marked P are those given by Irribarren's formula.

4. In the tests the actual incident wave steepness was between 1/15 and 1/20. Accuracy of measurements however was limited for smaller amplitudes. Therefore, for purposes of computation wave steepness of 1/15 for short waves and 1/20 for long waves were used.

5. Segment marked S.T. with index number showing value of λ is the Shoemaker and Thijsse zone of transition between strong and weak reflections, with limiting slopes computed from the inequality $- 0.35 \times \frac{2L}{H} < t/H < 0.6 \times \frac{2L}{H}$

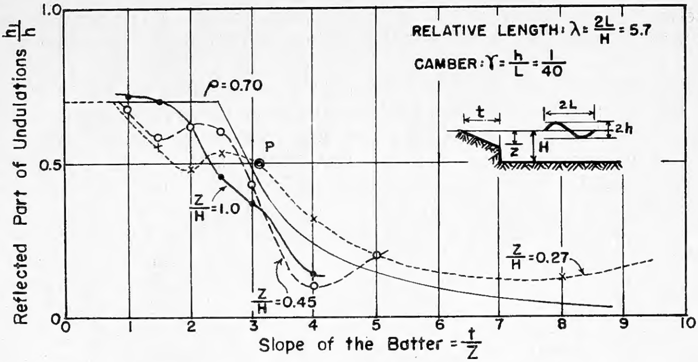


FIG. 5. REFLECTION OF SWELL ON BATTERS WITH DISCONTINUOUS SLOPE TESTS b

Note: 1. Experimental points corresponding to the same value of the ratio Z/H are connected by continuous curves.

2. The comparative curve with the angular point was figured from equations 2 and 3, using the values given for λ and Υ, (whence Υ_0) and an "intrinsic" coefficient of reflection ρ = 0.7

3. The point marked P is that given by the Irribarren formula.

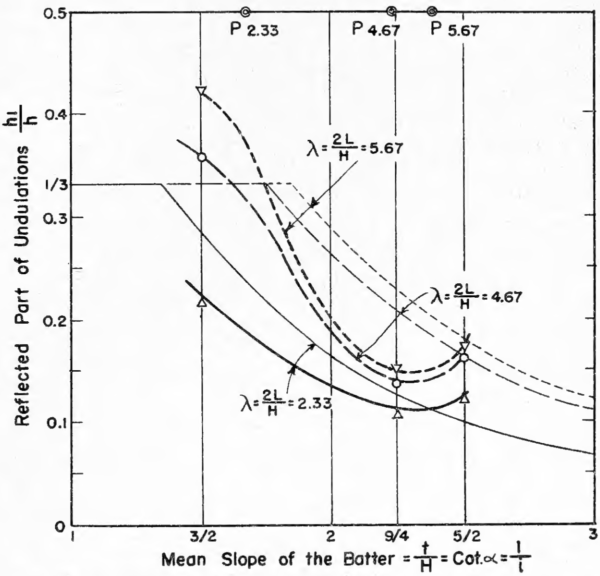


FIG. 6. REFLECTION OF SWELL ON SEAWALLS OF ENROCKMENTS AND ARTIFICIAL BLOCKS

Note: 1. Experimental points corresponding to the same wave length-water depth ratio are connected by continuous curves.

2. Comparative curves with angular point were figured from equations 2 and 3, using an "intrinsic" reflection coefficient ρ = 0.33

3. Points marked P are those given by Irribarren's formula.

for the steeper slopes, which influenced the author to assign a smaller "intrinsic" coefficient of reflection ρ to the discontinuous slopes.

Computations for the coefficient ρ from a minimum of available data for different types of structures from widely scattered sources showed considerable variation as expected, but the number of cases involved was insufficient for correlation. It appears in general, however, that the value of ρ is considerably less than the 0.8 and 0.7 used by the author for the case of a smooth impermeable slope. In Figure 6 there are summarized test results made systematically on large scale models (1:50) of seawalls constructed of rock and artificial blocks, and comparison is made with computed curves derived by equations 2 and 3 with ρ valued at 0.33. The author notes that in this case the Irribarren and Nogales formula "used for computation of batter limit would no longer be suitable without adjustment. In fact, the part effectively reflected which this formula gives for slopes is very sharply inferior to 50 percent (about a third)."

Conclusions presented by the author are summarized below. The reflecting power R of works built along the coast, being the ratio of the amplitudes of the reflected wave to that of the incident wave, varies according to the geometrical form (slope) of the structure and also with the physical nature of the surface in contact with the wave. Equation 2 is apparently a correct relationship for determining the effect of form on reflecting power, and shows that from a maximum value, or unity, the theoretical reflecting power R' decreases rapidly with decreasing slope, and decreases less rapidly with increasing steepness of the incident wave. The factor of the physical nature of the reflecting surface or the "intrinsic" coefficient of reflection ρ varies as the turbulence developed on contact of the wave with the reflecting surface. "For swells attacking the obstacle frontally or with moderate obliquity, its value seems to oscillate around 0.8 for relatively smooth batters, not very permeable and not washed over (overtopped) by incident waves; it diminishes, the whole being subject to certain variations, for rough batters, permeable or partly cleared (overtopped) by waves. In a well studied case, this factor has then been found to equal about 0.33."

