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**U.S. DEPARTMENT OF COMMERCE**
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Weather Bureau

# Western Region Sea State and Surf Forecaster's Manual

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Western Region

SALT LAKE CITY,
UTAH

July, 1970

## WESTERN REGION TECHNICAL MEMORANDA

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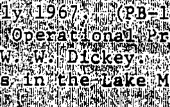

A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
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WEATHER BUREAU

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# WESTERN REGION SEA STATE AND SURF FORECASTER'S MANUAL

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLE AND APPENDIX

## LIST OF FIGURES AND TABLE AND APPENDIX (CONTINUED)



APPENDIX

# PREFACE

This manual is intended as a ready reference for operational techniques of wind wave, swell and breaker forecasting. No attempt is made to advance new concepts or present mathematical developments. Neither is any one wave forecasting system claimed to be superior to any other. Indeed it is the difficulty of defining the wind wave generating parameters that introduces differences between the various diagnostic and forecasting techniques. Given a well-defined wind field, differences in forecasts made using the various wave spectra and forecast schemes would be well within the limits of observational accuracy.

The physics of wind wave generation is very complex, with many unknowns, and with much of the theory yet to be developed. Mathematical solution of wind wave generation must, as yet, be approached through a series of approximations and simplifying assumptions. To satisfy marine operational requirements, it will be assumed that when winds blow over an appropriate fetch water waves will appear and propagate.

Water waves constitute a large domain ranging from capillary waves, with periods in fractions of a second, up through diurnal tides with periods of approximately 24 hours. Long period atmospheric or storm induced ocean waves may have periods measured in days or even weeks. This manual will present a stereotyped technique for predicting wind generated waves and as such will concentrate on a narrow band of the water wave spectrum.

WESTERN REGION SEA STATE AND SURF FORECASTER'S MANUAL

# I. INTRODUCTION

Geographical and climatological conditions divide the west coast of the United States into three separate sea state and surf regimes-- 1) Strait of Juan de Fuca to Cape Mendocino, 2) Cape Mendocino to Point Conception, and 3) Point Conception to Mexican border. However, a common requirement for the entire coast is an open ocean and coastal waters sea state forecast. While source regions of waves affecting different portions of the Pacific Coast vary radically, basic scientific concepts and mechanics of open water sea and swell forecasting are universal. Dictated by both air and water temperature, aquatic activity in the sea-land interaction area or "surf zone" varies markedly with changes in geographical area. It is this changing utilization of the marine environment, coupled with the geographical orientation of the coastline that divides the west coast surf or breaker forecast requirement into the three natural zones, each with its own distinctive problems. Techniques for forecasting breaker heights are also universal but bottom contours and beach or bar orientation must be specifically defined for each forecast point. Tidal currents must be given consideration when computing wave and breaker heights in many areas.

From the Strait of Juan de Fuca southward to Cape Mendocino the north-south oriented coastline is subject to wind waves or swells generated by storms traveling over mid and northern latitudes of the north Pacific Ocean. Small craft harbors of refuge are some distance apart and frequent heavy seas make coastal water sea state forecasts of vital concern. The primary user requirement of the "surf zone" forecast is for a description of waves or breakers over an offshore bar, along a breakwater or at a channel entrance, with only minor interest in beach breakers. Wave or breaker conditions over a bar are frequently critical for all types of watercraft. From the seaward side a mariner looks at the smooth back side of waves breaking over a bar. This deception may lull him into attempting a bar traverse through heavy breaking waves that were not apparent from the seaward side. Small boats may be swamped in this narrow band of heavy breaking seas with safe water only a few hundred feet away, both inside and outside the bar or breaker zone. These same seas may be sufficiently high as to cause a deep draft vessel to hit bottom while in a wave trough over the bar. There have been reports of medium and heavy tonnage vessels striking bottom while in heavy seas over the Columbia River bar where the channel is maintained at a minimum depth of 48 feet below mean lower low water.

Tidal currents strongly affect marine safety at many harbor entrances. A strong ebb tide current at a narrow harbor entrance will increase the height and steepness of incoming waves while shortening the wavelength. This combination of events may quickly produce an unstable breaking wave. In heavy seas this breaking wave takes the more hazardous form of a plunging breaker, which in the extreme may approach a tidal bore. Conversely during a flood tide incoming waves and tidal current tend to move in the same direction. This results in increased wave length, lower wave height, lower wave steepness, and generally flatter seas. Thus a harbor entrance that was navigable during slack and flood tide may become impassable during ebb tide. Along the Oregon-Washington coast navigable bays and estuaries are typically large relative to the width and depth of their respective channels. This results in strong tidal currents which tend to induce unstable or breaking waves as well as compounding the problem by contributing material to build and maintain offshore bars. Streamflow into the estuaries also contributes to the strength of the tidal currents.

Timing of tidal currents should not be inferred solely by reference to a tide table. For stations on the outer coast there is usually little difference between time of high or low water and beginning of ebb or flood current, but in narrow channels, landlocked harbors, or on tidal rivers, time of slack water may differ by several hours from time of high or low water stand. For the predicted times of slack water, and other data on currents, reference must be made to "Tidal Current Tables, Pacific Coast of North America". This volume is published annually by ESSA Coast and Geodetic Survey. It is necessary to know tide stages, tide ranges, and tidal currents when predicting breakers at certain harbor entrances, peak water level during a storm surge, stream levels within the reaches of tidal influence, and interpretation and verification of tsunami warnings and advisories. The usual magnitude of storm surges along the West Coast makes them of little consequence unless they occur during a period of unusually high tides. Similarly, a tsunami wave arriving during low tide would be less damaging than one arriving at high tide. Also, changing water depth with tidal phases may alter bottom slopes which must be considered in forecasting shoaling effects on breaking waves.

Progressing southward from Cape Mendocino to Point Conception bar and estuarine conditions become less important, as narrow estuaries give way to wide bays and offshore bars become smaller to practically nonexistent. Beach breaker forecasts are relatively unimportant, with only a brief summer swimming or surfing season. Along this intermediate stretch of coast the most frequent marine forecast problems are strong winds and heavy seas resulting from quickly deepening and rapidly moving winter storms. These conditions are most critical near the major headlands. During summer, strong northerly offshore winds along the eastern periphery of the Eastern Pacific High frequently cause heavy seas to plague fishing fleets and tugboat operators. Several harbors along this reach of the coast are, however, especially vulnerable to storm surges and tsunami wave damage. Source regions for waves or swells affecting this section of the coast are middle and northern latitudes of the north Pacific Ocean.

Due to the northwest-southeast orientation of the coast, the shielding effect of Point Conception and the sheltering effects of offshore islands, a different set of conditions affect sea states in southern California coastal waters. While shifting sand and shoaling is a constant problem at several marinas and small craft harbors, bar and estuary hazards, compared to those of the Pacific Northwest, are of minor concern. With heavy year-long utilization of beaches and periodic hazardous surf conditions, a continuing surf forecast service is of primary importance. Since ocean swells travel along great circle paths, seas generated in low-to-middle latitudes of the north Pacific Ocean can reach southern California nearshore waters while the landform precludes arrival of swells from more northerly latitudes. Thus, the frequency of heavy winter seas and surf is much lower over southern California waters than for the rest of the Pacific Coast. On the other hand, much of this coast is vulnerable to southerly swells and consequent heavy summer surf from seas generated by tropical storms off the Mexican and Central American coasts. Origin of low, long southerly swells building into very heavy breakers and dangerous rip currents has been traced to Southern Hemisphere storms as far away as the Ross Sea and southern Indian Ocean.

## II. SELECTING A SEA STATE FORECAST TECHNIQUE

Of several ocean wind wave forecasting techniques now in use, each has inherent advantages and disadvantages. Selection of the "best" wave forecasting system centers upon the ultimate user's requirements, forecast preparation time and the forecaster's proficiency in each technique. The mariner, whether he is a small boat operator or a deep draft captain, is primarily interested in what he might observe over the the bow of his craft. Thus his attention is concentrated on the higher seas he might encounter, or more precisely, the "significant" wave height and period. These same significant wave parameters are readily used in predicting bar, channel entrance, or surf zone conditions. These conditions are successively encountered as a boat traverses from deep into shallow water. Within present capabilities, this "significant" or "singular" wave is also more adaptable to computerized sea state forecasts than are the more complex spectra systems. Therefore, the "significant wave" and "significant breaker" forecast technique will be developed in this paper.

The "Significant Wave Method", more popularly known as the Sverdrup-Munk-Bretschneider (S-M-B) Method (1), is perhaps the most widely used of several current wave forecasting techniques. This system was developed by Sverdrup and Munk during World War II and was later updated by Bretschneider. It was the first operational system introduced, is the most widely used technique, and is applicable from deep water through shallow water as well as being adaptable to the widest range of wind wave producing fetches. While the S-M-B method evolved from theoretical considerations, the final formulation required an abundance of basic data for determination of certain constants and coefficients, in order to bring the mathematical development of ocean wind waves by linear solitary wave theory into agreement with observed ocean wave spectra. For this reason the S-M-B method can be considered as semitheoretical and semiempirical. After determination of fetch area, wind speed, wind duration and decay distance from a series of synoptic weather charts, the S-M-B wave and/or swell forecast is purely mechanical and requires a minimum of time. Forecast verification of this technique compares favorably with verification records achieved by any of the other systems.

The space-time wind field and wave generating system developed by Wilson (2) is also a significant wave forecast system, but applies more correctly only to deep water waves and would, therefore, be less applicable to shallow water forecasts. For variable moving fetches with variable wind speeds and durations, the Wilson technique should yield more accurate answers to deep water wave generation problems than the other systems. For the operational forecaster working within the present data frame and under a time handicap, the more complicated Wilson graphs and greater time consumption in forecast preparation would tend to negate the slight gain in accuracy.

The Wave Spectra method of Pierson-Neumann-James (P-N-J) (3) composes and projects the "significant range" of wind wave heights and wave periods through several families of curves. This system matches theoretical energy (or wave amplitude) spectra with a statistical approach to describe the apparent random state of a wind developed sea. This stochastic sea is then propagated through both time and space to yield a time-lapse spectral forecast for a target point. In effect, the P-N-J technique provides a systematic bookkeeping system to account for wave energy developed in a fetch and then dissipated through the dispersive effect of waves or swells traveling away from the generating area. While a series of "filters" concentrate attention to the more pertinent or statistically significant portion of the spectrum, considerably more detail is presented than is normally required. Computation and final display of a P-N-J sea state forecast is a lengthy exercise and one from which only selected forecast information would be extracted for the average marine forecast service customer. The coastal engineer or marine scientist might, on the other hand, have a definite requirement for the complete energy spectrum description and forecast.

Due to its brevity in both preparation and presentation, the S-M-B method was chosen as the optimum system available at the present time. The marine meteorologist may wish to explore other wind wave forecasting techniques. Other systems may be more advantageous for specific problems.

## III. DEFINITION OF COMMON TERMS

A few basic definitions are necessary to explain terms in ocean wind wave discussions. While the following lists are by no means exhaustive they will form the basic framework required for sea state and surf description and forecasting. The first group forms the descriptive platform while the second group defines the working tools.

SEAS - When a wind comes up, the sea surface almost instantaneously becomes covered with tiny ripples (or capillary waves) which form more or less regular arcs of long radius. As the wind continues to blow, the ripples increase rapidly in height and become waves while at the same time new wavelets are born and propagate. Soon a very large number of progressive waves are present. In generating areas, these families of randomly developed, irregularly shaped short crested waves are known as wind waves or seas.

SWELLS - As winds die down and/or seas leave the generating area, fairly uniform long crested waves propagate forward. These orderly waves leaving the generating area are known as swells. Metamorphosis from seas to swells is usually considered to be on a time scale of 15 to 20 hours. Note in Figure 1 the comparative spectral location and overlapping of wavelets, wind waves and swells.

FETCH - The fetch is an area of the sea surface over which a wind of uniform direction and near constant speed is, or has been, blowing for a period of several hours or more. While fetch areas may have various geometric shapes, the most practical procedure is to select a rectangular area containing the greater portion of a uniform wind field.

WIND WAVE (C) - Wave speed is the rate of advance of a single wave crest, usually expressed in knots. It is noted that this is the speed of a solitary sinusodial or trochoidal (a wave whose length is much greater than its amplitude) wave. Since individual or solitary waves are short crested and of limited duration, wave speed is difficult to observe. A theoretically computed wave speed is, therefore, used in a later section to evaluate wave modification by opposing or following tidal currents.

GROUP VELOCITY ($C_{gr}$) - The speed at which a wave front or a particular wave train advances from the fetch area. From energy considerations, it can be shown that wave group velocity is one half the solitary wave speed. Group velocity is the speed used to calculate wave arrival time from a distant source.

SIGNIFICANT WAVE ($H_{1/3}$ or $H_s$) - This is a statistical wave and is defined as the mean or average of the highest one-third of the waves in a given wave train or in a wave generating area. It also approximates the value that an experienced observer would usually assign when visually estimating sea heights.

BREAKERS - Breakers occur when a wave becomes sufficiently steep and unstable so that the wave crest breaks or spills down the advancing wave front in a display of white water. Depending upon the degree of wave steepness and upon the shoaling bottom slope, breakers may take the following forms (see Figure 2):

SPILLING BREAKERS - wave steepness is small and bottom slope gentle, with wave crest speed very slightly greater than trough speed. Crests break and curl with a gentle uniform flow of white water flowing down the advancing wave face. This is the more tranquil condition of light whitecaps or rather small waves gently rolling onto a beach.

PLUNGING BREAKERS - with greater wave steepness or instability and on a moderately sloping bottom, wave crest speed begins to exceed trough speed by increasingly greater amounts. Soon a large volume of crest water overtakes the wave front and plunges down the wave face. This is the most turbulent of breaker conditions.

SURGING BREAKER - when a stable wave advances up a very steep beach slope it will appear to run up with little change in wave shape and with a gradual decrease in wave height as the wave approaches the apex of its climb. There is little or no white water running down the wave face, with a gentle uniform backflow as the water recedes to meet the next incoming wave.

TIDAL BORE - the extreme case of a plunging breaker, but with a large volume of following water pushing the wave in such a manner as to present a moving vertical face, with crest and trough speeds identical. This is usually the case of unstable waves meeting a strong opposing tidal current or of a large volume of water advancing up a shallow bay or estuary. The tidal bore is independent of bottom slope.

WAVE STEEPNESS - A parameter describing wave stability and defined as the ratio of wave height to wave length (L). Theoretical maximum wave steepness is on the order of $H/L = 0.10$. When this limit is reached the peaking wave becomes unstable and breaks.

The following group of terms and symbols is used in the mechanics of sea, swell and surf forecasting. While some of these terms have already been defined, they are repeated here in their order of appearance in the forecast procedure:

| NAME | SYMBOL AND DIMENSION | DEFINITION |
|---|---|---|
| FETCH | None | Area of water over which wind speed and direction are uniform. |
| WIND SPEED | (U) Knots | Wind speed over a fetch. |
| FETCH LENGTH | (F) Miles | Length of fetch measured in the same direction as the wind is blowing. |
| DURATION OF WIND | ($t_d$) Hours | Length of time wind blew with same speed and direction over a fetch to produce a given sea. |

| NAME | SYMBOL AND DIMENSION | DEFINITION |
|---|---|---|
| MINIMUM DURATION | ($t_{min}$) Hours | Minimum time necessary for a given wind speed (U) to produce a fully developed sea in a given fetch. |
| EFFECTIVE DURATION | ($t_d$) Hours | The smaller of ($t_d$) or ($t_{min}$). |
| WAVE PERIOD | (T) Seconds | Time necessary for successive wave crests to pass a stationary point in the ocean. (Length of time between crests.) |
| FETCH PERIOD | ($T_F$) Seconds | Average period of significant waves in a fetch. |
| WAVE HEIGHT | (H) Feet | Height of wave from trough to crest. |
| WAVE LENGTH | (L) Feet | Distance between successive wave crests. |
| SIGNIFICANT WAVE HEIGHT | ($H_{1/3}$ or $H_S$) Feet | Average height of the highest one-third of the waves in a fetch or wave set. |
| FETCH WAVE HEIGHT | ($H_F$) Feet | Significant wave height developed in a fetch. Always equal to $H_{1/3}$. |
| AVERAGE WAVE HEIGHT | ($H_{avg}$) Feet | Average height of all the waves in a given sea. |
| DECAY DISTANCE | (D) Miles | Distance from leeward (downwind) edge of fetch to forecast point. |
| DEEP WATER WAVE HEIGHT | ($H_O$) Feet | Significant wave height after decay but before reaching shallow water to become surf (i.e., significant swell after decay height). |
| TRAVEL TIME | ($t_D$) Hours | Length of time necessary for waves to travel decay distance (D). |

The following terms and symbols, listed in order of appearance in forecast procedure, are used in the surf or breaker forecasting technique:

| NAME | SYMBOL AND DIMENSION | DEFINITION |
|---|---|---|
| DEEP WATER WAVE ANGLE | ($a_o$) Degrees | Angle between crests of the deep water wave and the bottom contours of a shoaling area. |
| WAVE STEEPNESS INDEX | ($H_o/T_o^2$) | Ratio of deep water wave height to square of deep water wave period. |
| BREAKER HEIGHT INDEX | ($H_b/H_o$) | Ratio of breaker height to deep water wave height. |
| BREAKER HEIGHT | ($H_b$) Feet | Height of breaker from trough to crest. |
| BREAKER TYPE | None | Classification of breaker as to spilling, plunging or surging. |
| BREAKER DEPTH INDEX | ($d_b/H_o$) | Ratio of depth at which waves start to break to deep water wave height. |
| WIDTH OF SURF ZONE | Yards | Horizontal distance between outermost breaker and limit of wave uprush on the beach. |
| BREAKER WAVE LENGTH | ($L_b$) Feet | Horizontal distance between successive breakers. |
| NUMBER OF LINES OF SURF | None | The number of lines of breakers in the surf zone. |
| REFRACTION INDEX | ($d_b/L_o$) | Ratio of depth at which waves start to break to deep water wave length. |
| COEFFICIENT OF REFRACTION | ($K_d$) | Percent of breaker height seen on beach after refraction occurs. |
| BREAKER ANGLE | ($a_b$) Degrees | Angle between the beach and the lines of breakers after refraction. |
| LONGSHORE CURRENT | Knots | Current parallel to beach due to breaker angle, breaker height, breaker period and beach slope. |

## IV. FUNDAMENTAL EQUATIONS

The simplest wave theory deals with waves that can be represented by a solitary sine wave curve and in which wave height is much smaller than wave length. More properly for large waves, the form would be a trochoid which may be described as the trace of a point on a disk which rolls along a flat surface. In water of constant depth (d) such waves travel with the speed

$$(1) \qquad C = \sqrt{g\frac{L}{2\pi} \tanh 2\pi\frac{d}{L}}$$

Where g is the acceleration of gravity, C, L, and d have been defined and tanh is the hyperbolic tangent.

If d/L is large, that is, if wave length is small compared to water depth the term $\tanh 2\pi \frac{d}{L}$ approaches unity and $C = \sqrt{gL/2\pi}$ . These waves are called deep water waves. If d/L is small, that is, if wave length is large compared to water depth, $\tanh 2\pi\frac{d}{L}$ approaches $2\pi$ d/L and $C = \sqrt{gd}$. These waves are known as shallow water waves.

In general, waves have characteristics of deep-water waves when water depth is greater than one-half wave length ( $d > L/2$). Discussion will be mainly with waves of this category.

From the above deep water wave equation the following relationships are noted:

$$(2) \qquad C = L/T = \sqrt{gL/2\pi}$$

$$(3) \qquad L = 2\pi \frac{C^2}{g} = gT^2/2\pi$$

$$(4) \qquad T = \sqrt{2\pi L/g} = 2\pi C/g.$$

With wave speed (C) in knots, wave length (L) in feet and wave period (T) in seconds, the above equations reduce to:

$$(5) \qquad C = 1.34\sqrt{L} = 3.03T$$

$$(6) \qquad L = 0.555C^2 = 5.12T^2$$

$$(7) \qquad T = 0.411\sqrt{L} = 0.33C$$

It can also be shown that the wave group velocity ($C_{gr}$) at which swell trains travel may be expressed as:

$$(8) \qquad C_{gr} = C/2 = 1.515T.$$

Thus, if one wave parameter is measured the other two can readily be computed. Although these equations are not routinely used in the daily forecast procedure, they do have an occasional application and are included here for ready reference. Equation 8 is especially useful for quickly computing wave travel time from a distant storm.

## V. GENERAL FORECAST PROCEDURE

The first step in preparing a sea state and surf forecast is to locate a fetch or generating area from which waves might reach the forecast point. Wind speed and duration are then evaluated for this fetch. With these values determined, it is then largely a mechanical process to follow through the nomograms to develop seas in the fetch, compute the decay of swells reaching the forecast point and finally develop the surf or breaker condition as deep water waves traverse the shallow water and die on the beach.

Determination of the generating area, or fetch, is the most subjective factor in the entire process of wave forecasting. While it is difficult to establish a rigid set of laws for fetch selection, the following rules and techniques will serve as a general guide in delineating fetch areas:

(a) Examine the weather map for an area over the ocean in which a wind of near constant speed and uniform direction is blowing, or has been blowing, and which would direct waves or swells toward the target area.