By use of the expression $R = \rho R'$ it is possible for the maximum wave amplitude (the sum of the amplitudes of the incident and reflected waves) to be determined immediately adjacent to the seaward face of a reflecting structure. To do this it is necessary to know the steepness ratio of the incident waves (preferably maximum and minimum) and the value for the "intrinsic" coefficient of reflection. For the latter a value of 0.8 is frequently suitable for smooth surfaces. However for smooth surfaces with steep slopes or vertical faces, where turbulence is reduced to a minimum, a value of one may be chosen, in agreement with current practice, which assumes the condition of clapotis where the maximum amplitude near the structure is twice the amplitude of the incident wave. For exterior coastal works constructed of enrockments or artificial blocks, this coefficient ρ is much smaller. Additional systematic tests are necessary to finally fix its value, but temporarily a coefficient of 0.3 should be considered as a minimum and a value of 0.6 as that assuring sufficient conservancy.

Use of the formula derived by Irribarren and Nogales should be limited to smooth surfaces not overtopped by the waves and gives the slope with a reflecting power of about 50 percent. If used with the rougher reflecting surfaces it is greatly over-conservative.

As the recommended values of the coefficient ρ are presently supported by a limited number of observations, additional testing is desirable to complete existing data and evaluate the various factors involved. Some examples are given as:

1. Influence of pronounced obliquity in direction of wave attack;

2. Influence of roughness of surface in contact with waves in relation to dimensions of the waves;

3. Influence of permeability of structures, or their capacity for absorption during uprush of the waves;

4. Influence of overtopping of the structure by waves;

5. Cases of beaches or very flat slopes for which the validity of equation 2 is problematical.

Additional investigation is also desirable to determine the character and magnitude of forces, shocks and general pressures to which the structures are submitted during wave attack.

Application of the methods described in this paper for determining reflecting power of the structures bounding an expanse of water does not of course give the maximum wave amplitude that can be expected at any point within the bounded expanse of water, but does define one necessary stage in such a complex problem.

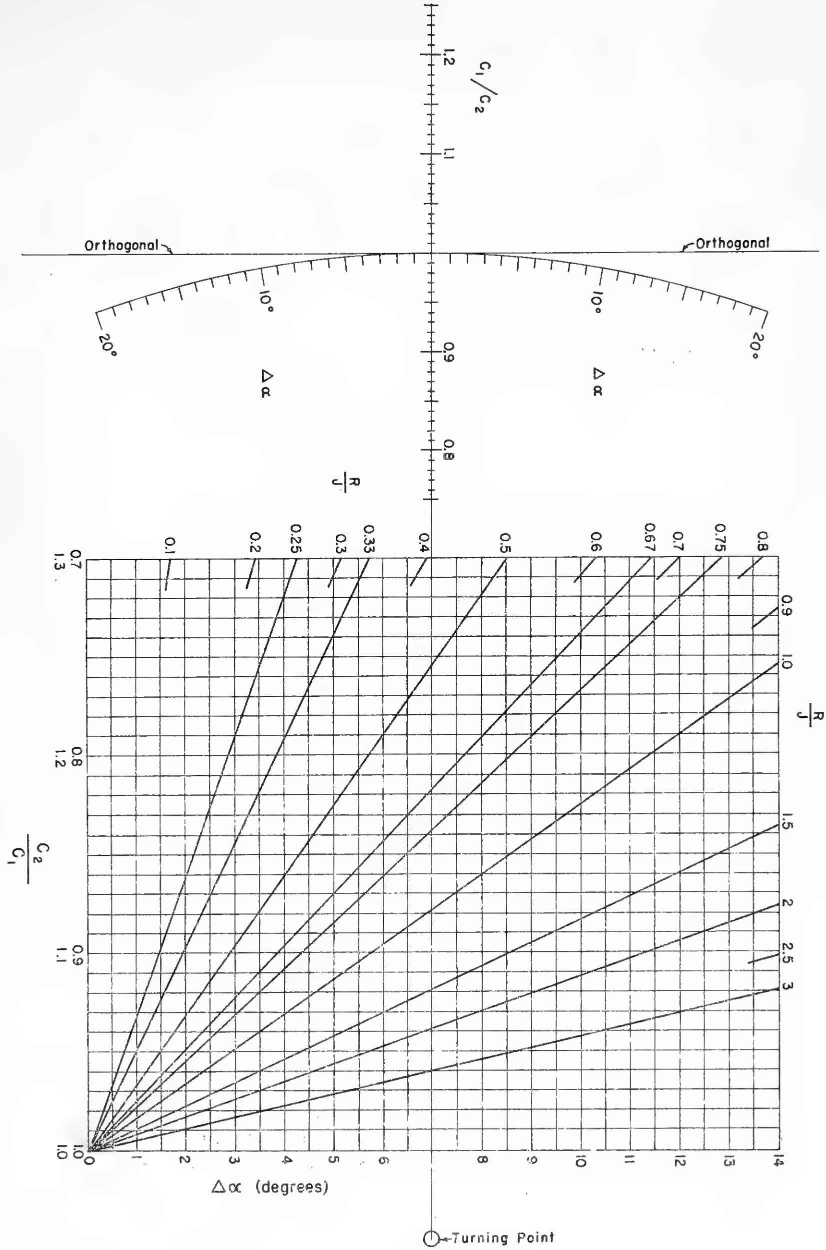
NOTICE OF PUBLICATION FOR NEW METHOD OF DRAWING WAVE REFRACTION DIAGRAMS

The Board wishes to call the attention of coastal engineers to an article on a new method of drawing wave refraction diagrams published in the Transactions of the American Geophysical Union, Volume 33, Number 6, December 1952. The article, entitled "The Direct Construction of Wave Rays" is by R. S. Arthur, W. H. Munk, and J. D. Isaacs.

The method employs a new type of overlay shown in Figure 1. The use of this overlay for ordinary cases (α less than 80°) is shown in Figure 2. From the wave period, values of C_1/C_2 for each contour interval may be computed. (C is the wave velocity, and the subscript 1 refers to the first of the two contours reached by the orthogonal, and the subscript 2 to the second. In the usual case the first contour will be the one toward deeper water, but the method works equally well whether proceeding from deep to shallow water, or shallow to deep water). To construct the orthogonal, sketch in a mid-contour between the two contours to be crossed, extend the orthogonal (in its original direction) to this mid-contour, and construct a tangent to the mid-contour at this point of intersection. Lay the line (on the overlay) labeled "orthogonal" along the incoming orthogonal with the point marked 1.0 at the intersection of orthogonal and mid-contour (see Figure 2a). Rotate the template about the "turning point" until the C_1/C_2 value corresponding to the contour interval being crossed intersects the tangent to the mid-contour. The turned orthogonal is drawn in this direction from a point on the incoming orthogonal equidistant from the two contours, when these distances (from point to contours) are measured along the incoming and turned orthogonals (see Figure 2b). The line so drawn is the "incoming orthogonal" for the next contour interval.

There is no difference in R/J procedures, and $\Delta\alpha$ values for R/J and C_1/C_2 are graphed on the template. An angular protractor has been put on the template to aid in turning these angles.

This new method of constructing refraction diagrams has been studied and used by personnel of the Board, and it is felt that it represents, in general, a simpler and quicker method of constructing refraction diagrams than the older ones now generally in use, and with no sacrifice in accuracy.



Orthogonal
Orthogonal
C_1/C_2
$\Delta\alpha$
$\Delta\alpha$
$\frac{R}{J}$
$\frac{C_2}{C_1}$
$\Delta\alpha$ (degrees)
Turning Point

FIG. I

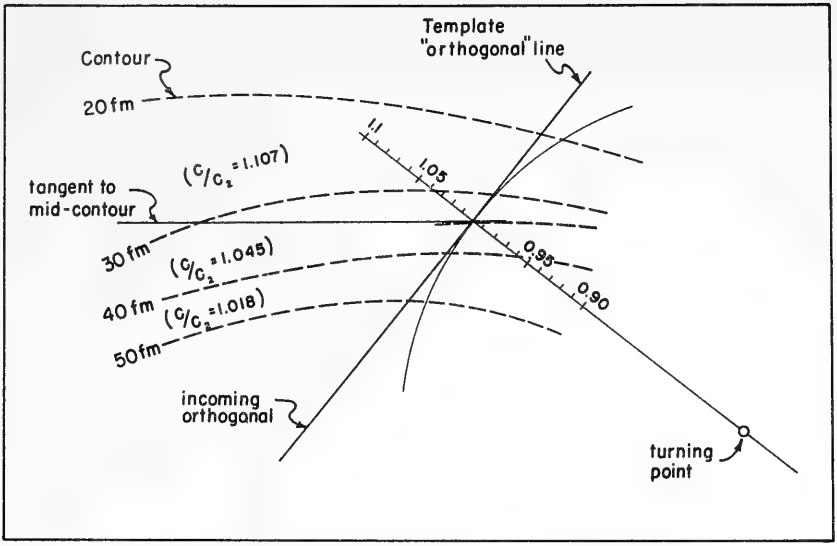
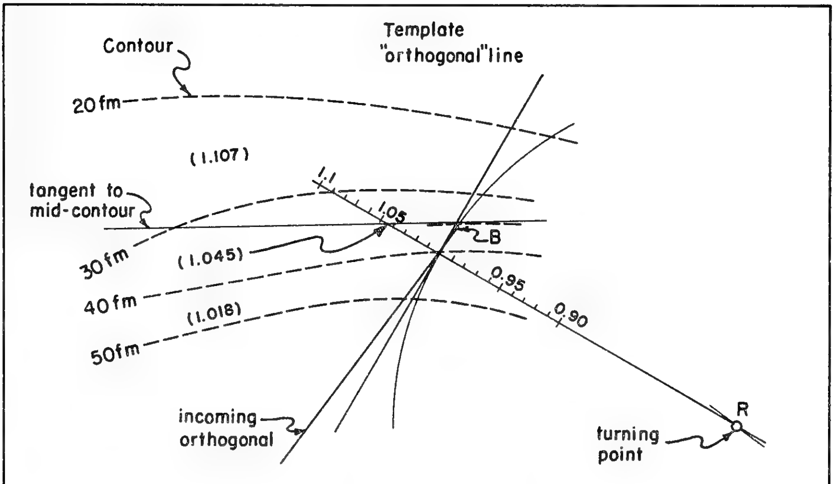