(b) Determine the boundary limits of this fetch by drawing a few lines outward from the suspected generating area to the point of forecast interest. The boundaries of the fetch area are then delineated by the area of slightly curved to straight isobars that form an angle of 30 degrees or less with the lines joining the generating area and the forecast point. This 30 degree angle is gross enough to include the normal cross isobar flow. This procedure is adequate for use with the NMC Pacific surface analysis, which is on a polar stereographic projection, for distances up to roughly 1500 nautical miles from the forecast area. For decay distances greater than 1500 miles, the great circle path followed by the ocean wave will vary considerably from the straight line drawn on the polar stereographic chart. The forecaster should lay out on the base map used for the Pacific surface analysis (or whatever surface weather chart he might use) a series of great circle paths leading to a central forecast point in his area. Possible fetch areas would then have a uniform wind field oriented parallel to, or at most 15 degrees divergent from, a great circle path directed to the target point. This 15 degree angle is determined empirically. However, for a strong wind field over a broad fetch, a slightly larger angular deviation between wind flow and great circle paths may be used, while marginal fetches would call for even less of a departure angle.

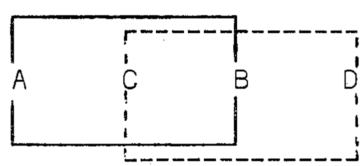
Great circle paths are determined by a point to point transfer of great circle lines from an Azimuthal Equidistant Projection or Great Circle Chart to the base weather map used by the forecaster. A plastic overlay, containing selected great circle paths, placed on the operational weather chart is a convenient way of showing great circle paths converging at the point of forecast interest as well as the direction of wind flow in the fetch which would direct waves toward the target area. Maps showing great circle paths converging at the Straits of Juan de Fuca, San Francisco, and Los Angeles are shown in the appendix. These paths were determined from U. S. Navy Hydrographic Office charts 6701, 6704, and 6711 respectively.

(c) With decay distances of 500 nautical miles or more consider only fetch areas with average winds of 20 knots or more. For fetches within 500 miles of the forecast point consider winds of 15 knots or more.

(d) Moving fetches pose a difficult problem for which no simple answer is available. Three cases will illustrate basic concepts used to evaluate moving fetches. The forecaster will be required to exercise his ingenuity in evaluating fetch areas that do not fit these simple examples.

(1) Fetch moves with the wind field.

Wind ⟶ Fetch movement ⟶

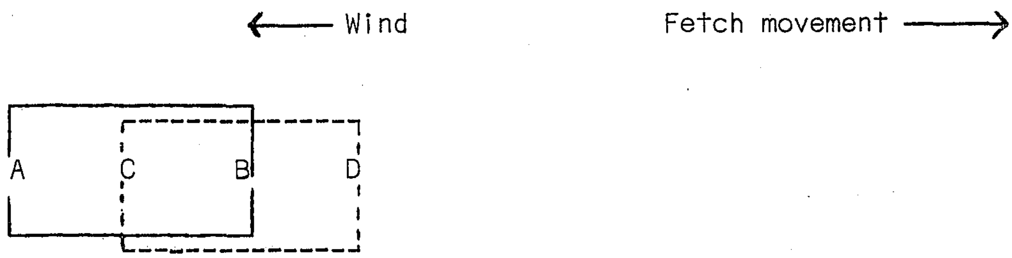



AB = Initial fetch

CD = Fetch six hours later

Use fetch CD, as waves generated in AB are carried along as the fetch moves forward. In rapidly moving storms the wind field moves forward at about the same speed as most of the wind waves. The wind then acts continuously on the same wave as the two advance. Wind duration then becomes effectively longer and the waves grow larger. A rapidly moving storm also leaves very little wave energy in its wake, since slower moving waves are left behind and have little growth due to short exposure to the active wind field. The net effect of a rapidly moving storm is for waves to spring up quickly with storm arrival, followed by an equally rapid decay as the storm passes. This is not true for a stationary or slow moving storm where the wave front moves out ahead of the storm, with newly generated waves being continually added to the rear of the wave field.

(2) Fetch moves opposite to wind field.

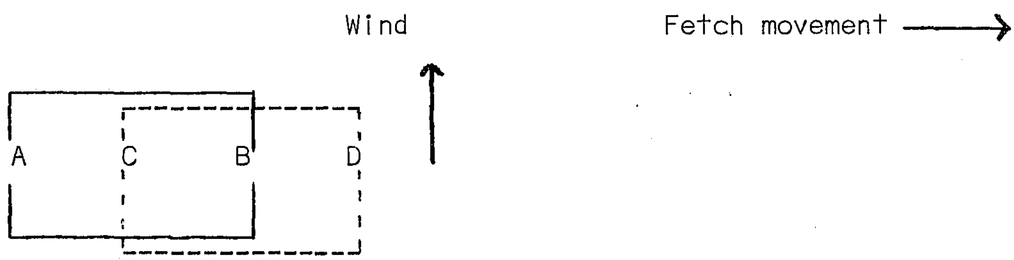



AB = Initial fetch

CD = Fetch six hours later

Use fetch AB as the best choice. CB might appear better but waves generated in CB will be moving into and maintain wave energy in AC, with a smaller contribution from BD.

(3) Fetch moves perpendicular to wind.




AB = Initial fetch

CD = Fetch six hours later

Use CB as fetch area. Other areas will contain waves, but they will be smaller than those in the overlapping section.

## WIND SPEED IN THE FETCH

When ship observations are available from a fetch area, the average reported wind speed is usually adequate for wave computations. If a fetch area is outlined without sufficient wind observations, the geostrophic wind speed may be used. Geostrophic wind speed is then reduced to a representative surface wind through corrections for isobaric curvature and near sea surface air stability. Figure 3 provides a method for making this correction. Sea and air temperature may be estimated from nearby ship reports or by referring back a few maps for representative ship observations that can be extrapolated to the time and area of interest. Lacking current data, normal sea surface temperature can be used. In the event data is so sparse as to preclude sea surface and air temperature estimates, an acceptable alternate would be to simply take 65 percent of the geostrophic wind speed as the effective surface wind speed.

MINIMUM FETCH VERSUS MINIMUM DURATION

Wind wave growth is a function of wind speed (U), length of time the wind blows ($t_d$), and length of fetch (F) over which a uniform wind is blowing. On inland waters, fetch width and water depth may also be controlling factors in wave development. As wind speed increases over a smooth stretch of water, a large number of tiny wavelets spring up. Propelled by the wind, each wavelet moves forward with a more or less regular arc of long radius. As wavelets grow and overlap, some waves crests will be in phase for an additive wave while others will be out of phase with their neighbor for a minimum wave Older waves continue to grow while smaller waves are continuously being born, all moving more or less with the wind. In a relatively short period a chaotic sea is developed with a random distribution of wave crests and many stages of wave development. For simplicity a boundary condition will be selected such that no waves enter the rear of the fetch; in this area both wave height and period will then be zero. At some early stage, the wind will have been blowing only long enough to generate waves of relatively small amplitude as illustrated by the lower dashed curve of Figure 4. That is, wave height (and period) is still limited by wind duration. Any fetch length greater than that from 0 to F will not produce waves higher than shown by the dashed line. This distance is known as the minimum fetch corresponding to the minimum duration which will cause waves as illustrated by the dashed growth curve.

A later stage of wave development is illustrated by the solid curve of Figure 4. Assume that the wind has now been blowing long enough to generate wave heights and periods given by the intersection of the solid curve with the ordinate representing the fetch front. After this point an increase in wind duration will not result in an increase in wave height or period. Waves start from zero amplitude at the rear of the fetch, increase under the influence of the wind as they progress to the fetch point, and then leave the fetch area. In this case wave growth is fetch limited. The length of time it takes a given wind over a specific fetch to cause a steady state (i.e., fully developed sea) is known as the minimum duration, $t_{min}$. The fetch length involved (in the case of a fully developed sea the total available fetch) is known as the minimum fetch corresponding to the minimum duration. Thus seas may be fetch limited, duration limited, or both, and care must be exercised in evaluating these parameters when entering the forecast nomogram.

WIND DURATION

For practical purposes, and especially from more distant or slow moving fetches, the duration of the average wind equals the time interval between the most recent chart showing the fetch and the first chart displaying the fetch, plus one-half the time interval between synoptic charts. The usual assumption is that the wind developed suddenly over the fetch and at a time midway between the chart first showing a fetch and the preceding chart. At times it is necessary to add a correction determined from height of waves present in the area when a fetch first develops. Only waves which travel at an angle equal to or less than 30 degrees from fetch wind direction should be considered when making this wind duration correction. An example will clarify these points.

Assume a fetch of at least 100 miles appears on a weather map with average wind speed 30 knots, and with ships in the fetch reporting eight-foot waves traveling downwind. Entering the left side of Figure 5 with a 30-knot wind and proceeding across to the eight-foot wave line gives a minimum fetch length of 40 nautical miles and a required wind duration of five hours to produce the observed waves. Thus the beginning point for timing the wind duration, in this example, would be five hours prior to the time of the first map on which the fetch appeared. Had no ship reports been available, a beginning time midway between the two charts would have been interpolated. With maps at six-hour intervals timing would have been started three hours before the time of the map first showing the fetch. Referring again to Figure 5, it can be seen that a 30-knot wind over a minimum fetch would produce six-foot waves in three hours. Straight interpolation would have indicated initial waves two feet lower than those observed.

Consider now a more difficult example with the following set of circumstances:

$U$ = 25 knots for

$t$ = 12 hours, and

$F$ = 500 nautical miles.

Then the wind increases to:

$U$ = 35 knots, for

$t$ = 12 hours, and

$F$ = 400 nautical miles.

Then the wind increases to:

$U$ = 50 knots for

$t$ = 18 hours, and

$F$ = 300 nautical miles.

The problem is as follows:

1. Enter Figure 5 at the left scale for $U$ = 25 knots and proceed to the right to whichever comes first,

value for t or value for F. In this case, at t = 12 hours read $H_s$ = 9 feet, $T_s$ = 8 seconds, and $F_{min}$= 110 miles. This indicates seas are limited by wind duration.

2. Now from $H_S$ = 9 feet at U = 25 knots proceed upward to the left along the dotted lines of $H_S^2T_S^2$ (lines of equal wave energy) to U = 35 knots and read $t_{min}$= 4.6 hours.

3. Then for U = 35 knots and $t_d$ = 4.6 + 16.6 hours (F = 400 miles not used, as it is further to right), read $H_S$ = 18 feet, $T_S$ = 11.2 seconds and $F_{min}$= 220 nautical miles. Again, wave height is limited by wind duration.

4. Now from $H_S$ = 18 feet at U = 35 knots proceed up the dotted lines of constant $H_S^2T_S^2$ to U = 50 knots and read $t_{min}$= 6 hours.

5. Then for U = 50 knots and $F_{min}$= 300 miles ($t_d$ = 6 + 18 = 24 hours not used) read $H_S$ = 33 feet, $T_S$ = 14.6 seconds at F = 300 miles with $t_{min}$= 18 hours. In this case, wave height is limited by fetch length.

DECAY NOMOGRAMS AND SEA STATE WORKSHEET

Assume that an appropriately oriented fetch of 500 nautical miles has been located 1500 nm from a point of forecast interest and over which a uniform wind of 42 knots has been blowing for 18 hours. This data is entered in steps 1, 2, 3, and 5 of the Sea and Swell Worksheet (Figure 6). Enter the left side of Figure 5 with U = 42 knots and move to the right to $t_d$ = 18 hours, which comes before F = 500 nm. This indicates that wave generation is duration limited. At the point U = 42, $t_d$ = 18, read $H_S$ = 25 feet, $T_F$ = 13 seconds and $F_{min}$= 270 nautical miles. These values are entered in step 4 of the worksheet.

For added illustration (not shown on the worksheet) assume a wind duration of 36 hours. Then proceed along the 42 knot line, arriving at F = 500 nm before reaching the 36 hour duration curve, giving $H_S$ = 30 feet, $T_F$ = 15 seconds and $F_{min}$= 500 nm. Additional wind duration will fail to produce higher waves in this fetch and wind wave generation is then fetch limited.

Going back to the duration limited case, enter the upper left panel of Figure 7 with T = 13 seconds and move upward to the decay distance line D = 1500 nm. From this point move horizontally to $F_{min}$= 270 nm in the upper right panel. Read there a $T_D/T_F$ ratio of 1.37 from the top of the nomogram. This value is entered in step 6 of the worksheet. In step 7 compute $T_D$ = 13 X 1.37 = 17.8 seconds. Enter the lower left panel of Figure 7 with $H_F$ = 25 feet, proceed vertically to D = 1500 nm and thence horizontally into the lower right panel to $F_{min}$= 270 nm. Read decay ratio $H_D/H_F$ = 0.28 in step 8. In step 9 compute $H_D$ = 25 X 0.28 = 7.00 feet. Rounding off these values, the 25 foot, 13 second significant wind wave at the leeward edge of the fetch has decayed to a significant swell of 7 feet with a period of 18 seconds after a 1500 nautical mile decay distance. From step 10 in the worksheet, using Figure 8 gives a fetch to forecast point travel time of 55 hours. This value should be added to the time the wind wave left the fetch to predict the arrival of swells in the forecast area (step 11). This travel time could also have been quickly computed from equation (8).

$$C_{gr} = 1.515T = 1.515 \times 18 = 27.27 \text{ knots}$$

$$1500 \text{ nm}/27.27 = 55 \text{ hours.}$$

THE BREAKER FORECAST

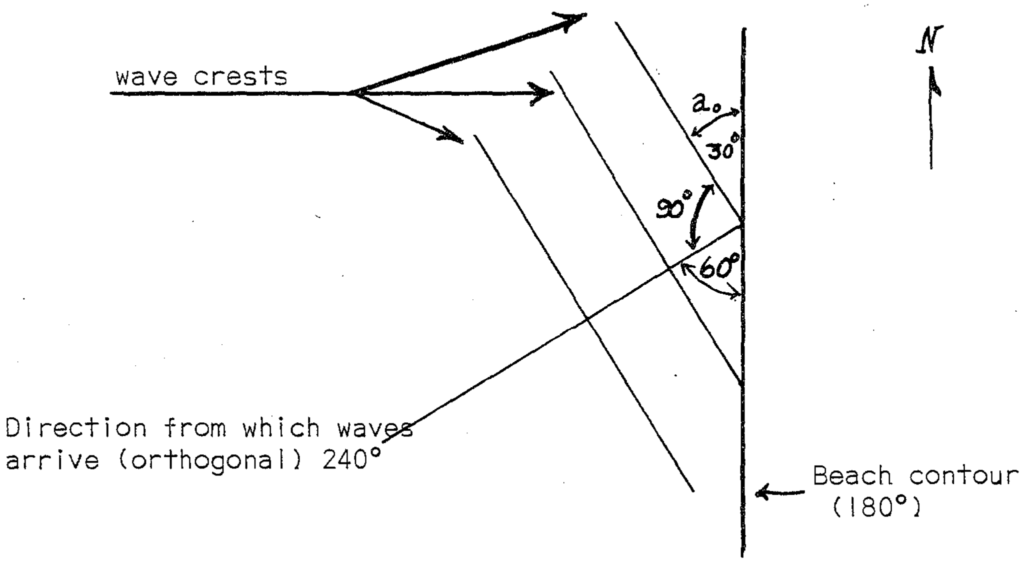
To satisfy the accuracy required by a coastal engineer, computer programs could print out breaker height for each combination of wave height, direction and period for waves arriving at any number of selected points. Breaker height forecasting would then be reduced to entering appropriate tables with the expected combination of deep water wave parameters for preprogrammed points. Similarly a catalog of refraction diagrams could be hand prepared for each combination of variables for selected beach locations. Either of these methods would produce a refined pinpoint forecast, but each requires an extensive one-time effort to generate the necessary tables or diagrams. However, a grossly smoothed system of graphs will produce a breaker height forecast of acceptable accuracy. Earlier work refined by Griswold (4), plus additional stereotyping by Holts (5), is the primary source of information and nomograms used in predicting breaker heights.

Prior to starting a breaker height forecast, a table of selected forecast areas should be prepared showing geographical orientation of uniform bottom contours and average beach slopes. Detailed charts published by the Coast and Geodetic Survey will furnish this information. Equipped with beach or bar orientation and bottom slope plus definition of deep water waves expected to reach a particular shoaling area, breaker forecasting is reduced to simply following the procedure outlined in the Surf Forecast Worksheet.

Data for steps 1,and 2 on the Surf Forecast Worksheet (Figure 9) are taken from steps 9 and 7 respectively of the Swell After Decay portion of the Sea and Swell Worksheet (Figure 6). In addition, the direction from which the deep water wave will arrive at the beach is known from the weather chart. From the previous sea and swell forecast example, for the deep water wave $H_D$ = 7 feet and $T_D$ = 18 seconds. Assume that waves are arriving from a direction of 240 degrees to a north-south beach with a 1:30 slope. Deep water wave crests are everywhere normal to the direction of motion of the wave (wave orthogonal). The wave crest angle ($a_o$) is complimentary to the angle between the wave orthogonal and the beach. Enter the angle ($a_o$) between wave crest and beach contours in step 3 of Figure 9. In this example:

wave orthogonal angle = 240 - 180 = 60 degrees

wave crest angle ($a_o$) 90 - 60 = 30 degrees.




Following the steps of the surf worksheet (Figure 9) and using surf graphs in Figures 10 through 22 gives significant breaker height of 12 feet. Statistically the maximum breaker height could be 1.87 times the significant breaker height, or 22 feet. Breakers would be predominately plunging and would induce a 1.8 knot longshore current on a smooth straight beach. Due to various beach orientations and bottom contours, it may be necessary to prepare breaker height forecasts for several points along a relatively short stretch of the coastline. Individual refraction diagrams may be necessary to accurately forecast breaker conditions caused by irregular bottom features. This is especially true near reefs or submarine canyons.

THE BAR PROBLEM

So far we have considered only breakers from waves moving onto a beach from deep still water. As waves encounter a tidal current, whether moving with, against or at an angle to the current, the wave length, steepness and wave speed will change, with only the period remaining constant. Waves will also change direction when they meet a current at an angle. The magnitude and direction of these changes is as yet largely unknown, and discussion will be limited to the more simple case of an incoming wave encountering either a directly opposing or following current.

Johnson (6) has developed the following wave modification rations:

$$(9) \quad \frac{C_c}{C_D} = 1/2(1 + a)$$

$$(10) \quad \frac{L_c}{L_D} = \left(\frac{1 + a}{2}\right)^2$$

$$(11) \quad \frac{H_c}{H_D} = \sqrt{\frac{2}{a(1+a)}}$$

Where: $a = \sqrt{1 + 4\left(\frac{V}{C_D}\right)}$ and V is the speed of the current in knots (positive for a following and negative for an opposing current). The "D" subscripts denote deep water waves while the "c" subscript denotes wave values in the current.

Equations 9, 10, and 11 may then be solved for any given combination of deep water wave measurements and current speeds. Since wave height is of greatest interest to the mariner, equation 11 has been graphed (Figure 23) to assist in evaluating effects of currents on breaker heights. Equations 10 and 11 may be combined in the form:

$$(12) \quad \frac{H_c}{L_c} = \frac{H_D}{L_D} \cdot \sqrt{\frac{2}{a(1 + a)}} \left(\frac{2}{(1 + a)}\right)^2$$

which defines the wave steepness of the modified wave. As this steepness parameter approaches the critical value (0.10 for practical use) the incoming wave becomes unstable and breaks. From these equations and from Figure 23 it can be seen that as an incoming wave meets an opposing (ebb) current the wave height and wave steepness increase quite rapidly with the wave approaching an unstable breaking condition.

While a following current may induce some wave instability, the normal trend is for lower wave heights with less wave steepness and generally flatter seas.

As an example, a set of conditions have been selected for a fully arisen sea that is commonly observed over many offshore bars in the Pacific Northwest. Since significant wave height is a statistical value that tends to be quite stable, a more realistic "average sea state" will be employed. From the Wilbur Marks Sea State Chart, Figure 24, note that a 22 to 27 knot wind generates seas with an average height of 7.9 feet, average period of 6.8 seconds and average wave length of 160 feet. Considering a solitary wave, the mean deep water wave speed would be $C = 3.03T = 3.03 \times 6.8 = 20.6$ knots and wave steepness $H_D/L_D = 7.9/160 = 0.049$. Let this wave meet a directly opposing or ebb tidal current of 3.0 knots.

Then $$a = \sqrt{1 + 4\left(\frac{-3.0}{20.6}\right)} = 0.65.$$

From (Equation 10): $$L_c = 160\left(\frac{1 + .65}{2}\right)^2 = 110 \text{ feet.}$$

From (Equation 11): $$H_c = 7.9\sqrt{\frac{2.0}{.65(1 + .65)}} = 11 \text{ feet.}$$

And $$\frac{H_c}{L_c} = \frac{11}{110} = .10.$$

Thus, the 8-foot stable wave has grown to 11 feet, the wave length has shortened to 110 feet and the wave steepness ratio has reached the unstable criterion or breaking point.

Conversely had the wave moved into a flood (following) current of 1.5 knots the parameter "a" would be 1.13, $H_c$ would be reduced to 7.2 feet, $L_c$ would lengthen to 180 feet and the wave steepness ratio would be 0.04.

A small boat operator could safely pass over the bar (or out of the tidal channel) with a flood tide or during slack water, but would experience considerable difficulty on ebb tide. Since water depth over most West Coast bars is not as shallow as the depth required to induce wave breaking ($d_b = 1.3\ H_b$ where $d_b$ is breaking depth and $H_b$ is breaker height) shoaling was not taken into account, even though the incoming wave would have started to feel bottom on the seaward side of the bar. In the case of a very shallow bar the current-induced increase in wave height would be additive to the shoaling effect.