FIG. 2a - USE OF THE SNELL'S LAW TEMPLATE



Note: The template has been turned about R until the value C/C_2 = 1.045 intersects the tangent to the mid-contour. The template "orthogonal" line lies in the direction of the turned orthogonal. This direction is to be laid off at some point "B" on the incoming orthogonal which is equidistant from the two contours along the incoming and outgoing orthogonals.

FIG. 2b - USE OF THE SNELL'S LAW TEMPLATE

PROGRESS REPORTS ON RESEARCH SPONSORED BY
THE BEACH EROSION BOARD

Abstracts from progress reports on several research contracts in force between universitites or other institutions and the Beach Erosion Board, together with brief statements as to the status of research projects being prosecuted in the laboratory of the Beach Erosion Board, are presented as follows:

I. University of California, Status Report No. 7, 1 Dec 1952 through 21 Jan 1953.

The purpose of the present contract is to study the movement of sand in the shallow water immediately off shore and also around the ends of breakwaters and headlands. The primary objective is to drill bore holes through the sand fill at Santa Barbara Harbor, to procure undisturbed samples of the fill and of the offshore sediments that were beneath the water just prior to the time the fill was deposited. These studies should provide information on the nature of the sediments under different conditions of transport of sand, off shore and on the fill area.

Trips have been made to Santa Barbara to determine the most advantageous places to place the bore holes and to make arrangements with drilling contractors. Arrangements are now pending with the city authorities of Santa Barbara for permission to drill upon the city beaches. Drilling will start as soon as possible after permission to drill is granted.

During the course of the year laboratory experiments on model beaches have been carried out in the Fluid Mechanics Laboratory of the University of California, under the direction of H. A. Einstein, J. W. Johnson, and Parker D. Trask for the purpose of ascertaining the mode of transport of sand along the beach and around headlands. A report on this work by Ning Chien and Huon Li was issued in August 1952 by the Institute of Engineering Research as Series 14, Issue No. 13.

II. Scripps Institution of Oceanography, Quarterly Progress Report No. 14, October-December 1952.

The quarter saw the completion of the study of the areal and seasonal variations in beach and nearshore sediments at La Jolla, California. Copies of the report have been duplicated and forwarded to the Beach Erosion Board. The areal distribution of physical properties indicated that the sediments varied in a systematic manner from one locality to another. It was found that the sediments could be divided into types on a basis of particle-size distribution, and that these types were characteristic of the environment of deposition. The areal distribution patterns show a pronounced alignment of sediment properties, which in general is parallel to the beach and surf zone, a fact which is important to the understanding of nearshore processes because it suggests that processes causing such alignment and banding of sediment attributes should in the main have isolines of intensity parallel to the beach. Topographic surveys showing the changes in sand level indicate that beach material migrates seaward during periods of large waves and landward during periods of small waves. The most pronounced changes in sand level occur in depths of less than 30 feet, but some seasonal effects may extend to much greater depths. The greatest change in sediment size also took place from the beach foreshore out to depths of about 30 feet. In this zone the sediments tended to be coarser during the winter and spring when the beaches were cut back, and finer in the fall following the summer fill.

The results of laboratory experiments to evaluate the effect of accelerative forces in the orbital current meter system have enabled the computation of the discrepancy in orbital velocity measurements due to virtual mass for various combinations of wave height, period, and depth of water. In general it was found that the error caused by virtual mass was negligible for velocity measurements just outside of the breaker zone, but that the discrepancies increase with decreasing wave period and height and with increasing water depth.

Research continues into ways to take fuller scientific advantage of recent developments in techniques and gear for underwater diving. In one such operation, divers forced test rods into the sandy bottom at depths of 30 feet off Scripps Beach more than six months ago. The first major change in bottom level, as indicated by the rods, took place later in the fall. It appears that there was a 21-inch fill during a 47-day period.

A paper is in preparation that will discuss a new method for calculating wave intensity along a single ray.

III. New York University Bi-Monthly Progress Report, 1st Report, for period 1 Jan 1953 to 28 Feb 1953.

Work on the project began on 1 February. The three objectives of the contract are (1) the collection of statistical wave data for points in deep water offshore from six selected coastal areas, (2) the development of an electronic wave analyzer, and (3) the continuation of theoretical investigations concerned with wave phenomenon.

Statistical Wave Data. The statistical data available from weather ships has been studied and much data was collected during the time from 9 February through 21 February on wave conditions over the North Atlantic. This data will be available when needed as a starting point for the description of wave conditions at the selected offshore points.

Theoretical development. Professor Neumann, in connection with other research, has derived a theoretical power spectrum for the waves which shows many important points of agreement with the actual sea surface. An important theoretical work by Rice has been studied and the results of the paper have been applied to the analysis of ocean wave records. The true meaning of the significant height and the significant "period" is explained by these results. The conclusion is that the significant height is a measure of the total area under the power spectrum which can be fairly reliable, but that the significant period is a very poor statistic which in a "sea" record is practically useless. Other results such as the fact that L is not equal to $gT^2/2\pi$ for actual waves in deep water have been obtained and verified.

IV. The Agricultural and Mechanical College of Texas, Quarterly Report for Period ending 31 Dec 1952.

The Plan of Attack. This called for the most probable method of obtaining suitable wave data for the study of friction and percolation losses. Since the true swell in the Gulf of Mexico occurs only during the hurricane season, a field party consisting of two men was organized to obtain wave data during this season. Permission was obtained to install wave recorders at Pure Oil Structures A and B and also in an old abandoned Coast Guard light house, all in the Atchafalaya Bay Region of the Gulf of Mexico. The remaining six months of the contract would be devoted to the analysis of the wave data obtained during the hurricane season. In addition it was planned to obtain wave data during the winter season on the generation of wind waves in shallow water.

During the third quarter of this contract period the following progress was made.

Field Operations. Three field trips, one during each month, were made to the Atchafalaya Bay Region. October being the last month of the hurricane season, it was hoped that additional data could be obtained on waves suitable in the study of friction and percolation losses. Mechanical difficulty of two recorders and one pressure head prevented the recording of waves, which were about 1-1/2 to 2 feet high and a 3-1/2 to 4 second period. These instruments were brought back to the Department of Oceanography and were repaired.

During the December field trip, one pressure head was installed permanently at Pure Oil Structure A, and is now again in operation. Waves will be recorded 30 minutes twice daily during the remaining winter season to obtain wave data on the generation of waves in shallow water. The other two pressure heads and one recorder have been returned to the Department of Oceanography. The previous plan of installing one wave recorder permanently on Structure B, to obtain additional wave data, has been abandoned at this time, since the regular daily transportation between Structures A and B has been curtailed temporarily.

Wave Data. The analysis of the wave records taken last summer has essentially been completed. Refraction diagrams are being constructed to eliminate the effect of refraction before determining the actual loss of energy due to friction and percolation.

Theoretical Investigations. An analytical study has been initiated on friction loss of waves. A method is developed which will give a more direct solution for the friction wave height as compared to the solution by successive approximations as given by Putnam and Johnson.

The data obtained during the field trip last summer will be used to determine the friction factors associated with the bottom materials and wave characteristics. The bottom materials at the Atchafalaya Bay Region consist of a gelatinous mud, particle size range between .001 mm and .004 mm, with a mean particle diameter of .002 mm. No percolation loss is expected of the wave data obtained last summer, and consequently percolation need not be considered. A report on this study will be completed by March 1, 1953.

V. Waterways Experiment Station, Vicksburg, Mississippi, Quarterly Report for Quarter ending 31 December 1952.

Wave Run-up on Shore Structures. The purpose of this study is to investigate the relationship between water level, wave height, wave period and beach slope and wave run-up on selected types of shore structures used to prevent erosion caused by wave action.

Tests are being conducted using a scale of 1:17 in a wave flume 120 feet long, 5 feet wide and 5 feet deep. Waves are generated by a plunger-type wave machine. Wave heights are measured by a parallel-rod-type wave gage. Selected structures are placed on molded beaches, and the height of wave run-up (for no overtopping) and the amount of water overtopping the structure are determined.