## VI. FORECAST EXAMPLES

### FORECAST FOR THE GOLDEN GATE

One of the most severe storms and highest seas of the past 50 years along the central California coast occurred from February 7 - 9, 1960. Figures 25 through 28 show the surface charts for this storm. The storm center developed quite rapidly with warm sector winds of 30 knots appearing on the 07/12Z chart (not shown). By 1800Z a fetch (area within dashed lines of Figure 25) had developed with U = 30 knots, $t_d$ = 9 hours (6 hours from 1200Z to 1800Z plus one half the time interval between maps when the wind was assumed to have sprung up) and F = 1100 nm. Entering Figure 5 with U and $t_d$, read $H_F$ = 10.5 feet, $T_F$ = 8.3 seconds and $F_{min}$= 90 nm with wave height duration limited. Since there is no decay area these waves would be occurring off the Golden Gate by 07/18Z.

Wind in the fetch then quickly increased to an average of 40 knots for the ensuing 6 hours (Figure 26). Now follow the dotted lines of constant wave energy from U = 30 knots and $H_F$ = 10.5 feet upward to U = 40 knots and read $t_{min}$= 4 hours. Then from the fetch of Figure 26, U = 40 knots, $t_d$ = 4 + 6 = 10 hours and F = 1100 nm. Entering Figure 5 with these values, read $H_F$ = 18 feet, $T_F$ = 10.5 seconds and $F_{min}$= 125 nautical miles. This would be the sea state by 08/00Z. This gradient then held with 40 knot winds for an additional 12 hours. The fetch length still exceeded 1,000 nm on the 08/00Z chart. This fetch length could still be used, as the trough was expected to flatten with a slow veering of the winds, but with winds still within a sector that would direct waves toward the Golden Gate. Waves would initially arrive from the southwest and gradually shift into the west as the front passed over the Golden Gate near 08/15Z (Figure 27). With winds holding at 40 knots up to 08/12Z, duration time is now 22 hours and from Figure 5, seas would grow to $H_F$ = 25 feet, $T_F$ = 13.2 seconds and $F_{min}$= 350 nm. Frontal and post-frontal winds averaged 45 knots for another 12 hours (Figure 27). From U = 40 knots and H = 25 feet move up the energy lines to U = 45 knots and read $t_{min}$= 14 hours. The Then $t_d$ = 14 + 12 = 26 hours. Moving along the 45 knot line to $t_d$ = 26 hours and read a wave height of 33 feet at 15.2 seconds. This would be the sea state off the Golden Gate at 09/00Z. The fetch was shortening rapidly as the low moved onshore. During the following 12 hours seas should diminish quickly and gradually veer into an arrival direction from the northwest. Seas of 33 feet with a period of 12 seconds were reported off the Golden Gate near the end of this storm. The shorter-than-forecast wave period would appear to be a common observer bias of reporting average wave period while estimating the larger or significant wave height.

### COLUMBIA RIVER BAR FORECAST WITH STABLE SWELLS

Figure 29 shows the synoptic pattern off the Pacific Northwest as of 0000Z December 3, 1969. The indicated fetch had been in operation for a period of 18 hours with 35-knot winds by map time. An additional 12 hours of wind duration was added to account for 16-foot seas already in the area when the fetch first developed. As indicated on the worksheet (Figure 30) a 10 foot, 16 second significant swell would reach the mouth of the Columbia River by 04/0400Z. The fetch persisted for another 9 hours and it would take 12 hours for midfetch waves to pass out of the leading edge of the generating area. Thus about 20 hours of heavy swells could be expected from this storm.

As the swell train approaches the mouth of the Columbia River it would move against an average 4 knot current during ebb tide. From Equation 5, and Figure 23 (or Equation 11) there would be an increase of significant swell height from 10 feet in still water to 12 feet in the tidal current. This example illustrates a stable swell with a long period and long wave length and with the shorter wave lengths generally absent from the wave spectrum. Only a slight increase of wave height is noted when the swell invades the tidal current.

COLUMBIA RIVER BAR FORECAST WITH WIND WAVES

Wind duration of the fetch shown in Figure 31 was 6 hours with the fetch forecast to move to the Columbia River mouth in the next 12 hours. Fetch winds had been near 30 knots but decreased to 20 knots for a 25-knot average over the total 18-hour duration, giving a forecast arrival time of 1800Z November 23, 1969. With U = 25 knots and $t_d$ = 18 hours, $H_F$ = 11 feet and $T_F$ = 9 seconds with no decay (Fig.5). From Equation 11 this significant wave height would increase to 15 feet as it meets the average 4.0 knot ebb tidal current over the Columbia bar. While these seas are duration limited they are approaching a fully arisen sea and, as discussed earlier, the Sea State Chart must be entered for "average seas" in order to more closely estimate random sea conditions over the bar. Interpolating in the 22 to 27 knot bracket, a sea containing an 11-foot significant wave would have an average wave height of about 7.1 feet with an average period of 6.5 seconds and average wave length near 147 feet. This average wave (from Figure 23) would increase to about 12 feet and from Equation (10) decrease its wave length to 99 feet with a resulting wave steepness of 0.12. The shorter wave lengths would then be plunging type breaking waves superimposed on the longer more stable significant waves and would break before reaching a height of 12 feet.

From the Tidal Current Tables, on November 23, 1969 maximum ebb tide at Cape Disappointment Light (near the Columbia River channel entrance) occurred at 1616PST with a maximum ebb flow of 5.85 knots (use of current prediction tables is fully explained in each issue of the Tidal Current Tables and is not repeated here). The forecast just completed would then be issued as follows:

"Significant waves of 11 feet at 9 second periods over the Columbia bar by 10 a.m. today increasing to near 15 feet with heavy breaking waves at maximum ebb tide near 4 p.m. and decreasing again to 10 feet at slack water. Much lower seas Monday."

## VII. SOUTHERN CALIFORNIA SEA STATE FORECASTS

Southern California's offshore islands present a complex array of shielding, refracted wave rays and open exposures to the sharply curved main coastline (see table ). The most meaningful approach to a local sea state and surf forecast, within present capabilities, is simply to modify the open ocean wave or swell for points with a direct exposure (i.e., open windows) to the expected arrival direction. A more intuitive or empirical adjustment is then usually sufficient for estimating wave or breaker heights in more sheltered areas, but this would be very time consuming and would still require a number of gross assumptions or estimates. With a few local exceptions, waters within breaker inducing depth leading to the major beaches have comparatively uniform bottom contours with approximately a 1:30 slope. Windows or open exposure areas were measured directly from appropriate Coast and Geodetic Survey charts.

The deep water or open ocean wave forecast is prepared as in previous sections. Now, however, one can immediately eliminate any area north of a 295 degree great circle path converging on San Diego as a possible fetch area. This is due to the shielding of the landform near Point Conception. On the other hand the tropical eastern Pacific and the south Pacific Ocean are frequent spawning grounds for swells that may induce heavy surf on southern California beaches during spring, summer and early autumn. Very intense storms often remain nearly stationary in the far south Pacific Ocean for extended periods. Seas of 30 to 40 feet, or more, are not at all uncommon in these storms. Should these seas be propagated along a great circle path leading to southern California they will arrive, after a 5000 to 6000 mile decay, as very low and very long swells with abundant wave energy. These 20 to 24 second period swells with wave lengths in excess of 1,000 feet frequently pass undetected over vast areas of the ocean. Upon reaching shoaling waters along the southern California coast, swell heights will increase as wave lengths shorten, with very heavy breakers pounding exposed shores.

While western north Pacific typhoons may be in areas with open windows to southern California, the geometry of their circulation is not conducive to directing heavy swells toward southern California. Eastern Pacific tropical storms and hurricanes frequently direct heavy swells toward southern California. Techniques for predicting wind waves developed by tropical storms and hurricanes are the same as for extratropical storms. The only difference is the greater difficulty encountered in determining surface wind flow in a hurricane and fetch boundaries that would direct waves toward a specific target area.

### SWELLS AND BREAKERS FROM A WINTER STORM

Early in its life the deep low of Figure 32 directed very heavy swells toward Hawaii with resulting gigantic breakers and extensive property damage. Slowing of the storm's forward speed in its final stages gave an effective duration time of 48 hours for winds in the indicated fetch. As indicated on the sea and swell worksheet (Figure 33), seas of 21 feet with periods of 13 seconds were developed in the fetch. These seas decayed over 1,200 nautical miles to an 8-foot swell, reaching southern California coastal waters 50 hours later. Following through the surf forecast procedure (Figure 34) the 8-foot swell would shoal to a significant breaker of 9.9 feet with maximum possible breakers of 18.5 feet. A glance through the beach exposure table would indicate those beaches with an open window to waves arriving from 290 degrees. Breakers of 12 to 18 feet with some sets to 20 feet were observed on many southern California beaches from this storm. These heavy breakers occurred during a period of unusually high tides and caused extensive property damage along the coast.

SWELLS FROM THE SOUTHERN HEMISPHERE

The low-pressure center shown in Figure 35 had moved slowly eastward from the New Zealand area but did not display an orientation that would direct swells toward southern Califirnia until 0000Z 13 July 1969. With 24-hour map continuity, it can be assumed that the fetch developed suddenly, changed orientation or moved into an open window area at 12/1200Z. The 0000Z map for 14 July indicated that the fetch had remained essentially unaltered for an additional period of 24 hours. A sea state and breaker height forecast was prepared from the fetch shown in Figure 36. Lacking ship observations, 65 percent of the geostrophic wind or a wind speed of 36 knots was used with a duration time of 36 hours and a fetch of 1,000 nautical miles. Then as shown on the sea and swell worksheet (Figure 37) 26-foot seas with an average period of 14.3 seconds would be found in the fetch with a minimum fetch requirement of 600 miles. During their 4,800-mile trip with a travel time of 160 hours, these seas would decay to a 5.7 foot 20 second swell arriving in southern California's coastal waters along a 210 degree great circle path.

Surf forecasts were made for individual beaches. Selecting Newport Beach for an example and following the surf computation procedure (Figure 38) these deep water waves would produce a 7.8 foot significant breaker and a 14 foot maximum breaker with a 20-second period and an arrival time of 20/1600Z.

Due to attenuation of the swells as they pass through islands of the South Pacific and through various wave fields on their long journey from the Southern Hemisphere, the swells would arrive at southern California in sets of variable wave trains. In a case such as this, the first visual indication of a south swell is a slow increase in breaker heights with a confused arrival direction. As energy increases, the southerly swell becomes more apparent. As the significant swell arrives it is usually seen that swells and breakers will be about half the expected heights for periods of 15 to 20 minutes followed by a set of 10 or 12 breakers approaching the forecast values. Therefore forecast swell and breaker heights from such a distant storm are subjectively modified. In this particular instance the forecast, which was issued on Wednesday 16 July, read as follows:

"Increasing southerly swells Saturday becoming 4 to 5 feet with breakers 6 to 8 feet and occasional sets to 12 feet on south facing beaches Sunday. Very strong rip currents and local hazardous swimming conditions with high breakers Sunday. Decreasing southerly swell and lower breakers late Monday."

For a more localized forecast, it is noted from Table I that Port Hueneme, Zuma, Malibu-Surfrider, Santa Monica, Redondo, San Clemente, Oceanside, Del Mar, and Mission beaches are all open to swells arriving from 210 degrees and would feel the full effect of the southerly swell. Huntington Beach and Seal Beach have marginal exposure to swells from this direction and would tend to have slightly lower breakers. Newport Beach would appear to be marginal but, due to heavy refraction induced by the Newport submarine canyon and by beach curvature, the full force of the heavy breakers would be felt. This is especially true for the area just to the north of the Newport Pier.

## VIII. ACKNOWLEDGMENT

The authors are indebted to Allen D. Cummings, Marine Meteorologist, San Francisco WBFO, for checking computations and constructive additions to and changes in the text.

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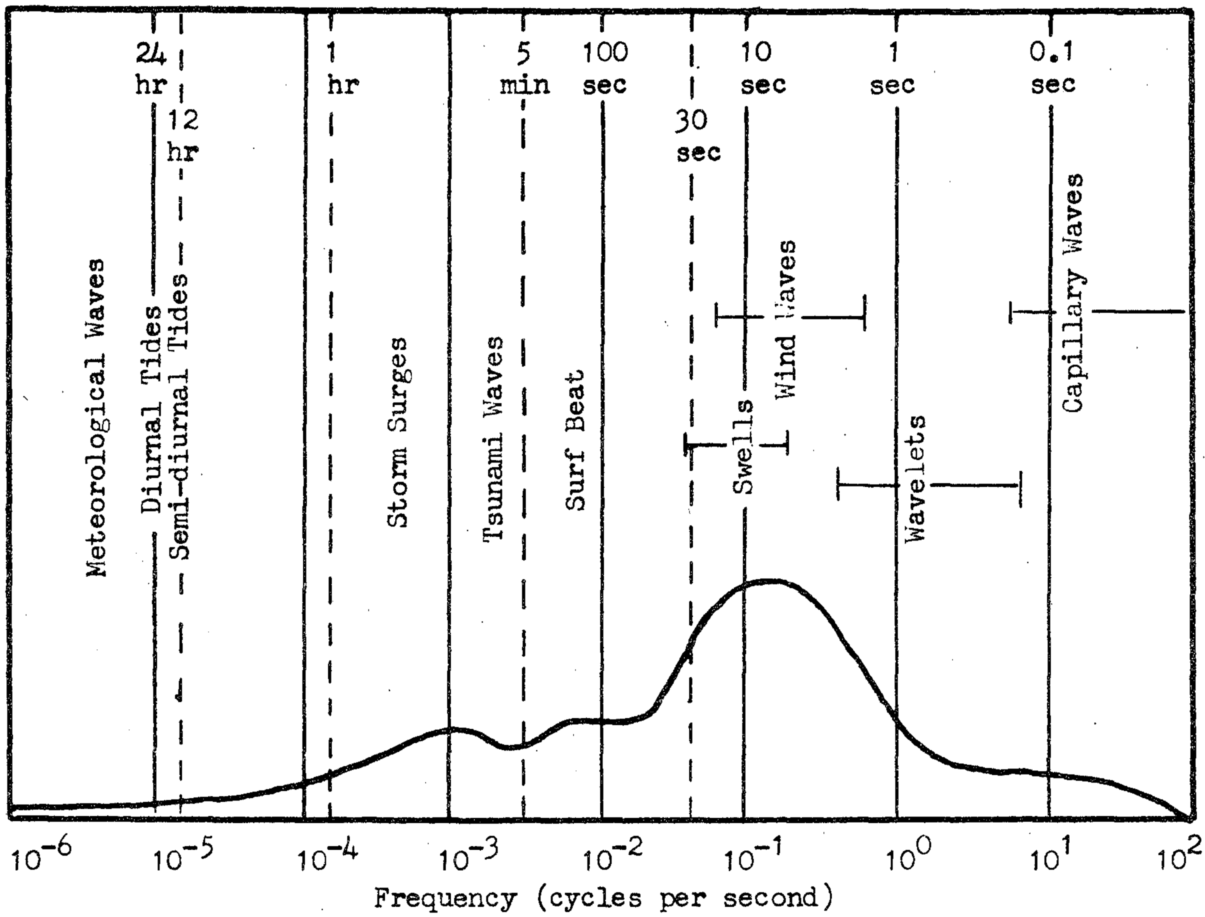



Figure 1. Water Wave Spectrum (with comparative energy distribution curve in arbitrary units)

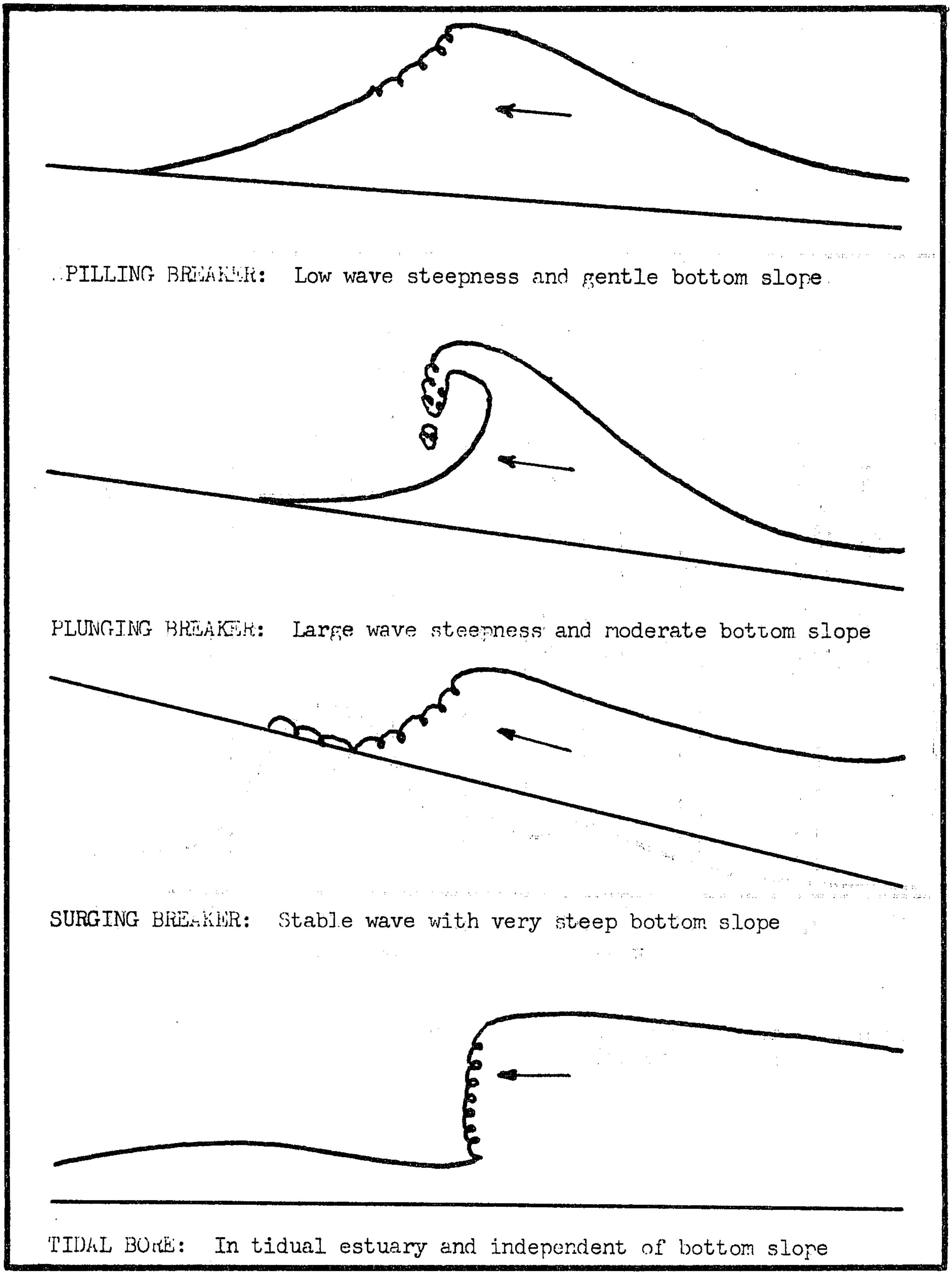
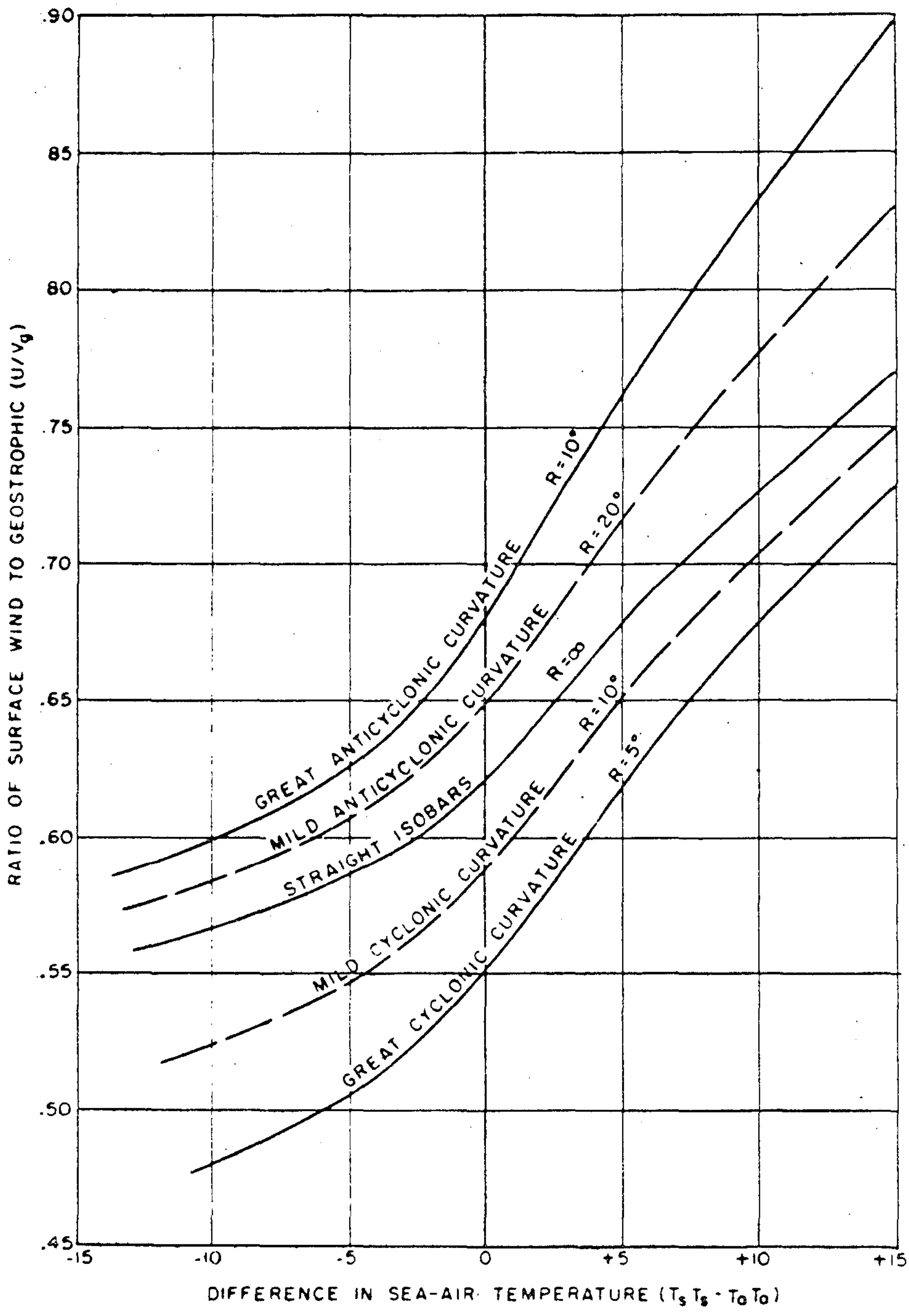