Tests to determine the volumes of overtopping water for vertical-faced, monolithic seawalls with crown elevations of +6.0, +0.9, +12.0 and +15.0 ft. swl, using a beach slope of 1 on 10 and water depths of 25.0, 29.5 and 34.0 ft., were completed during the quarter.

VI. Beach Erosion Board, Research Division, Project Status Report for Quarter Ending 31 March 1953.

In addition to the research projects under contract to the various institutions which are reported on above, the Research Division of the Beach Erosion Board is carrying out certain projects with its own facilities. The main projects were described in Vol. 6, No. 4 of the Bulletin (October 1952) and a short description of the work accomplished through the last quarter is given below.

Study of Effects of Tidal Fluctuations on Wave Produced Beach Profiles - Testing was resumed in February and the testing for the 4-hour tidal cycle completed. Further testing has had to be discontinued for the present due to the priority of other work.

Statistical Wave Data on the Great Lakes - A report has been prepared on the Lake Michigan data and is to be published soon. Reports on the Lake Erie and Lake Ontario data are presently being prepared.

Correlation of Along Shore Currents and Waves - Preliminary analysis of the data collected at Mission Bay shows that with the very low waves observed (always less than 5 feet and mostly less than 2 feet), the visual observations were not of sufficient accuracy to permit an adequate comparison between theory and observation.

Preparation of Reports Based on Mission Bay Data - (a) The compilation of the additional data on leadline survey error has been completed and combined with the previous report on echo sounder survey error to be published as a Board Technical Memorandum. (b) An analysis of a number of profiles was prepared by the Danish engineer Per Bruun on his visit here and a comparison made with Danish data.

Study of Pressures Developed by Waves Breaking Against Vertical Structures - A few additional tests were run, and the entire set of data is being analysed and a report being prepared.

Manual on Wave Forecasting - A manual giving the latest and most accurate methods of applying the Sverdrup-Munk-Bretschneider curves for all types of weather and wave conditions involving both moving and stationary fetches is being prepared.

In addition to the above, project reports on the Equilibrium Profile of Beaches, A laboratory investigation of the Vertical Rise of Solitary Waves on Impermeable Structures and the Study of the Quantity of Sand in Suspension in Coastal Waters have been completed and are being edited for publication and distribution as Beach Erosion Board Technical Memoranda.

Analysis of the data on the Correlation of Effectiveness of the South Lake Worth Inlet By-passing Plant and The Study of Effects on Beach Profiles of Varying Wave Periods has been completed and reports are being circulated to the staff for comment prior to publication.

BEACH EROSION STUDIES

Beach erosion control studies of specific localities are usually 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 costs of these studies are divided equally between the United States and the cooperating agencies. Information concerning the initiation of a cooperative study may be obtained from any District or Division 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 summary of reports transmitted to Congress since the last issue of the Bulletin and list of authorized cooperative studies follow:

SUMMARIES OF REPORTS TRANSMITTED TO CONGRESS

CONNECTICUT - NIANTIC BAY TO CONNECTICUT RIVER

The area studied comprises the shore of Long Island Sound and Niantic Bay between Bay Point on the east side of Niantic Bay and the mouth of Connecticut River. It includes a short section of shore in the Town of Waterford and the shores of the Towns of East Lyme and Old Lyme, a total length of about 13 miles. This shore area is about 35 miles east of New Haven, Connecticut, and about 105 miles east of New York City. It is extensively developed as a resort and residential area, with improvements ranging from cottages to small estates. The permanent population of the three towns is about 15,000, but the summer population of Old Lyme and East Lyme is about 23,500. Two small town-owned beaches and Rocky Neck State Park are included in the area.

Long Island Sound is a tidal arm of the Atlantic Ocean. Tides are semi-diurnal, the mean range increasing gradually from 2.7 feet at Millstone Point in Waterford to 3.5 feet at Saybrook. Spring ranges are respectively 3.2 and 4.2 feet at these locations. Maximum tide of record at Saybrook was 9.9 feet above mean high water. Tides 3 feet or more above mean high water occur about once a year. With a tidal stage of 3 feet above mean high water, the maximum height of breakers landward of the low water line is about 4.5 feet at the east end of the study area and 5 feet at the west end. Larger waves can reach the shore only during infrequent higher tides. Ocean swells entering Long Island Sound between Race Point and Little Gull Island may affect littoral processes, but the waves of primary importance are those generated in the sound. Ordinary short storm waves cause littoral movement and offshore loss of beach material. The influence of swells is probably insufficient to cause appreciable return of material from offshore by wave action. The greater fetch and wind movement are from the west and southwest but a substantial percentage of storm waves is generated by east winds. The predominant direction of littoral drift is north along shores aligned generally north and south. There is generally no predominant direction of littoral drift along shores aligned generally east and west, except for the section west of Brighton Point where the drift is predominantly westward, probably due to the influence of the tidal draw of the Connecticut River.

The study area is characterized by headlands of unconsolidated glacial material with some rock outcrops, between which wave-built bars have been formed and the landward areas generally have filled and become marshy. The Connecticut River transports and deposits material in Long Island Sound, some of which probably reaches either the beaches or offshore bottom in the western portion of the study area. The headlands formerly supplied ample material to the intervening beaches, but the headlands are now generally protected by seawalls and revetments. The supply of material has thus been reduced or eliminated, and consequently the beaches have slowly deteriorated. Groins have been found to be capable of causing minor accretion areas and stabilizing a narrow band along the upper portion of the beach, but the natural supply of material is insufficient for the formation of adequate protective beaches by groins alone. The building and maintenance of adequate beaches may be accomplished by artificial placement of sand. The rate of loss of fill can be reduced by groins.

The Division Engineer and the Beach Erosion Board concluded that the best plans for the protection and improvement of beaches within the study area were as follows:

a. Giants Neck - Direct placement of sand fill along the west bank of the Pataguanset River.

b. White Sand Beach - Direct placement of sand fill along the easterly 1,400 feet of this beach and construction of an impermeable groin at the west limit of the fill.

They also found that the proposed project for White Sand Beach is justified by evaluated benefits, but that the limited public interest other than recreational involved in the improvement, and the minor Federal aid for which the project would be qualified did not warrant adoption of a Federal project for protection of this area. They recommended that local interests consider adoption of a project for the protection and improvement of this beach, in accordance with the plan outlined in the preceding paragraph. The shore at Giants Neck is privately owned and thus not eligible for Federal assistance in the cost of protective measures.

In accordance with existing statutory requirements the Board stated its opinion that:

a. It is inadvisable for the United States to adopt projects authorizing Federal participation in the cost of protecting and improving the shores within the area studied;

b. The public interest involved in the proposed improvements for these shores is small and primarily local; and

c. No share of the expense should be borne by the United States.

The Chief of Engineers concurred with the recommendations of the Beach Erosion Board.

RACINE COUNTY - WISCONSIN

The area studied embraces the Lake Michigan shore of Racine County with a length of about 14 miles. The land from the north county line to Wind Point, a distance of $5\frac{1}{2}$ miles is little developed, thence south about $3\frac{1}{2}$ miles to the north breakwater of Racine Harbor the shore is developed for residential and park use. South of the harbor for a distance of 1.7 miles, the city of Racine has built a discontinuous breakwater offshore and is filling parts of the area between the breakwater and the shore. A sewage disposal plant occupies a low area between the lake and the bluff for the next 1/4 mile. Thence southward an industrial plant occupies about 1/2 mile of frontage. The remaining frontage to the south county line is partly developed for residential use and part is farm land. The populations of the county and city are about 109,000 and 71,000 respectively.

The coast within Racine County consists of bluffs of silty clay with generally narrow beaches of sand and pebbles. North Beach, lying just north of the north harbor breakwater, is sandy and has a maximum width of about 450 feet. North of the harbor, the principal publicly owned portions of shore frontage are Shoop Park, Zoological Park and North Beach. The latter two are used as municipal bathing beaches. South of the harbor, the city of Racine is obtaining riparian rights and proposes to use the filled area between the offshore breakwaters and the shore for park purposes. The city also owns the Sewage Disposal Plant just south of the city limits.

The purpose of the study was to determine the most effective methods of preventing erosion of the shore by waves and currents. The district engineer, in cooperation with the division engineer and the Beach Erosion Board, investigated the history and present conditions along the shores of Racine County, analyzed the factors affecting the problem, and developed plans for protective measures, as desired by the cooperating agency.

The shores of Racine County have a general history of erosion by waves and currents. During periods of high lake stages, waves pass over the generally narrow beaches. Upon reaching the toe of the bluff they cause undercutting and slumping. The material thus removed is generally too fine to remain on the beach. Material is moved southward alongshore due to the prevailing direction of wave approach from the northeast. This material and that derived from the bluffs in the immediate vicinity are insufficient to stabilize the shore. Where there is a moderate volume of littoral drift, it may be impounded by groins to widen the beach. Protective beaches may also be artificially placed and retained by groins. Such artificially placed beaches have the advantages of providing immediate protection and preventing possible adverse effects of depriving adjacent portions of shore of material. Walls and revetments are alternative methods of preventing waves from reaching erodible bluff material.

The district and division engineers and the Beach Erosion Board concluded that the most effective methods of preventing erosion of the shore by waves and currents are by protective beaches, impounded by groins or artificially placed and retained by groins, and by stone revetments, selection of the particular method for each reach of shore to be based on conditions of littoral drift in the reach and the use requirements of the shore.