Figure 2. BREAKER TYPES




SURFACE WIND SCALE

Figure 3

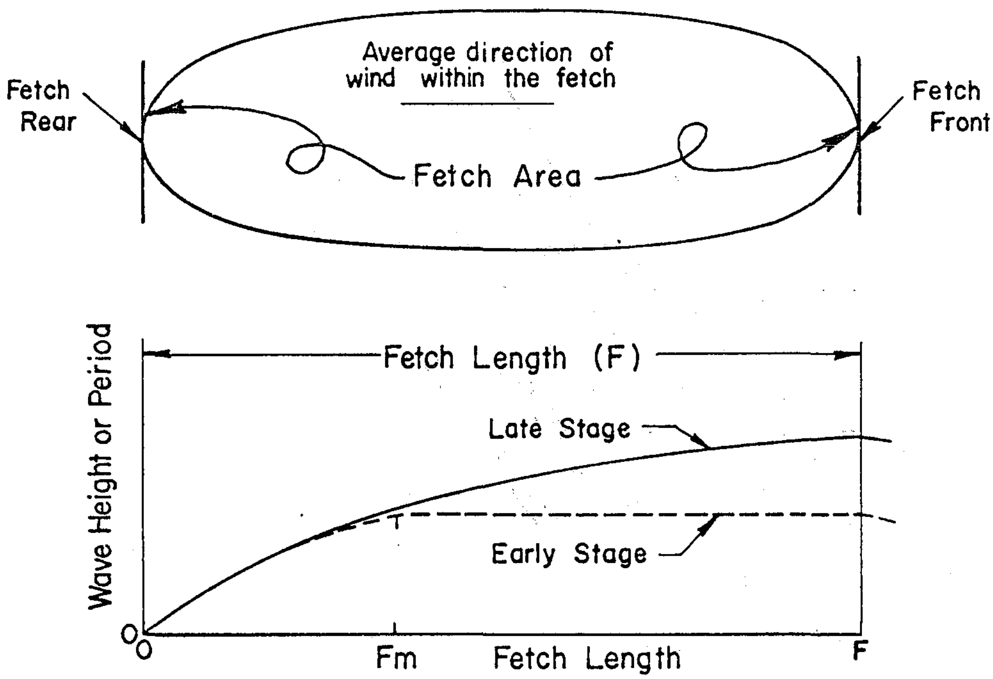



FIGURE 4 WAVE DEVELOPMENT WITHIN A FETCH

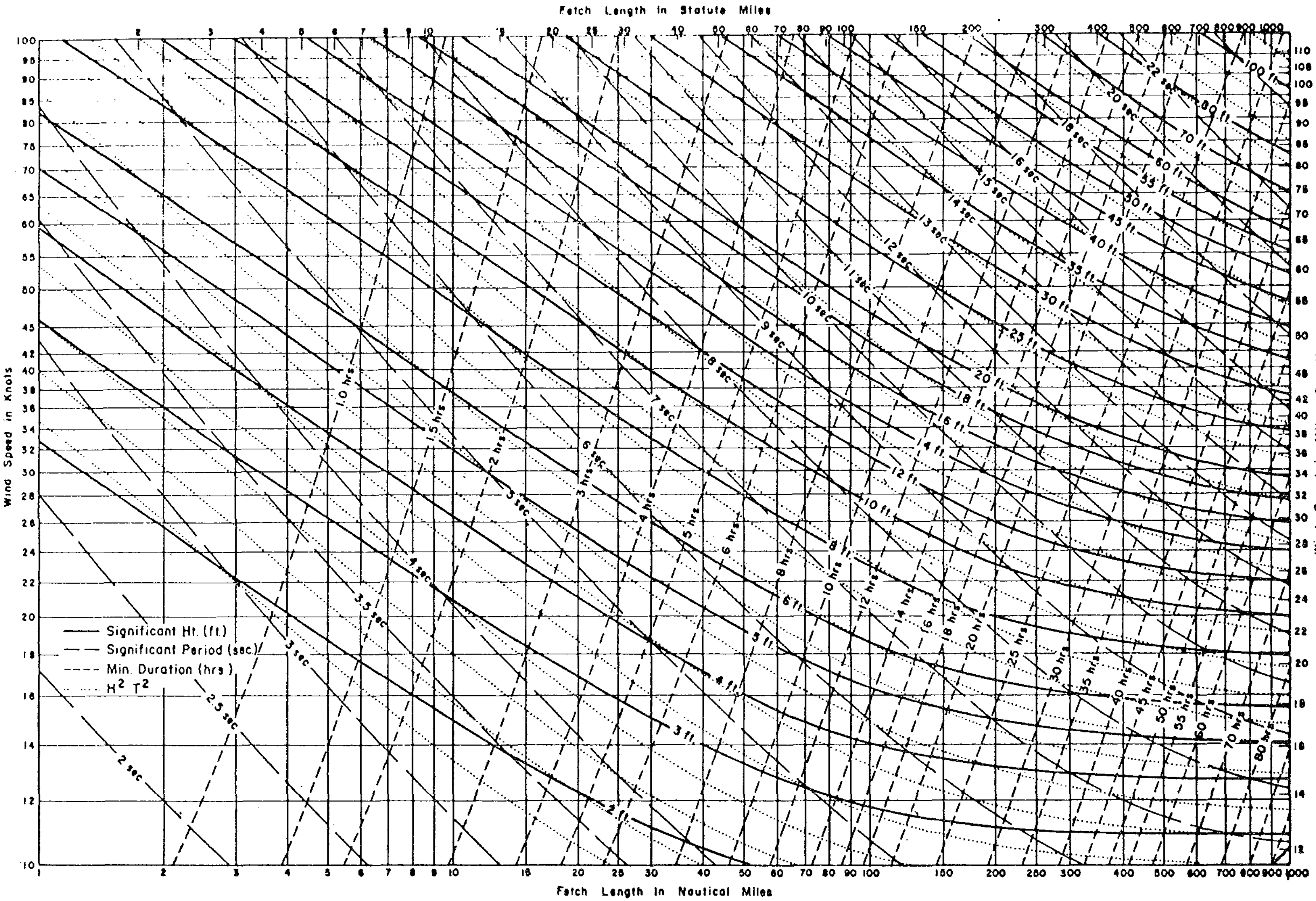



FIGURE 5' DEEP WATER WAVE FORECASTING CURVES AS A FUNCTION OF WIND SPEED, FETCH LENGTH, AND WIND DURATION

( for Fetches 1 to 1,000 miles )

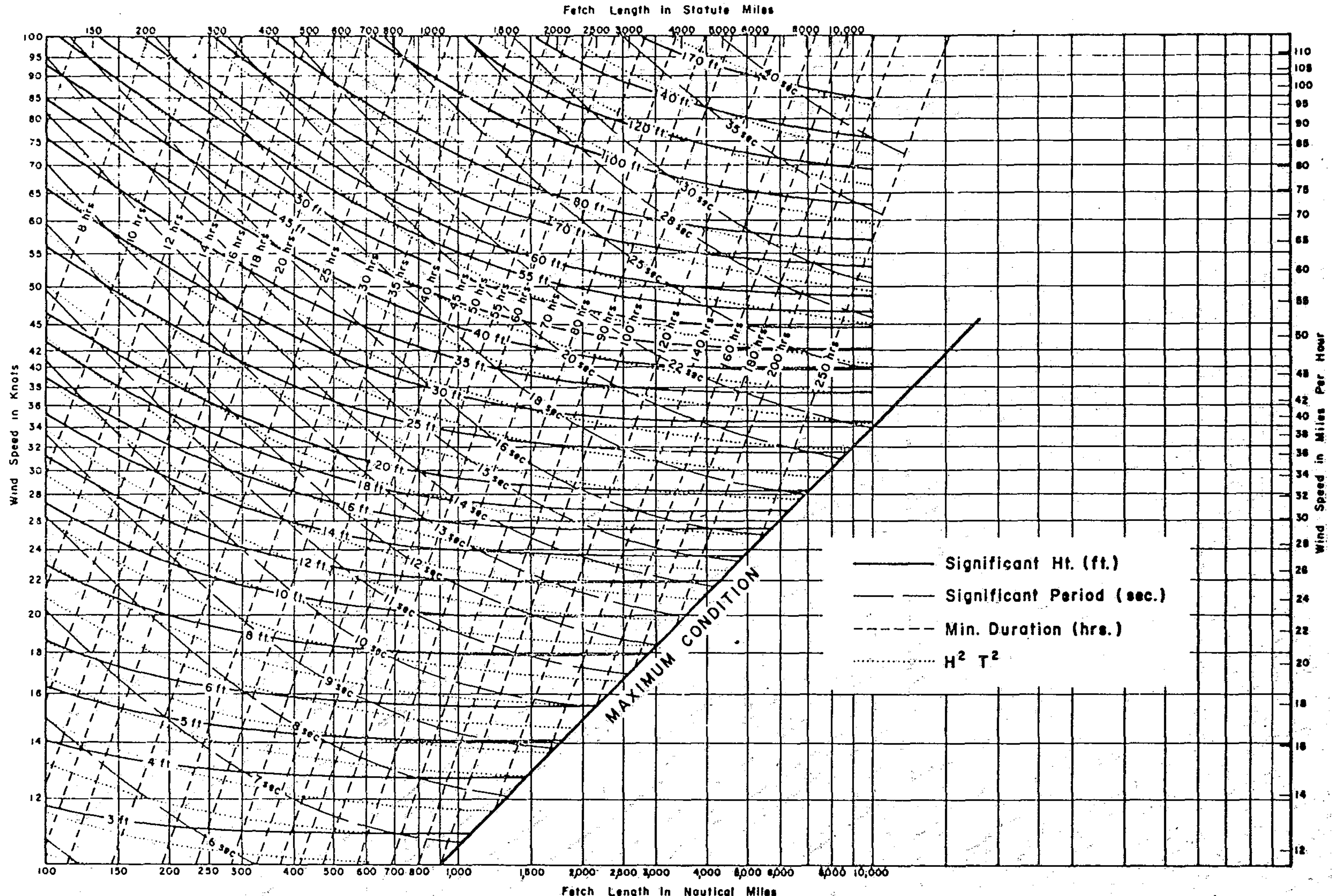



FIGURE 5A DEEP WATER WAVE FORECASTING CURVES AS A FUNCTION OF WIND SPEED, FETCH LENGTH, AND WIND DURATION

(for Fetches 100 to > 1,000 miles)

## SEA AND SWELL WORKSHEET

FETCH # ________ CHART DATE ____________________ MONTH ____________________

***************************************************************************

### FETCH

| | | | |
|---|---|---|---|
| 1. Wind speed over fetch: | $U$ = | 42 | KTS |
| 2. Length of fetch: | $F$ = | 500 | N. M. |
| 3. Duration of winds: | $t_d$ = | 18 | HRS |

***************************************************************************

### SEA IN FETCH

| | | | |
|---|---|---|---|
| 4. Enter Figure 5 with U (step 1) and F or $t_d$ (step 2 or 3) whichever comes first while going across graph from left to right and record: | $H_F$ = | 25 | FT |
| | $T_F$ = | 13 | SECS |
| | $F_{min}$ = | 270 | N.M. |

***************************************************************************

### SWELL AFTER DECAY

| | | | |
|---|---|---|---|
| 5. Measure decay distance D: | D = | 1500 | N.M. |
| 6. Enter upper portion Figure 7 with $T_F$ (step 4) and D (step 5) - move horizontally across to $F_{min}$ (step 4) then vertically to $T_D/T_F$ | $T_D/T_F$ = | 1.37 | |
| 7. $T_D/T_F$ from step 6 and T (step 4) com-compute $T_D=T_F \times \underline{1.37}$: | $T_D$ = | 17.8 | SECS |
| 8. Enter lower portion of Figure 7 with $H_F$ (step 4) to D (step 5) - move horizontally across to $F_{min}$ (step 4) then down to $H_D/H_F$: | $H_D/H_F$ = | 0.28 | |
| 9. Qith $H_D/H_F$ (step 8) and $H_F$ (step 4) compute $H_D = H \times \underline{0.28}$: | $H_D$ = | 7.00 | FT |
| 10. Enter Figure 8 with $T_D$ (step 7) and D (step 5) to find $t_D$ (travel time): | $t_D$ = | 55 | HRS |
| 11. Add $t_D$ (step 10) to Date/Time of map for ETA of swell: | ETA | _____/_____ | Z |

FIGURE 6

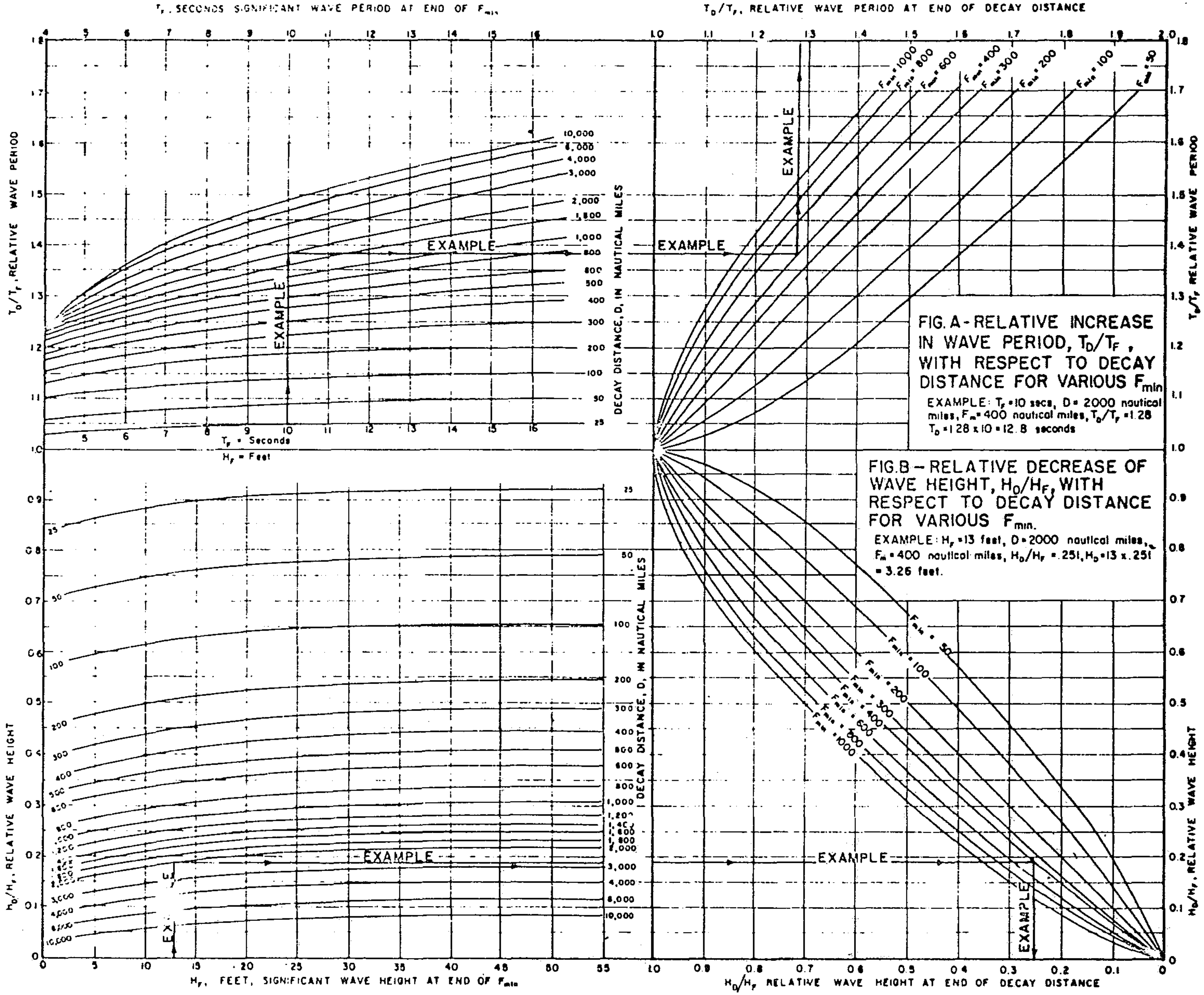



Figure 7 DECAY CURVES (Bretschneider, 18)

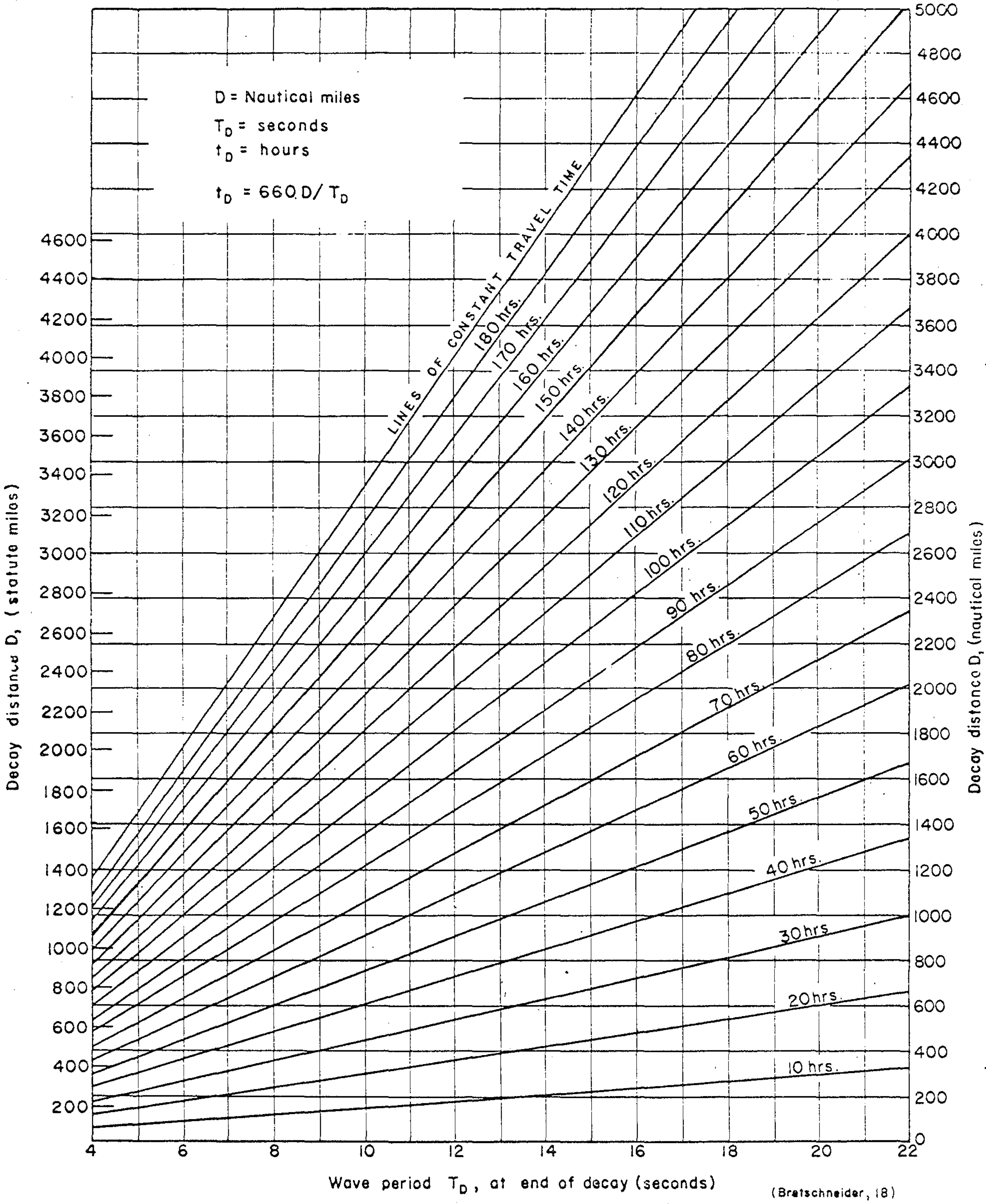



FIGURE 8 TRAVEL TIME OF SWELL BASED ON $t_D = D/C_g$

SURF FORECAST WORKSHEET

BEACH NAME ____________ BEACH SLOPE 1:30 ____________ ETA SURF ____________

*******************************************************************************

FROM OBSERVED OR FORECAST SWELL

1. Deep water wave height: $H_o$ = 7 ft.

2. Deep water wave period: $T_o$ = 18 sec.

3. Angle between deep water waves and depth contours $a_o$ = 30 deg.

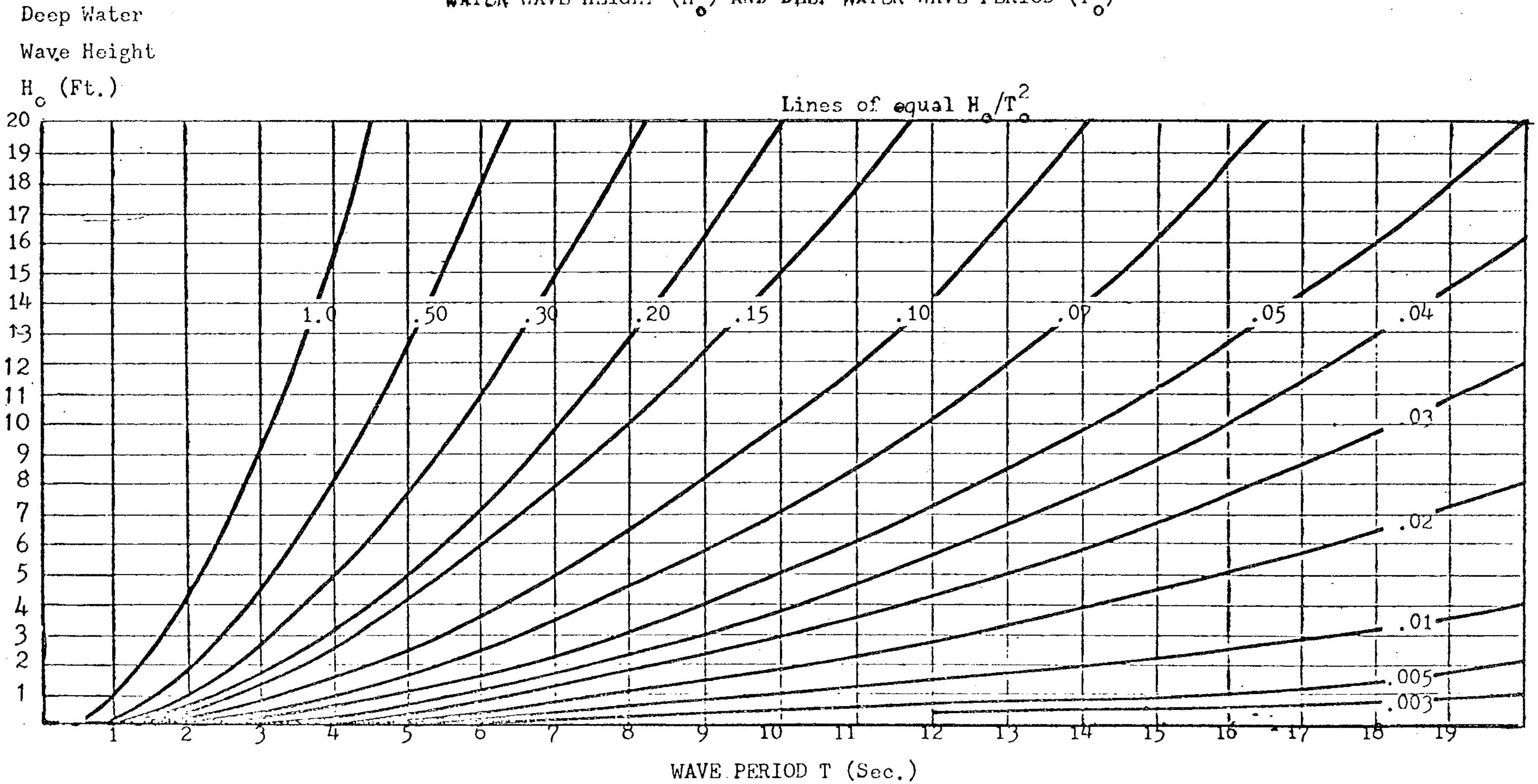
*******************************************************************************

SURF CALCULATIONS

| Step | Figure | With | And Read |
|---|---|---|---|
| 4 | 10 | $H_o$ from step 1 and $T_o$ from step 2 | $H_o/T_o^2$ .021 |
| 5 | 11 | $H_o/T_o^2$ from step 4 | $H_b/H_o$ 1.85 |
| 6 | 12 | $H_o$ from step 1 and $H_b/H_o$ from step 5 | $H_b$ 13 ft. |
| 7 | 13 | $H/T^2$ from step 4 and Beach Slope from heading | Breaker Type Plunging |
| 8 | 14 | $H_o/T_o^2$ from step 4. If $H_o/T_o^2 < .01$ go to next step | $d_b/H_o$ 2.45 |
| 9 | 15 | $H_o$ from step 1 and $d_b/H_o$ from step 8 or use $d_b = 1.3\ H_o$ if $H_o/T_o^2 < .01$ | $d_b$ 17 ft. |
| 10 | 16 | $d_b$ from step 9 and Beach Slope from | Width of Surf Zone 170 yds. |
| 11 | 17 | $d_b$ from step 9 and $T_o$ from step 2 | $L_b$ 425 ft. |
| 12 | 18 | $L_b$ from step 11 and Width of Surf Zone from step 10 | No. Lines of Surf 1 |
| 13 | 19 | $d_b$ from step 9 and $T_o$ from step 2 | $d_b/L_o$ .011 |
| 14 | 20 | $a_o$ from step 3 and $d_b/L_o$ from step 13 | $a_b$ 7.5 deg.<br>$K_d$ .93 |
| 15 | 21 | $H_b$ from step 6 and $K_d$ from step 14<br>Max $H_b$ = 1.87 (cor $H_b$) = 22 ft. | $H_b$ corrected for refraction<br>cor $H_b$ 12 ft. |
| 16 | 22 | $a_b$ from step 14 and Beach Slope from heading. $H_b$ from step 15 and $T_o$ from step 2 | Longshore Current 1.8 kts. |

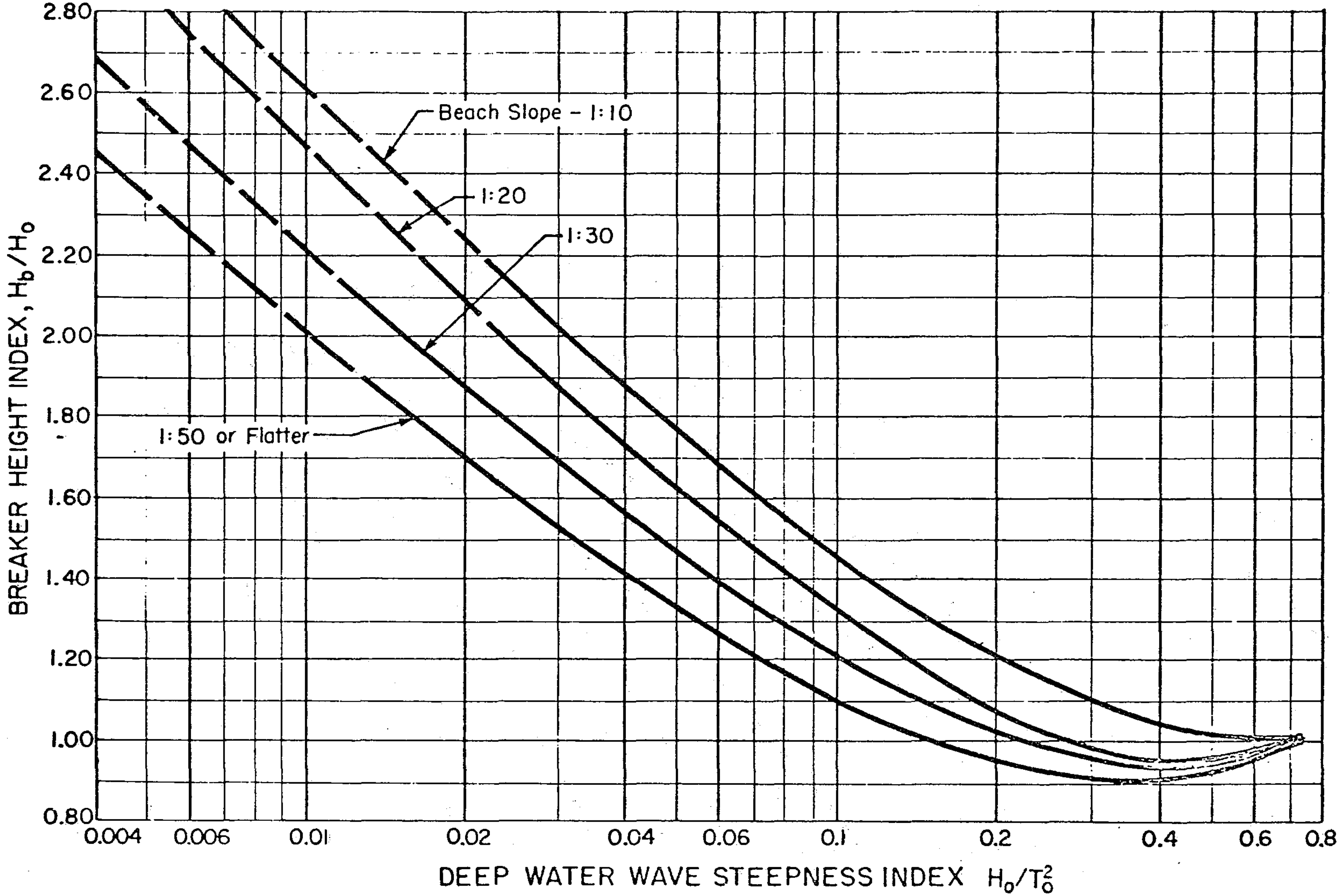
FIGURE 9

DEEP WATER WAVE STEEPNESS INDEX ($H_o/T_o^2$) AS A FUNCTION OF DEEP WATER WAVE HEIGHT ($H_o$) AND DEEP WATER WAVE PERIOD ($T_o$)




Graph for Determining the Deep Water Wave Steepness Index

FIGURE 10




GRAPH FOR DETERMINING THE BREAKER HEIGHT INDEX

FIGURE 11

BREAKER HEIGHT ($H_b$) AS A FUNCTION OF DEEP WATER WAVE HEIGHT ($H_o$) AND BREAKER HEIGHT INDEX ($H_b/H_o$)

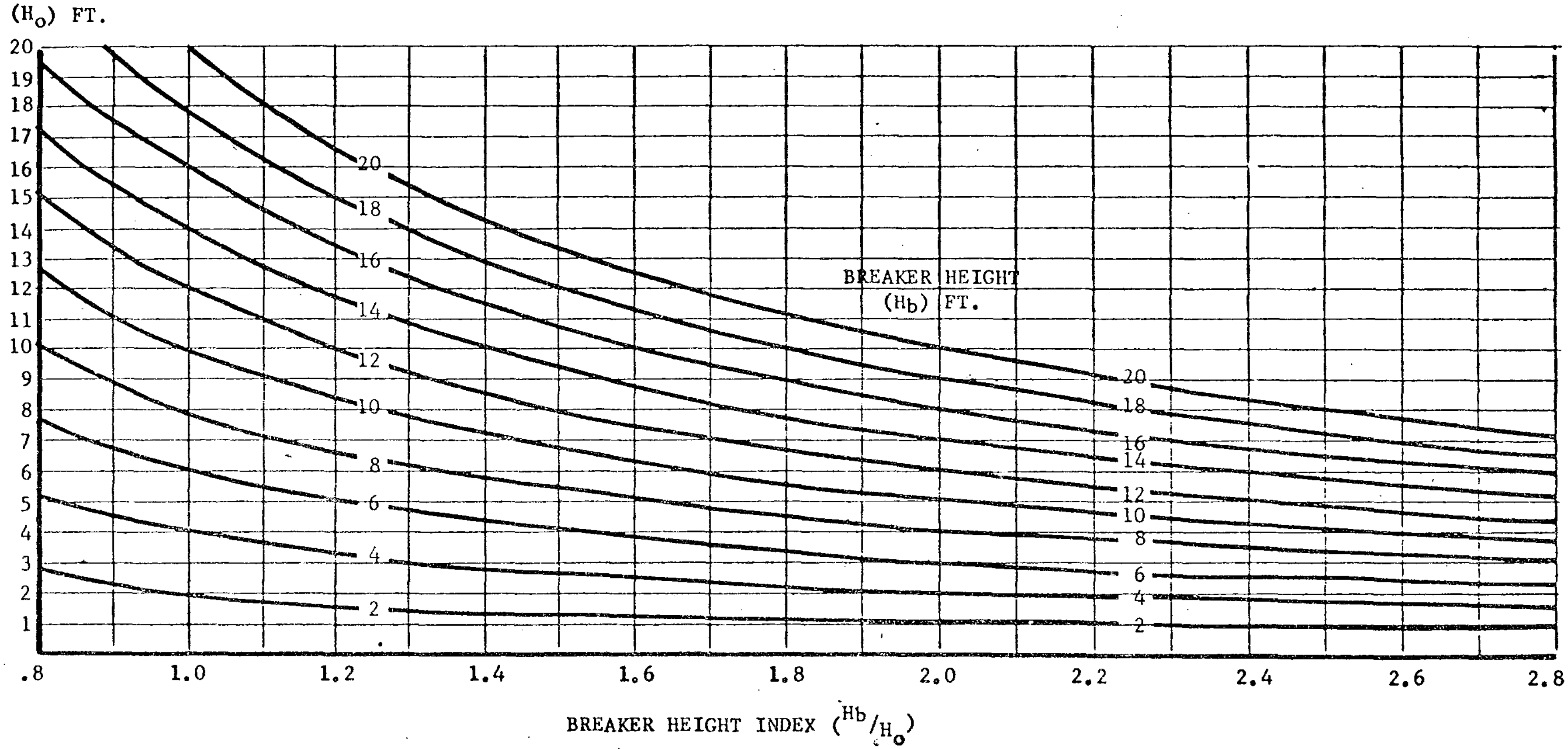
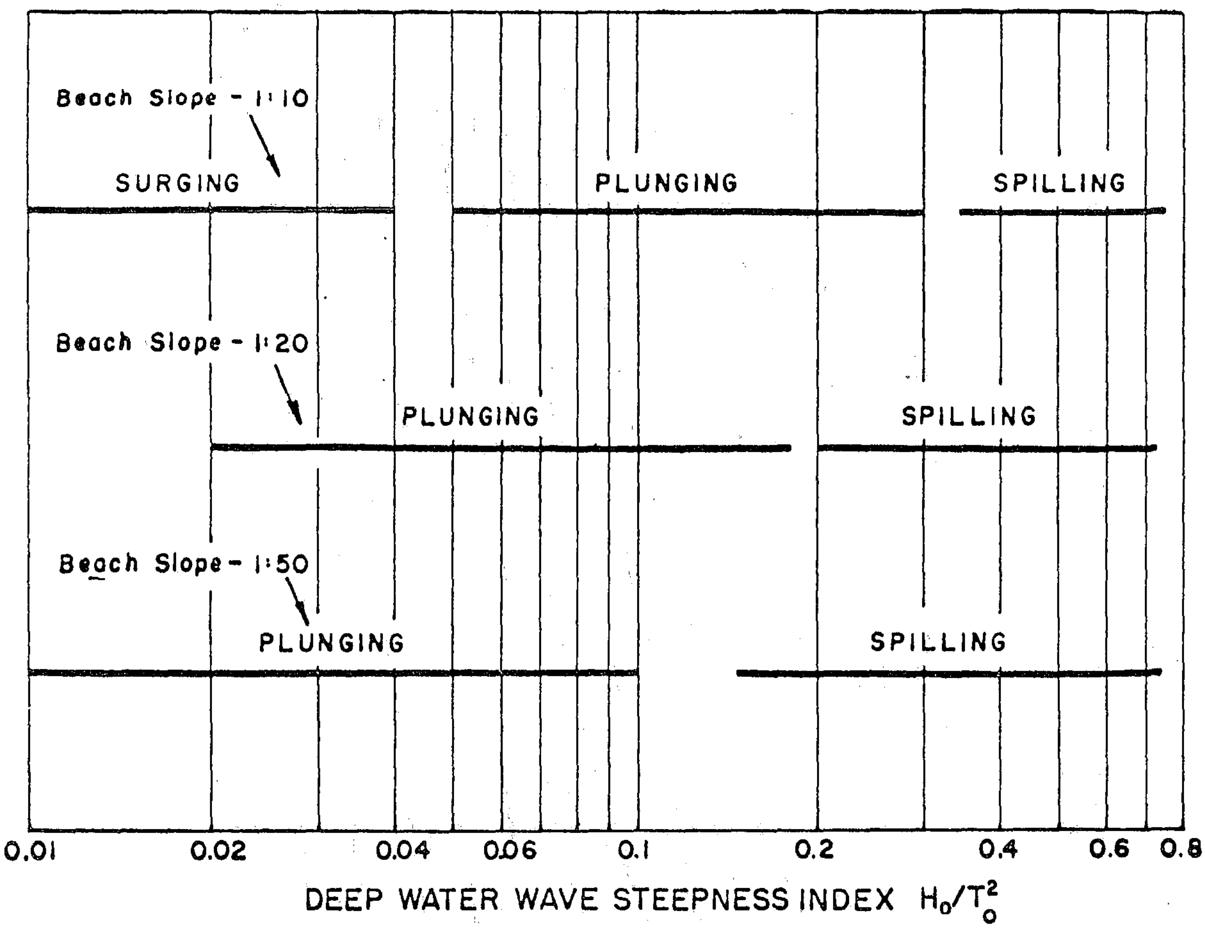



FIGURE 12

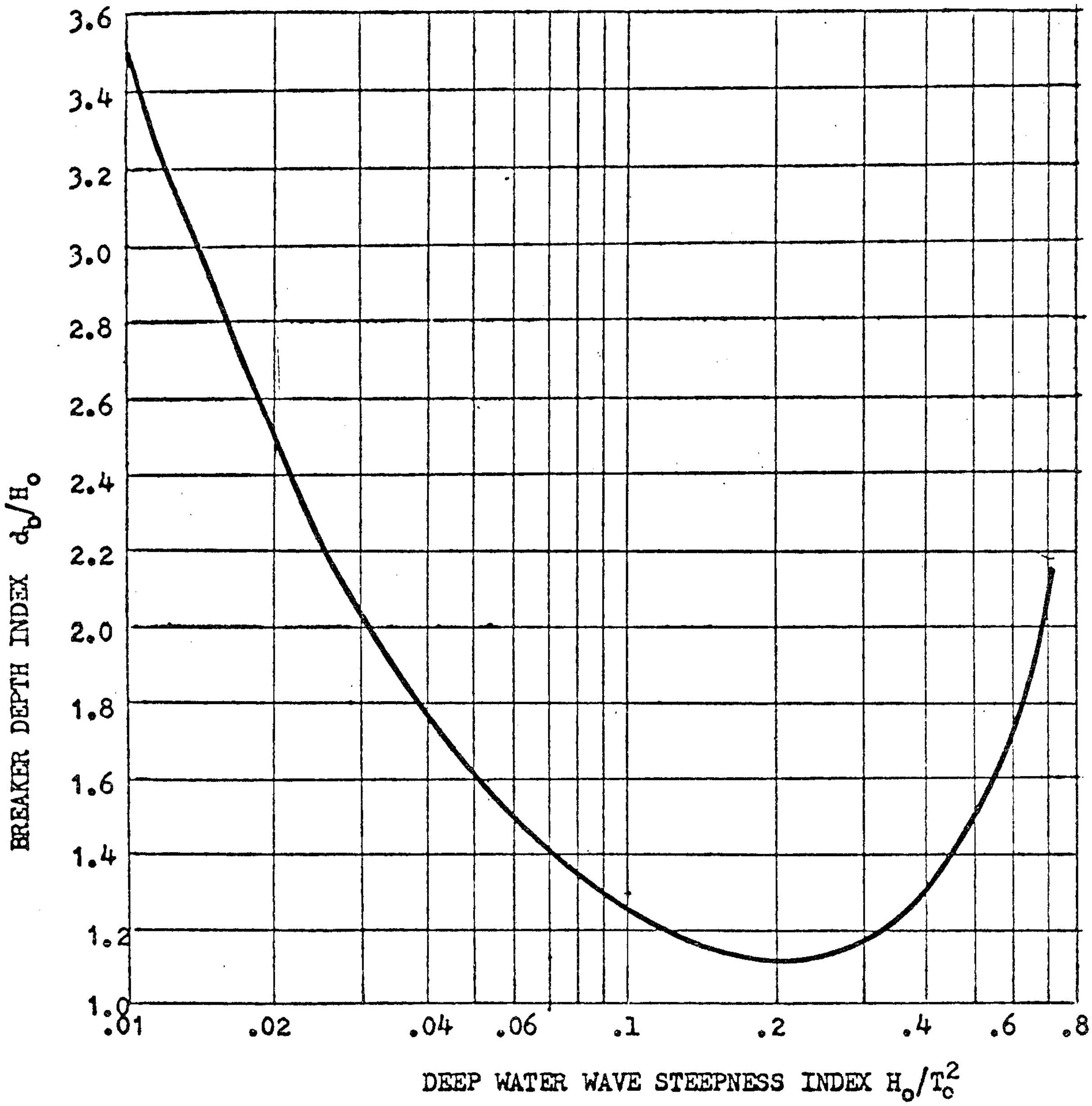
BREAKER TYPE AS A FUNCTION OF DEEP WATER WAVE STEEPNESS INDEX $(H_o/T_o^2)$




**GRAPH FOR DETERMINING THE BREAKER TYPE**

FIGURE 13

BREAKER DEPTH INDEX ($d_b/H_o$) AS A FUNCTION OF DEEP WATER WAVE STEEPNESS




**Graph for Determining the Breaker Depth Index.**

FIGURE 14

DEPTH OF BREAKING ($d_b$) AS A FUNCTION OF DEEP WATER WAVE HEIGHT ($H_o$) AND BREAKER DEPTH INDEX ($d_b/H_o$)