In accordance with existing statutory requirements, the Beach Erosion Board stated its opinion that:

a. it is not advisable for the United States to adopt a project at this time authorizing Federal participation in the cost of shore protection in Racine County, Wisconsin;

b. the public interest involved in the proposed improvements is small, being limited to the value of a minor amount of publicly owned property being lost through erosion; and

c. no share of the expense should be borne by the United States.

The Chief of Engineers concurred generally in the views and recommendations of the Beach Erosion Board.

AUTHORIZED COOPERATIVE BEACH EROSION STUDIES

NEW HAMPSHIRE

HAMPTON BEACH. Cooperating 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

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.

CONNECTICUT

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

N.Y. STATE PARKS ON LAKE ONTARIO. Cooperating Agency: Department of Conservation, Division of Parks.

Problem: To determine the best method of providing and maintaining certain beaches and preventing further erosion of the shores at Selkirk Shores, Fair Haven Beach and Hamlin Beach State Parks, and the Braddock Bay area owned by the State of New York.

NEW JERSEY

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 or coastal protection.

NORTH CAROLINA

CAROLINA BEACH. Cooperating Agency: Town of Carolina Beach

Problem: To determine the best method of preventing erosion of the beach.

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.

TEXAS

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

Problem: 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

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 were studied in order of priority as requested by the cooperating agency. Only study remaining to be completed includes the shore from Euclid City to Chagrin River.

TERRITORY OF HAWAII

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

Listed below with accompanying abstracts are reports of some of the research performed by the University of California for the Office of Naval Research.

"An Electronic Instrument for the Statistical Analysis of Ocean Waves" by W. W. Lund.

"In this paper is described an electronic instrument that is the result of an attempt to develop an accurate and stable analogue computer to aid in the analysis of ocean wave data. In developing the instrument all the circuits were designed, constructed, tested, and modified several times before the final instrument evolved. It is a self-contained instrument in that it requires no auxiliary calibrating equipment. Information is fed into the instrument in the form of an electrical voltage. The output data are presented by direct-reading counter dials. Although the instrument has some small imperfections, its operation so far has proven to be quite satisfactory."

"Comparisons of Wave Forecasts" by C. L. Bretschneider, D.K. Todd and Lt. H. L. Kimberley, USN.

Three forecasters made wave forecasts for the same period and from the same set of weather maps utilizing the since modified Sverdrup-Munk methods and curves. Comparisons of wave heights and periods were made between the different forecasters. It was found that one forecaster was consistantly higher in his heights than either of the other two forecasters. In general, the disagreement between forecasters was relatively large for both the height and the period comparisons. The discrepancies were due to each forecaster's interpretation of the meteorological elements used in wave forecasting. A number of tables of errors that might be expected from the interpretation of the meteorological elements have been prepared. From these tables it is seen that unless the forecasters agree in the interpretation of the meteorological elements large errors in the wave forecasts can be expected.

From three different sets of weather maps for the same period one forecaster made separate forecasts utilizing the since modified Sverdrup-Munk methods and curves. The comparisons of wave heights and period here also were in large disagreement. The discrepancies were due to the analysis of the synoptic situation and the drawing of the isobaric pattern, and also to the method of application of the wave forecasting theory. The method of application of the principles in wave forecasting does not hold for all types of weather maps of different time intervals, and this introduces large discrepancies in the wave forecasts, even though the forecaster may be consistant in the interpretation of the meteorological elements.

"Surf Conditions and Beach Profiles Records for Santa Margarita River Beach, Oceanside, California for 1949" by R.L. Wiegel, Lt. D. A. Patrick, CEC, USN, and Lt. H. L. Kimberley, USN.

During a study of amphibious oceanography by the University of California for, and in conjunction with, the U. S. Marine Corps the opportunity developed for measuring wave and beach conditions at the mouth of the Santa Margarita River (just north of Oceanside, California) for a period of nearly one year. For this period continuous records of significant and maximum wave heights with wave period are presented together with beach and bottom profiles sounded at one to three-week intervals. No attempt has been made to correlate the wave data with beach changes; however, the data are of interest, especially as there are two jetties immediately south of the beach.

"Comparisons of Beach Elevation at Limits of Backrush and Uprush with USC and GS Tide Predictions on Several Pacific Ocean Beaches" by D. A. Patrick, Lt., CEC, USN.

In conjunction with other field studies in amphibious oceanography data were obtained concerning the elevations of and distances between the limits of uprush and backrush of waves breaking on the beach. This report presents the results of attempts to correlate these two limits with USC and GS tide predictions on several Pacific Ocean beaches. The author concludes that no simple empirical relationships exist between elevations of limits of backrush and uprush and the USC and GS tide predictions, but the limit of backrush is a more reliable index to tide prediction than the limit of uprush. He also concludes that the variabilities of the elevations of limits of backrush and uprush are at best a very obscure function of the tide stage and of the beach slope.