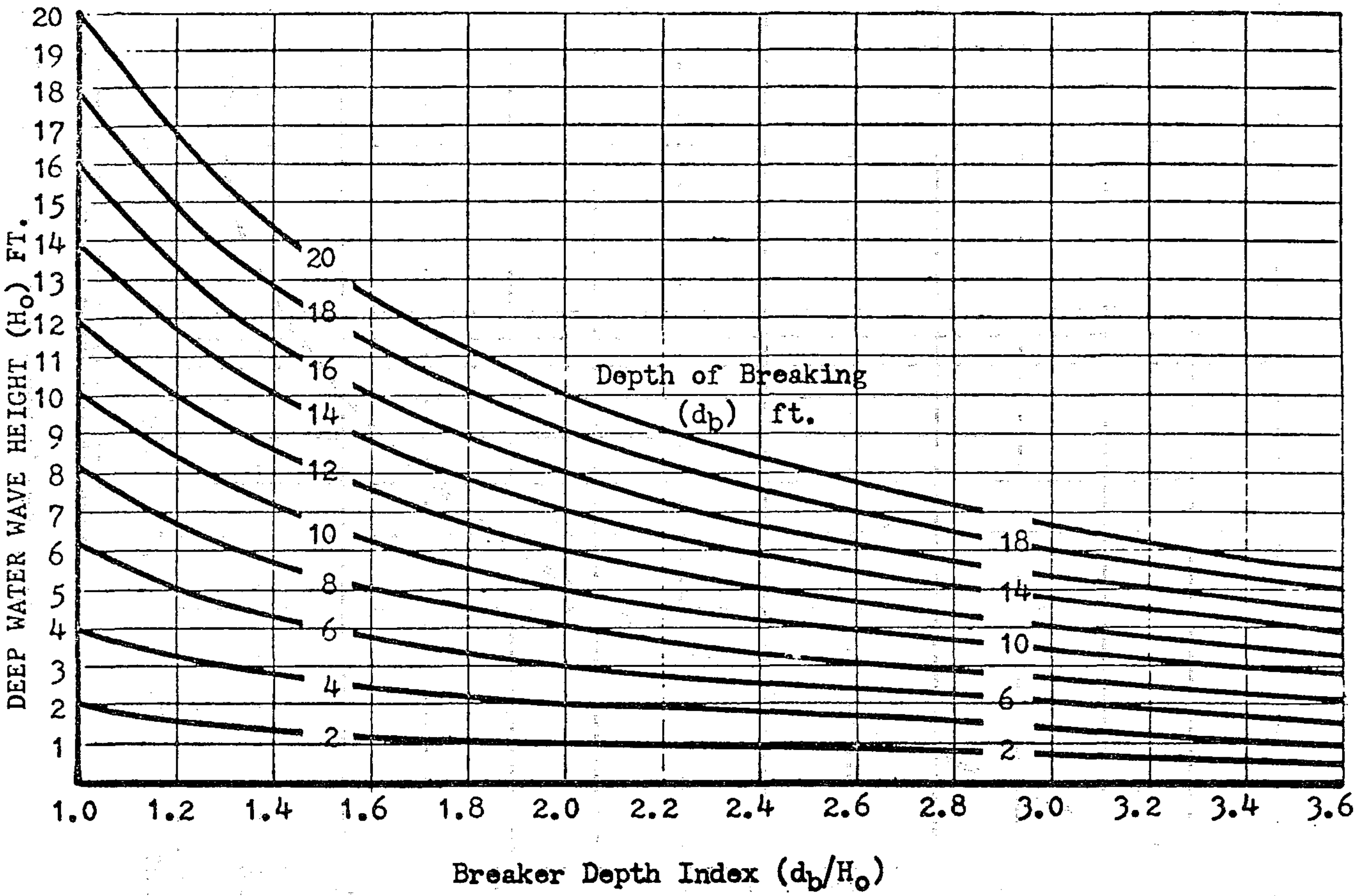
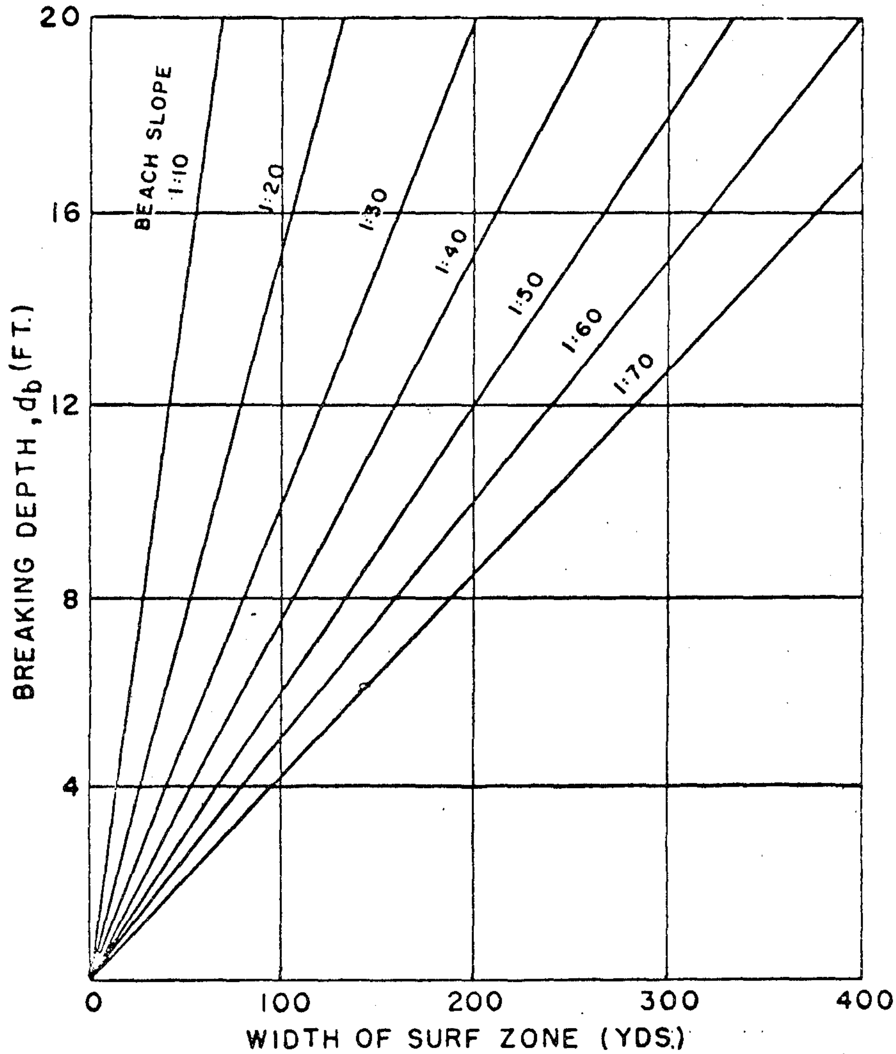



FIGURE 15

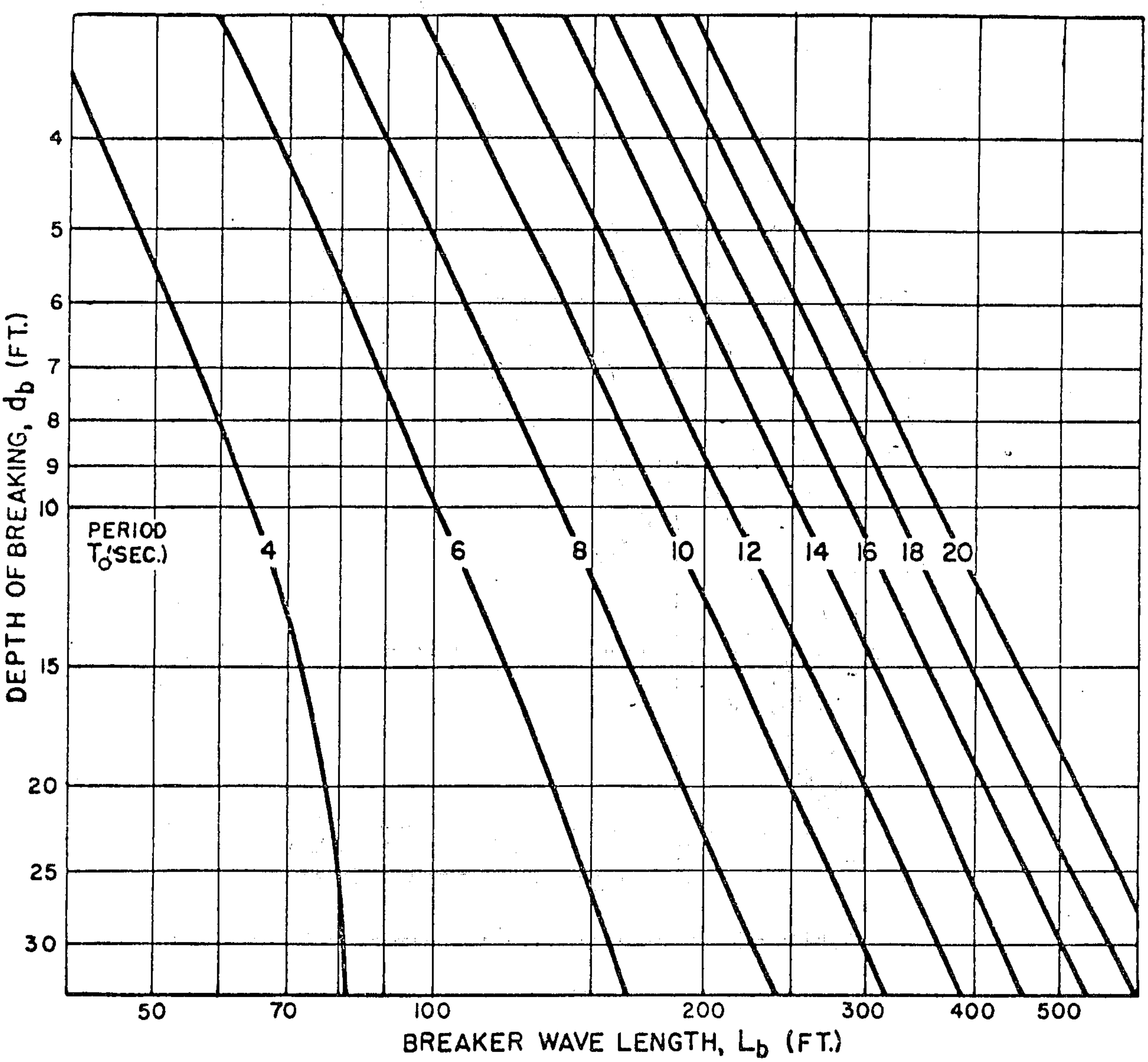
WIDTH OF SURF ZONE AS A FUCTION OF BREAKING DEPTH ($d_b$) AND BEACH SLOPE




**GRAPH FOR DETERMINING THE WIDTH OF THE SURF ZONE**

FIGURE 16

BREAKER WAVE LENGTH AS A FUNCTION OF DEPTH OF BREAKING ($d_b$) AND DEEP WATER WAVE PERIOD ($T_o$ Sec)




**GRAPH FOR DETERMINING THE BREAKER WAVE LENGTH**

FIGURE 17

NUMBER OF LINES OF SURF

as a function of

WIDTH OF SURF ZONE AND BREAKER WAVE LENGTH

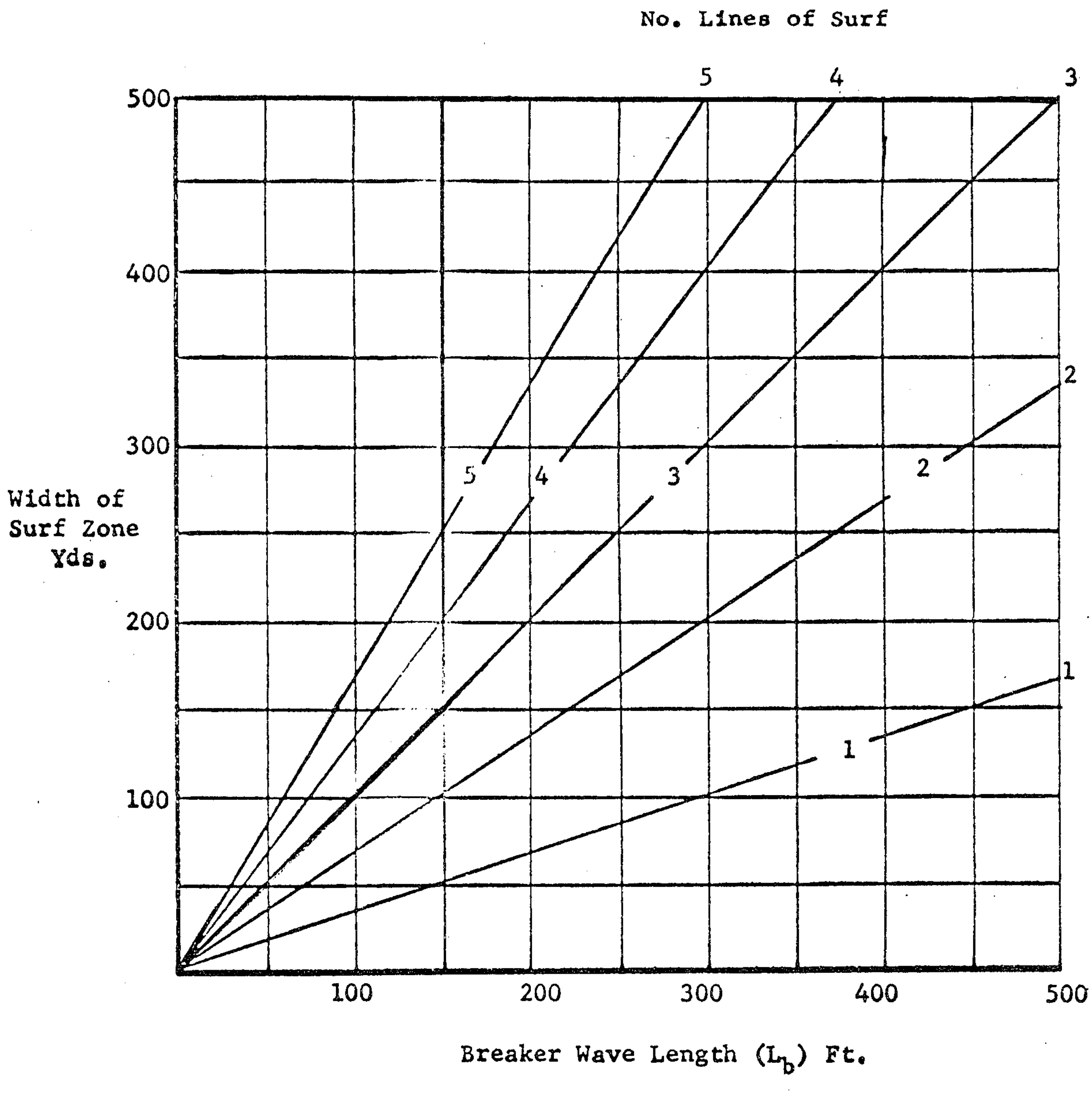



FIGURE 18

RATIO OF DEPTH OF BREAKING TO DEEP WATER WAVE LENGTH
AS A FUNCTION OF DEPTH OF BREAKING AND WAVE PERIOD

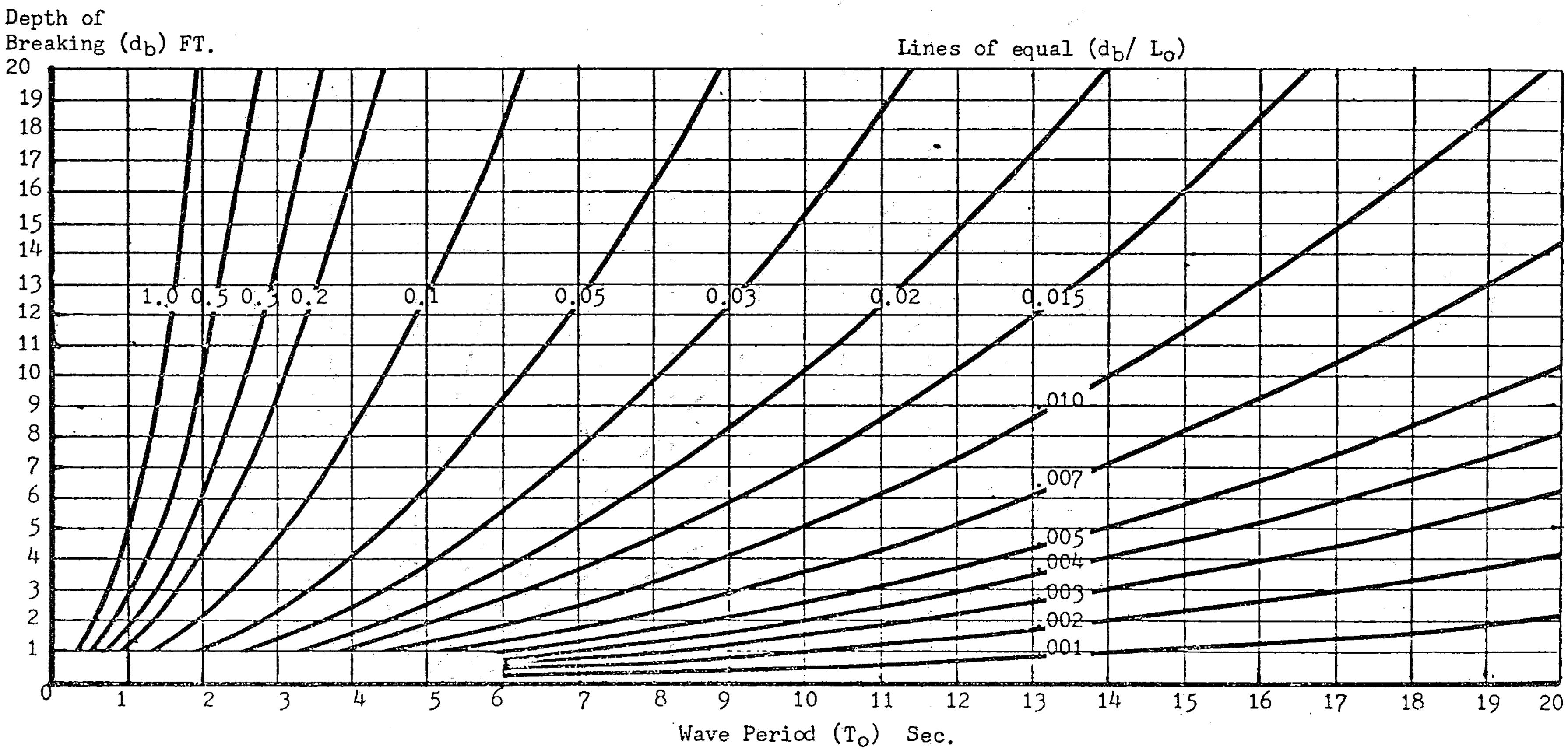
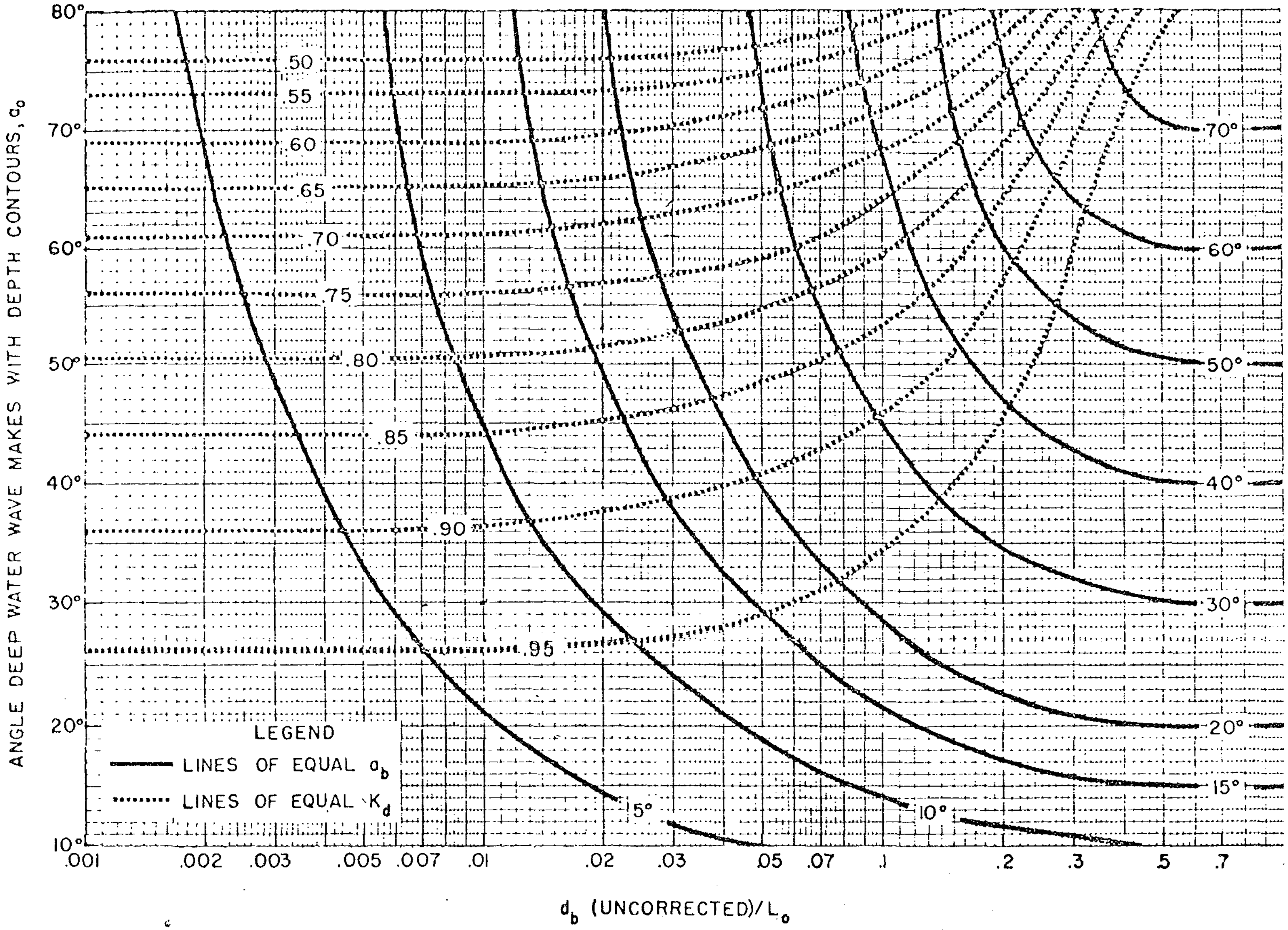



FIGURE 19




GRAPH FOR DETERMINING THE COEFFICIENT OF REFRACTION $K_d$ AND THE BREAKER ANGLE $a_b$

FIGURE 20

BREAKER HEIGHT ($H_b$) CORRECTED FOR REFRACTION AS A FUNCTION OF COEFFICIENT OF REFRACTION ($K_d$) AND UNCORRECTED BREAKER HEIGHT ($H_b$)

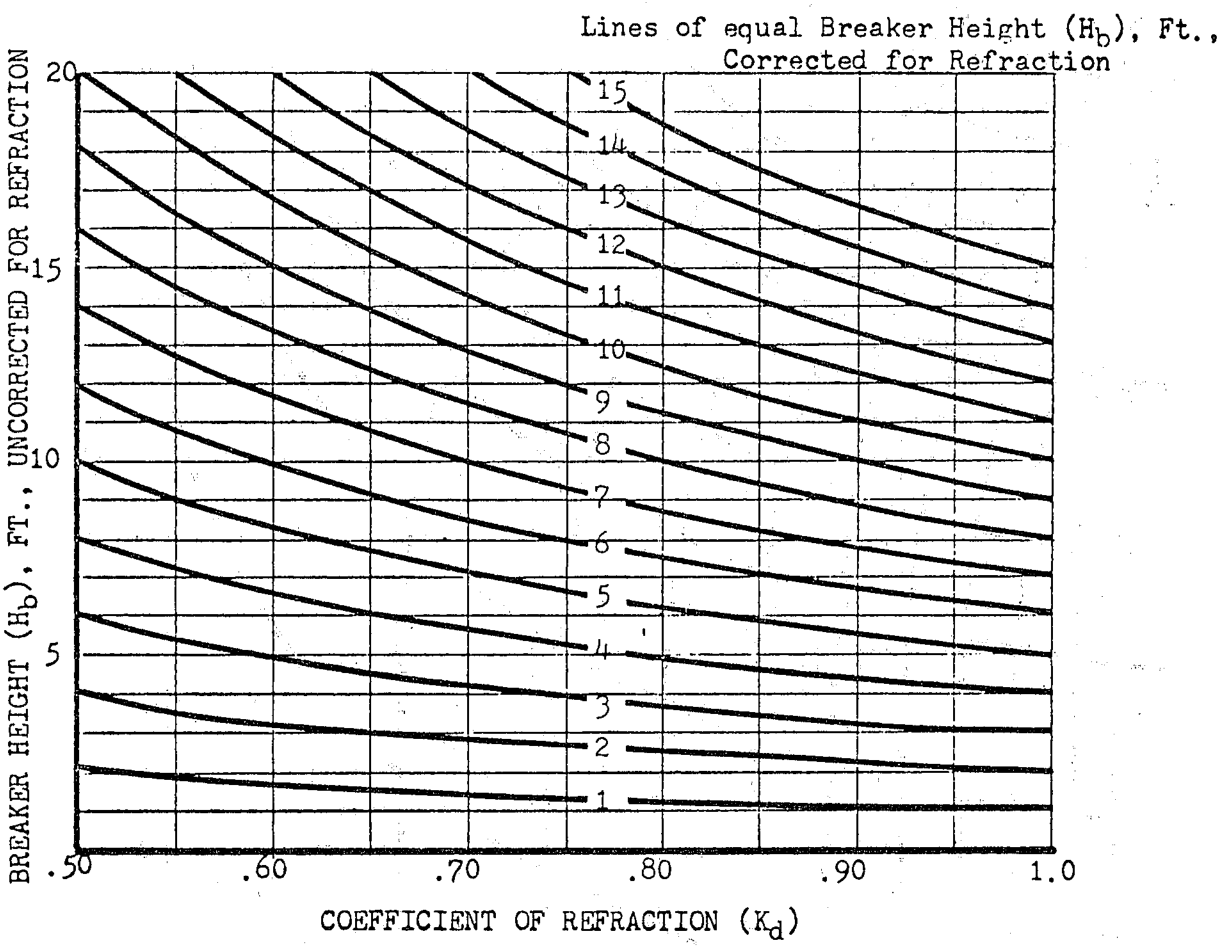
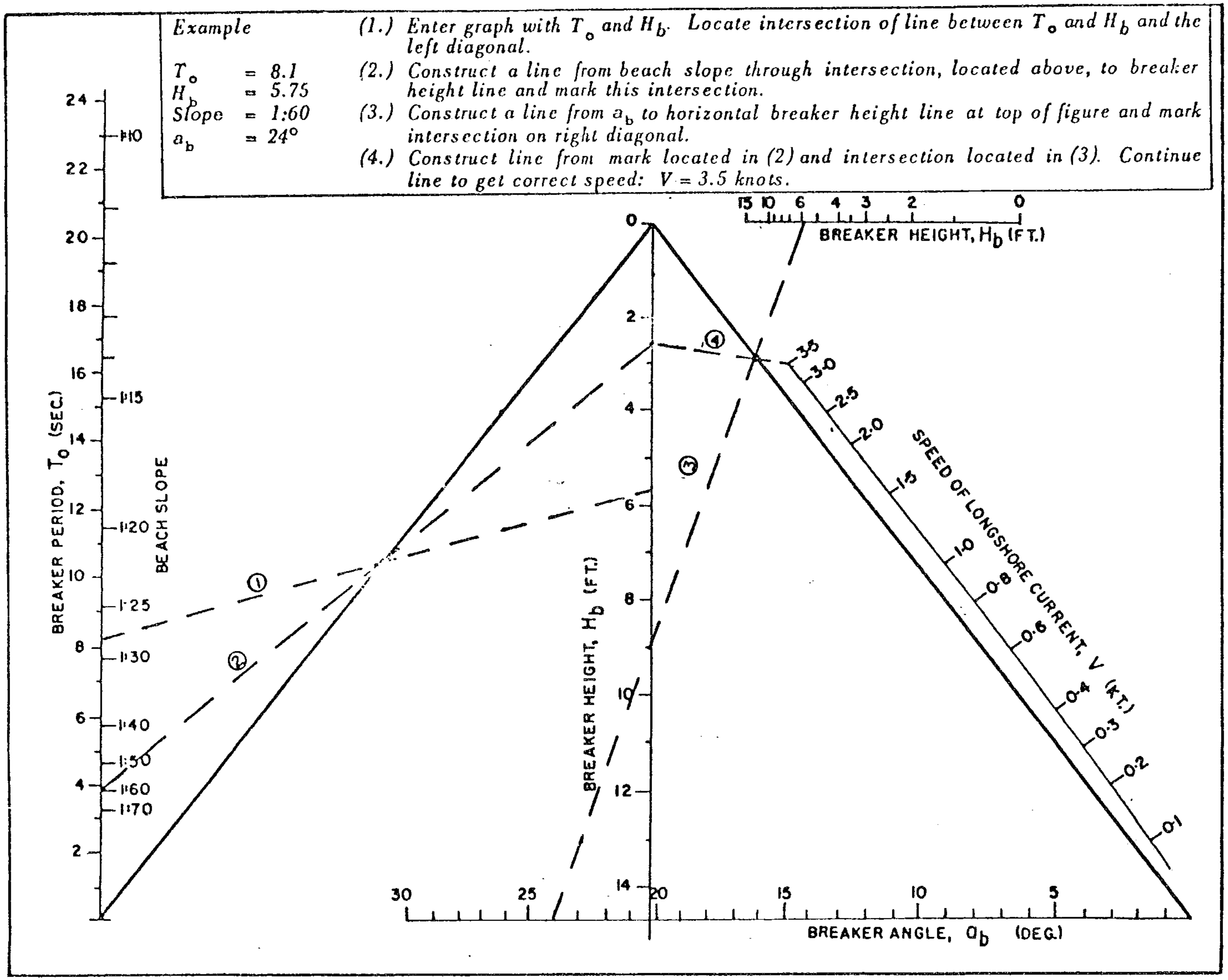



FIGURE 21




NOMOGRAM FOR DETERMINING THE SPEED OF THE LONGSHORE CURRENT

FIGURE 22

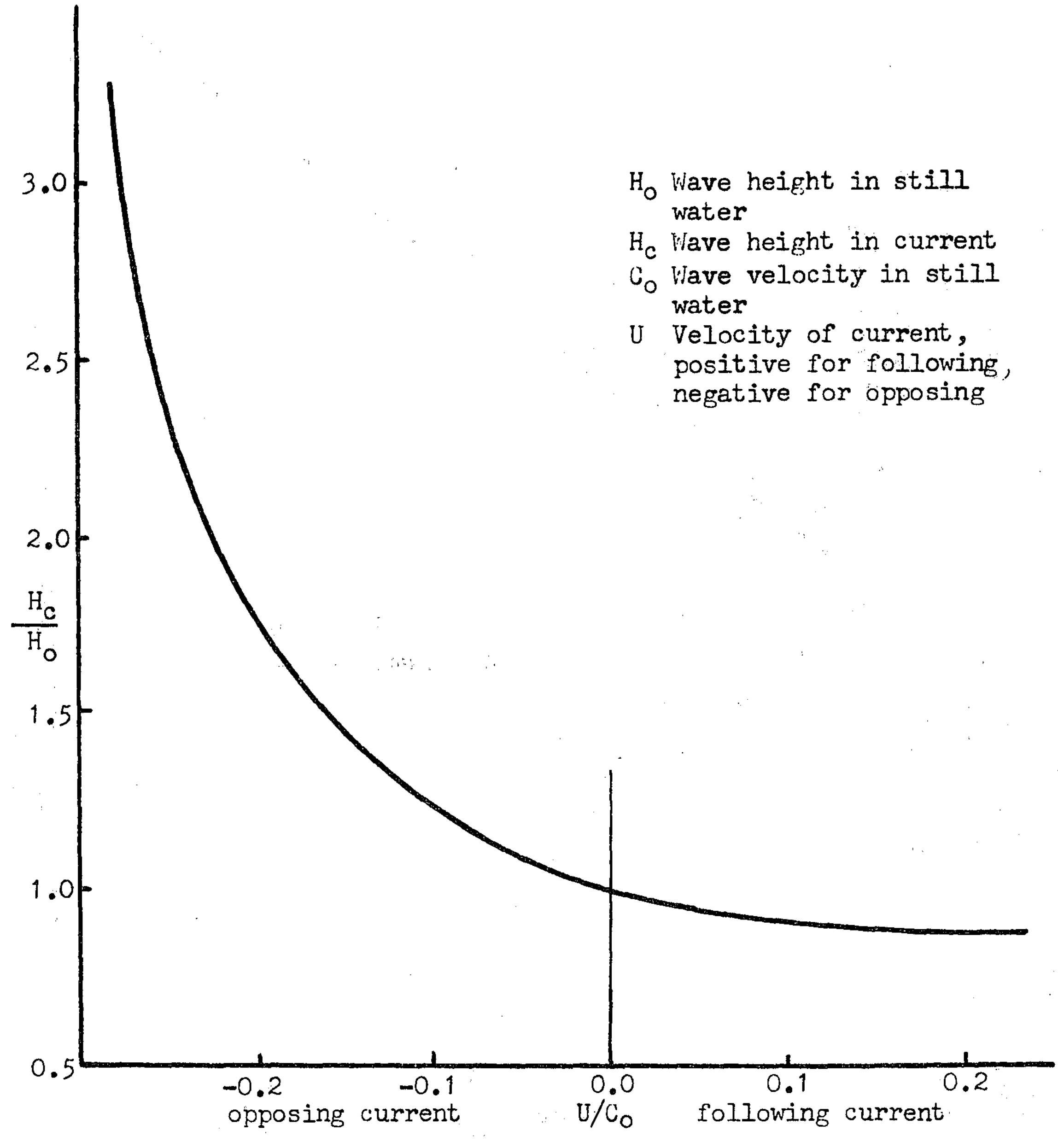



Figure 23. Change in wave height in an opposing or following current (from Scripps Institution of Oceanography, 1944)

# SEA STATE CHART

**WIND AND SEA SCALE FOR FULLY ARISEN SEA**

| SEA-GENERAL: Sea State[1] | SEA-GENERAL: Description[2] | WIND[3]: (Beaufort) Wind Force | WIND: Description | WIND: Range (Knots) | WIND: Wind Velocity (Knots) | SEA[3]: Wave Height Feet: Average | SEA: Wave Height Feet: Significant | SEA: Wave Height Feet: Average 1/10 Highest | SEA: Significant Range of Periods (Seconds) | SEA: $T_{max}$ (Period of Maximum Energy of Spectrum) | SEA: $\bar{T}$ (Average Period) | SEA: $\bar{L}$ (Average Wave Length) | SEA: Minimum Fetch (Nautical Miles) | SEA: Minimum Duration (Hours) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | Sea like a mirror. | 0 | Calm | Less than 1 | [a] 0 | 0 | 0 | – | – | – | – | – | – | – |
| | Ripples with the appearance of scales are formed, but without foam crests. | 1 | Light Airs | 1 - 3 | 2 | 0.05 | 0.08 | 0.10 | up to 1.2 sec | 0.7 | 0.5 | 10 in. | 5 | 18 min |
| 1 | Small wavelets, still short but more pronounced; crests have a glassy appearance, but do not break. | 2 | Light Breeze | 4 - 6 | 5 | 0.18 | 0.29 | 0.37 | 0.4-2.8 | 2.0 | 1.4 | 6.7 ft | 8 | 39 min |
| | Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses. | 3 | Gentle Breeze | 7 - 10 | 8.5 | 0.6 | 1.0 | 1.2 | 0.8-5.0 | 3.4 | 2.4 | 20 | 9.8 | 1.7 hrs |
| | | | | | 10 | 0.88 | 1.4 | 1.8 | 1.0-6.0 | 4 | 2.9 | 27 | 10 | 2.4 |
| 2 | Small waves, becoming larger; fairly frequent white horses. | 4 | Moderate Breeze | 11-16 | 12 | 1.4 | 2.2 | 2.8 | 1.0-7.0 | 4.8 | 3.4 | 40 | 18 | 3.8 |
| | | | | | 13.5 | 1.8 | 2.9 | 3.7 | 1.4-7.6 | 5.4 | 3.9 | 52 | 24 | 4.8 |
| | | | | | 14 | 2.0 | 3.3 | 4.2 | 1.5-7.8 | 5.6 | 4.0 | 59 | 28 | 5.2 |
| 3 | | | | | 16 | 2.9 | 4.6 | 5.8 | 2.0-8.8 | 6.5 | 4.6 | 71 | 40 | 6.6 |
| 4 | Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray). | 5 | Fresh Breeze | 17-21 | 18 | 3.8 | 6.1 | 7.8 | 2.5-10.0 | 7.2 | 5.1 | 90 | 55 | 8.3 |
| | | | | | 19 | 4.3 | 6.9 | 8.7 | 2.8-10.6 | 7.7 | 5.4 | 99 | 65 | 9.2 |
| | | | | | 20 | 5.0 | 8.0 | 10 | 3.0-11.1 | 8.1 | 5.7 | 111 | 75 | [illegible] |
| 5 | Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray). | 6 | Strong Breeze | 22-27 | 22 | 6.4 | 10 | 13 | 3.4-12.2 | 8.9 | 6.3 | 134 | 100 | 12 |
| | | | | | 24 | 7.9 | 12 | 16 | 3.7-13.5 | 9.7 | 6.8 | 160 | 130 | 14 |
| | | | | | 24.5 | 8.2 | 13 | 17 | 3.8-13.6 | 9.9 | 7.0 | 164 | 140 | 15 |
| 6 | | | | | 26 | 9.6 | 15 | 20 | 4.0-14.5 | 10.5 | 74 | 188 | 180 | 17 |
| | Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. (Spindrift begins to be seen). | 7 | Moderate Gale | 28-33 | 28 | 11 | 18 | 23 | 4.5-15.5 | 11.3 | 7.9 | 212 | 230 | 20 |
| | | | | | 30 | 14 | 22 | 28 | 4.7-16.7 | 12.1 | 8.6 | 250 | 280 | 23 |
| | | | | | 30.5 | 14 | 23 | 29 | 4.8-17.0 | 12.4 | 8.7 | 258 | 290 | 24 |
| | | | | | 32 | 16 | 26 | 33 | 5.0-17.5 | 12.9 | 9.1 | 285 | 340 | 27 |
| 7 | Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well marked streaks along the direction of the wind. Spray affects visibility. | 8 | Fresh Gale | 34-40 | 34 | 19 | 30 | 38 | 5.5-18.5 | 13.6 | 9.7 | 322 | 420 | 30 |
| | | | | | 36 | 21 | 35 | 44 | 5.8-19.7 | 14.5 | 10.3 | 363 | 500 | 34 |
| | | | | | 37 | 23 | 37 | 46 7 | 6-20.5 | 14.9 | 10.5 | 376 | 530 | 37 |
| | | | | | 38 | 25 | 40 | 50 | 6.2-20.8 | 15.4 | 10.7 | 392 | 600 | 38 |
| | | | | | 40 | 28 | 45 | 58 | 6.5-21.7 | 16.1 | 11.4 | 444 | 710 | 42 |
| 8 | High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected. | 9 | Strong Gale | 41-47 | 42 | 31 | 50 | 64 | 7-23 | 17.0 | 12.0 | 492 | 830 | 47 |
| | | | | | 44 | 36 | 58 | 73 | 7-24.2 | 17.7 | 12.5 | 534 | 960 | 52 |
| | | | | | 46 | 40 | 64 | 81 | 7-25 | 18.6 | 13.1 | 590 | 1110 | 57 |
| | Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shocklike. Visibility is affected. | 10 | Whole Gale* | 48-55 | 48 | 44 | 71 | 90 | 7.5-26 | 19.4 | 13.6 | 550 | 1250 | 63 |
| | | | | | 50 | 49 | 78 | 99 | 7.5-27 | 20.2 | 14.3 | 700 | 1420 | 69 |
| | | | | | 51.5 | 52 | 83 | 106 | 8-28.2 | 20.8 | 14.7 | 736 | 1560 | 73 |
| 9 | | | | | 52 | 54 | 87 | 110 | 8-28.5 | 21.0 | 14.8 | 750 | 1610 | 75 |
| | | | | | 54 | 59 | 95 | 121 | 8-29.5 | 21.8 | 15.4 | 810 | 1800 | 81 |
| | Exceptionally high waves (Small and medium-sized ships might for a long time be lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected. | 11 | Storm* | 56-63 | 56 | 64 | 103 | 130 | 8.5-31 | 22.6 | 16.3 | 910 | 2100 | 88 |
| | | | | | 59.5 | 73 | 116 | 148 | 10-32 | 24 | 17.0 | 985 | 2500 | 101 |
| | Air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected. | 12 | Hurricane* | 64-71 | > 64 | > 80[b] | > 128[b] | > 164[b] | 10-(35) | (26) | (18) | ~ | ~ | ~ |

*For hurricane winds (and often whole gale and storm winds) required durations and fetches are rarely attained. Seas are therefore not fully arisen.

a) A heavy box around this value means that the values tabulated are at the center of the Beaufort range.

b) For such high winds, the seas are confused. The wave crests blow off, and the water and the air mix.

1) Encyclopedia of Nautical Knowledge, W.A. McEwen and A.H. Lewis, Cornell Maritime Press, Cambridge, Maryland, 1953, p. 483

2) Manual of Seamanship, Volume II, Admiralty, London, H.M. Stationery Office, 1952, pg 717-718

3) Practical Methods for observing and forecasting Ocean Waves, Pierson, Neumann, James, N.Y. Univ. College of Engin. 1953.

FIGURE 24

This table compiled by Wilbur Marks, David Taylor Model Basin

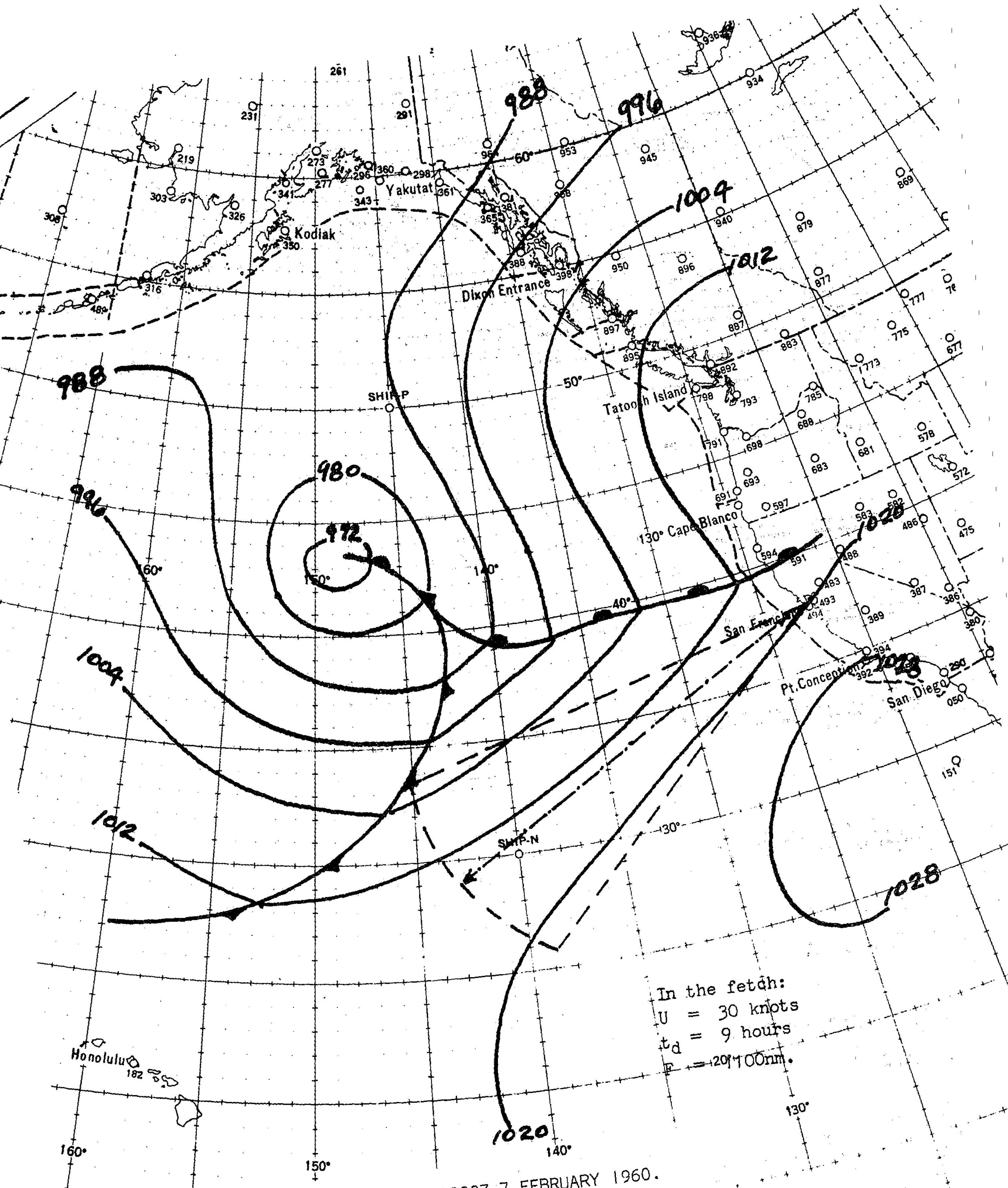



FIGURE 25. SURFACE CHART 1800Z 7 FEBRUARY 1960.

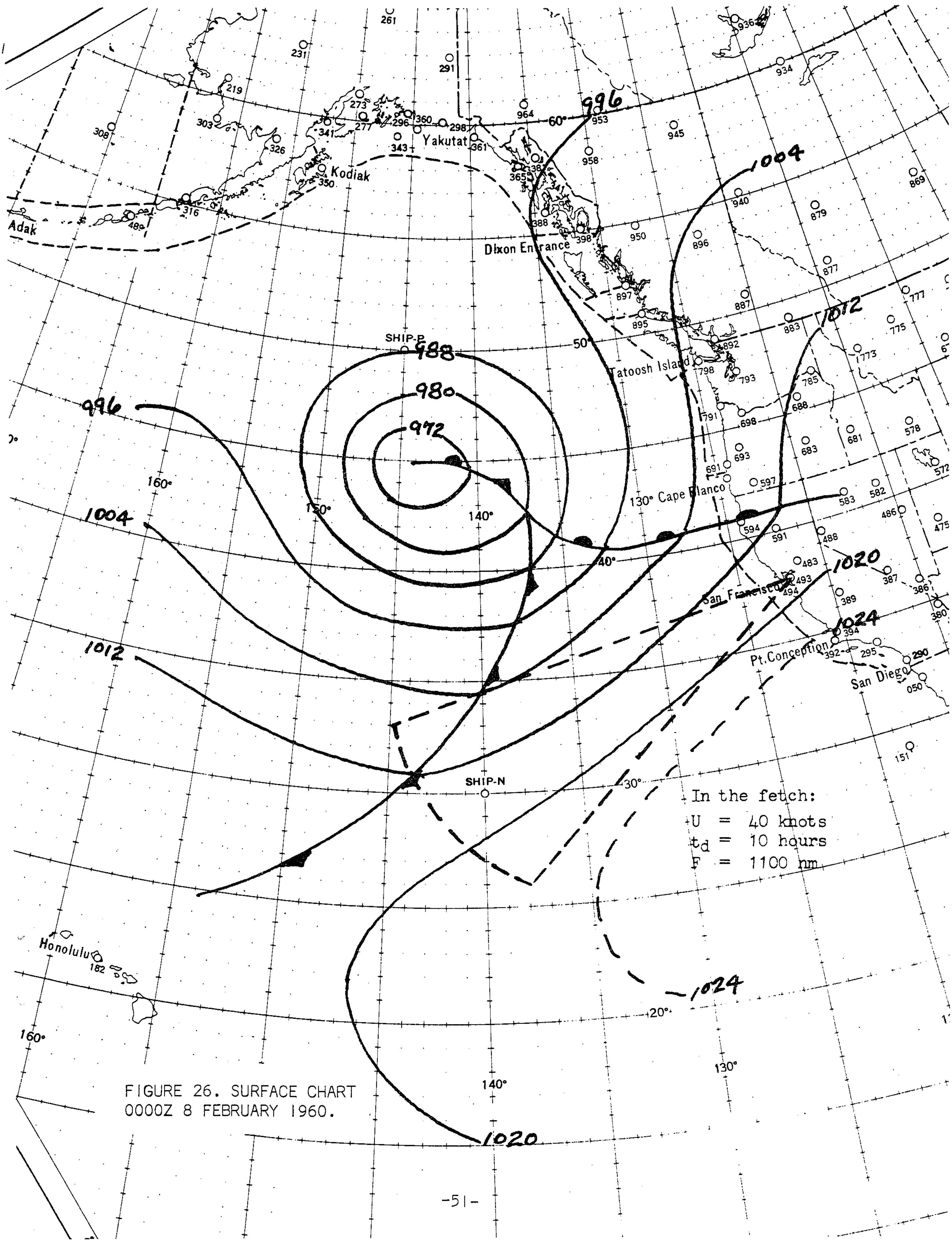



FIGURE 26. SURFACE CHART
0000Z 8 FEBRUARY 1960.

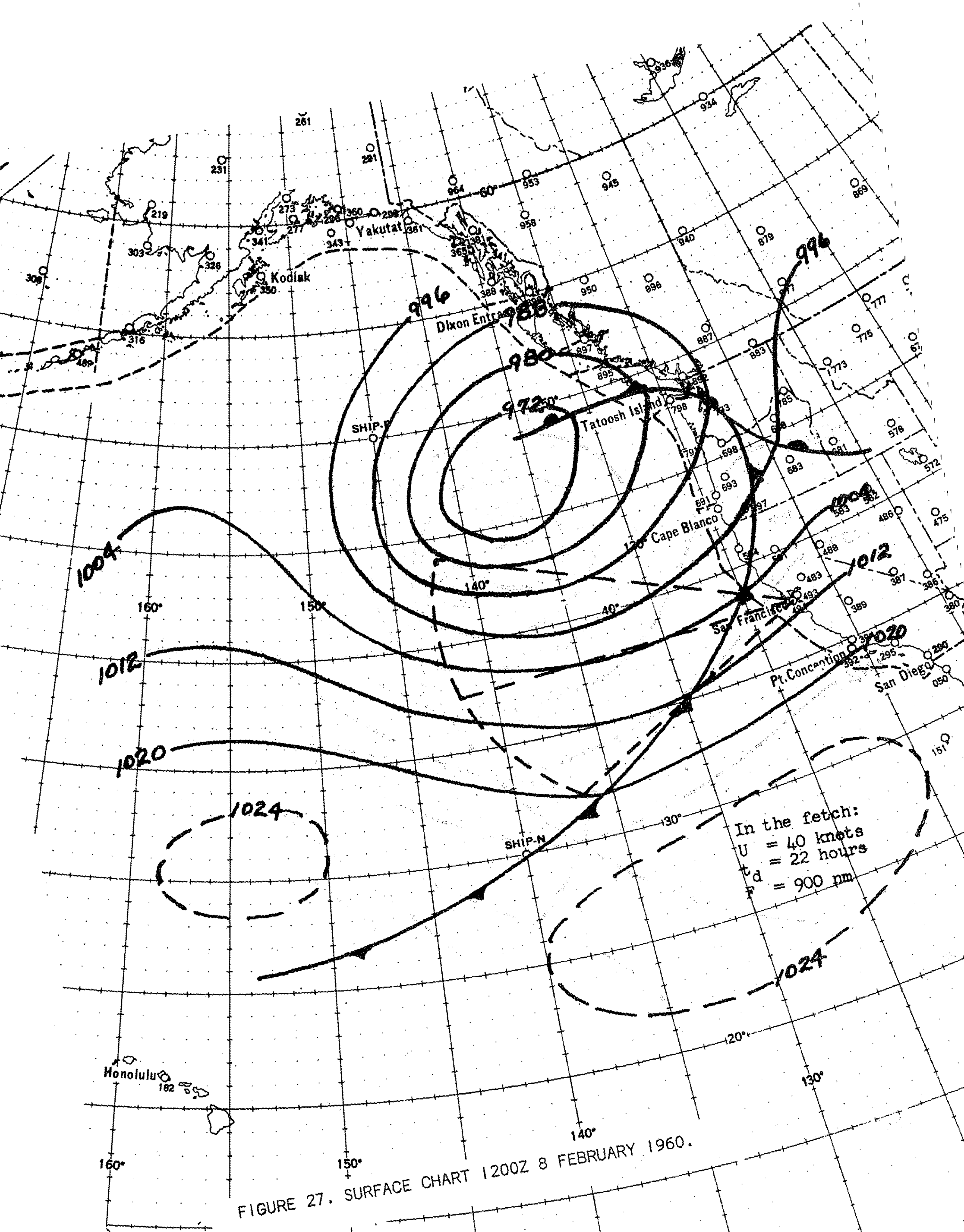



FIGURE 27. SURFACE CHART 1200Z 8 FEBRUARY 1960.

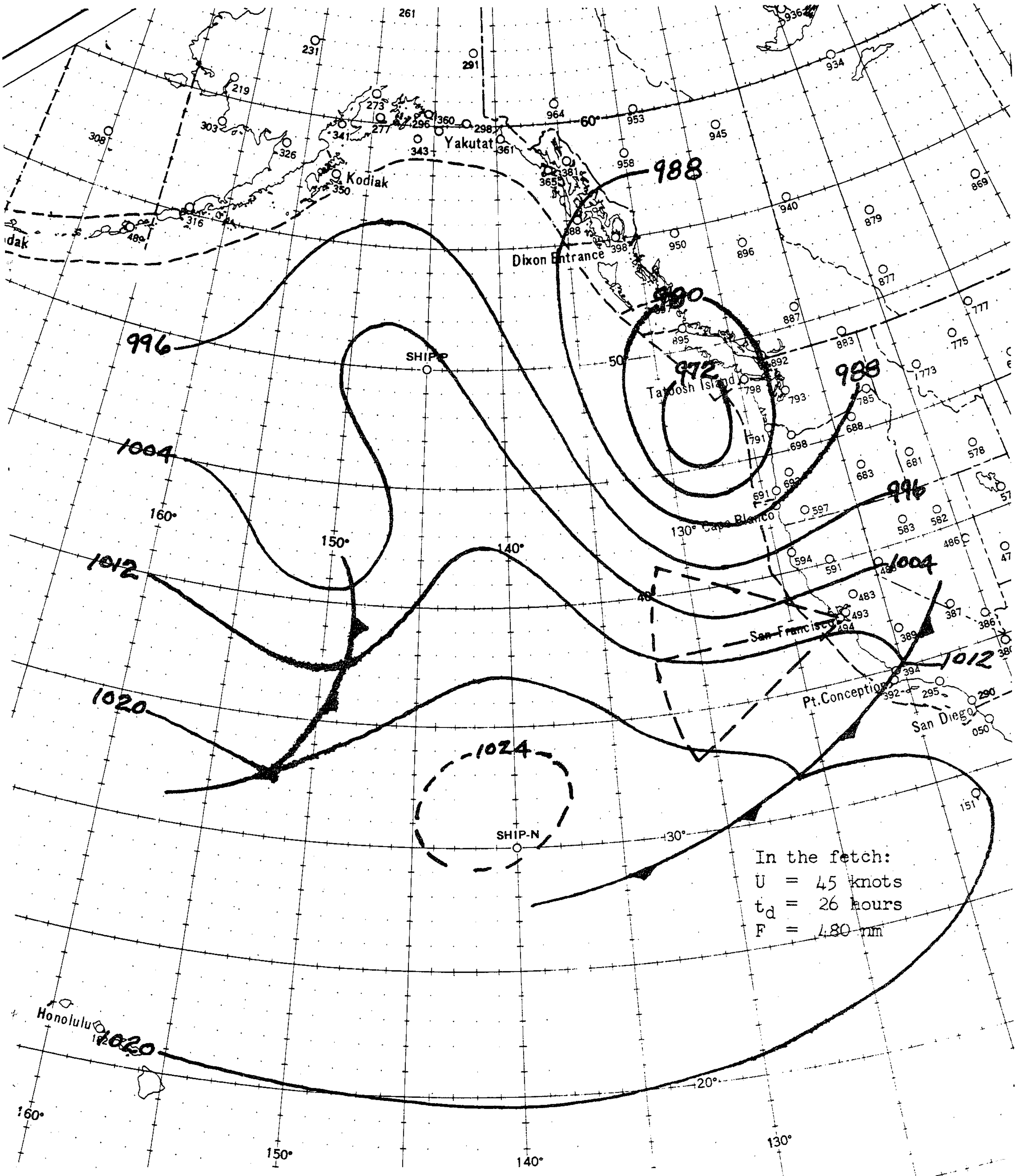



FIGURE 28. SURFACE CHART 0000Z 9 FEBRUARY 1960.

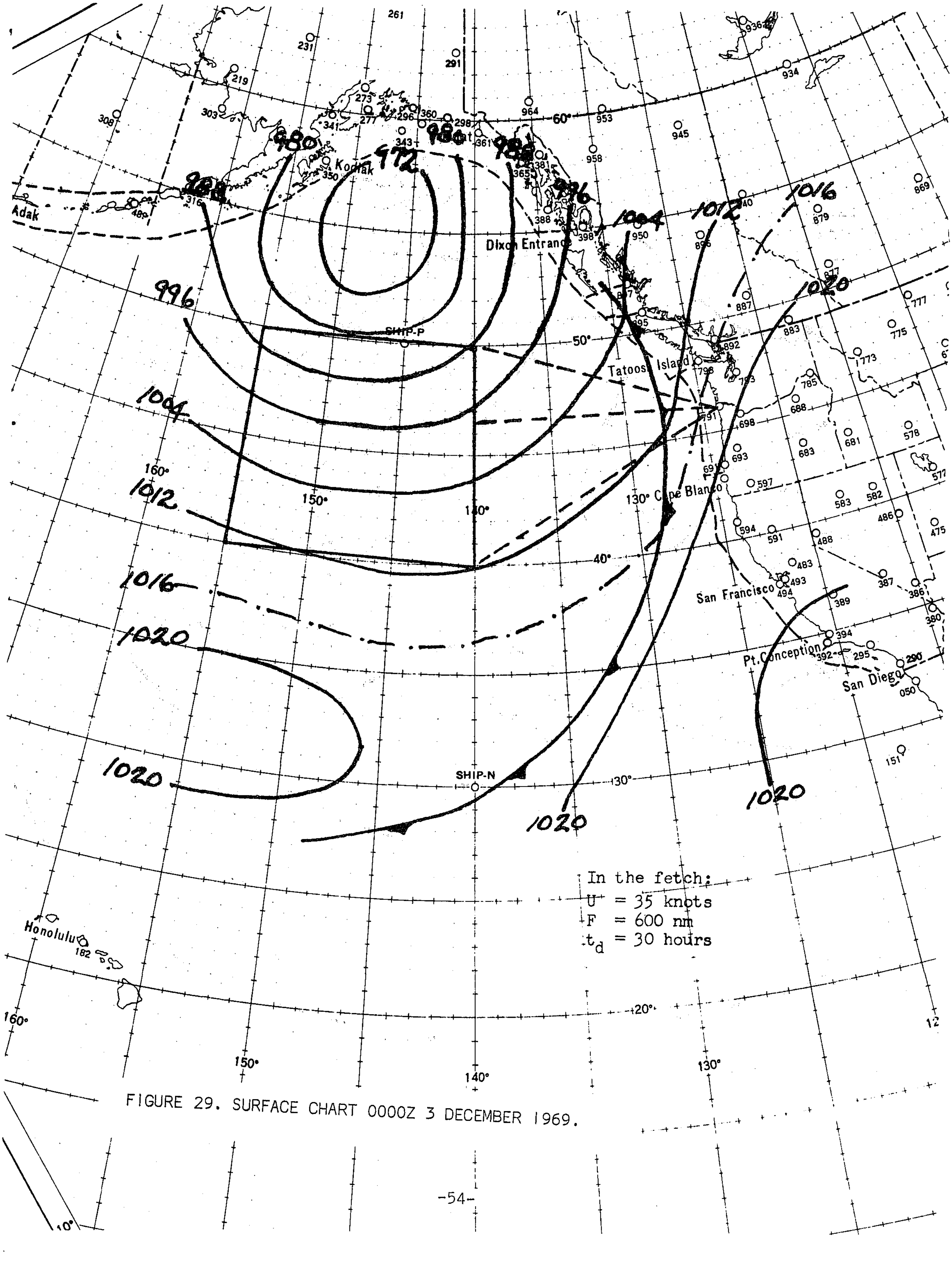



FIGURE 29. SURFACE CHART 0000Z 3 DECEMBER 1969.

SEA AND SWELL WORKSHEET

FETCH # ________ CHART DATE 03/0000Z MONTH December 1969

****************************************************************************

FETCH

1. Wind speed over fetch: $U$ = 35 KTS.
2. Length of fetch: $F$ = 600 N.M.
3. Duration of Winds: $t_d$ = 30 HRS.

****************************************************************************

SEA IN FETCH

4. Enter Figure 5 with U (step 1) and F or $t_d$ (step 2 or 3) whichever comes first while going across graph from left to right and record: $H_F$ = 23 ft. $T_F$ = 13.3 secs. $F_{min}$ = 460 N.M.

****************************************************************************

SWELL AFTER DECAY

5. Measure decay distance D: D = 680 N.M.

6. Enter upper portion Figure 7 with $T_F$ (step 4) and D (step 5) - movie horizontally across to $F_{min}$ (step 4) then vertically to $T_D/T_F$ — $T_D/T_F$ = 1.23

7. $T_D/T_F$ from step 6 and $T_F$ (step 4) compute $T_D = T_F \times$ 1.23: T = 16 secs.

8. Enter lower portion of Figure 7 with $H_F$ (step 4) to D (step 5) - move horizontally across to $F_{min}$(step 5) then down to $H_D/H_F$: $H_D/H_F$ = 0.43

9. With $H_D/H_F$ (step 8) and H (step 4) compute $H_D = H_F \times$ 0.43: $H_D$ = 10 ft.

10. Enter Figure 8 with $T_D$ (step 7) and D (step 5) to find $t_D$ (travel time): $t_D$ = 28 hrs.

11. Add $t_D$ (step 10) to Date/Time of map for ETA of swell: ETA 04 / 0400 Z

FIGURE 30. Columbia River Stable Swell.

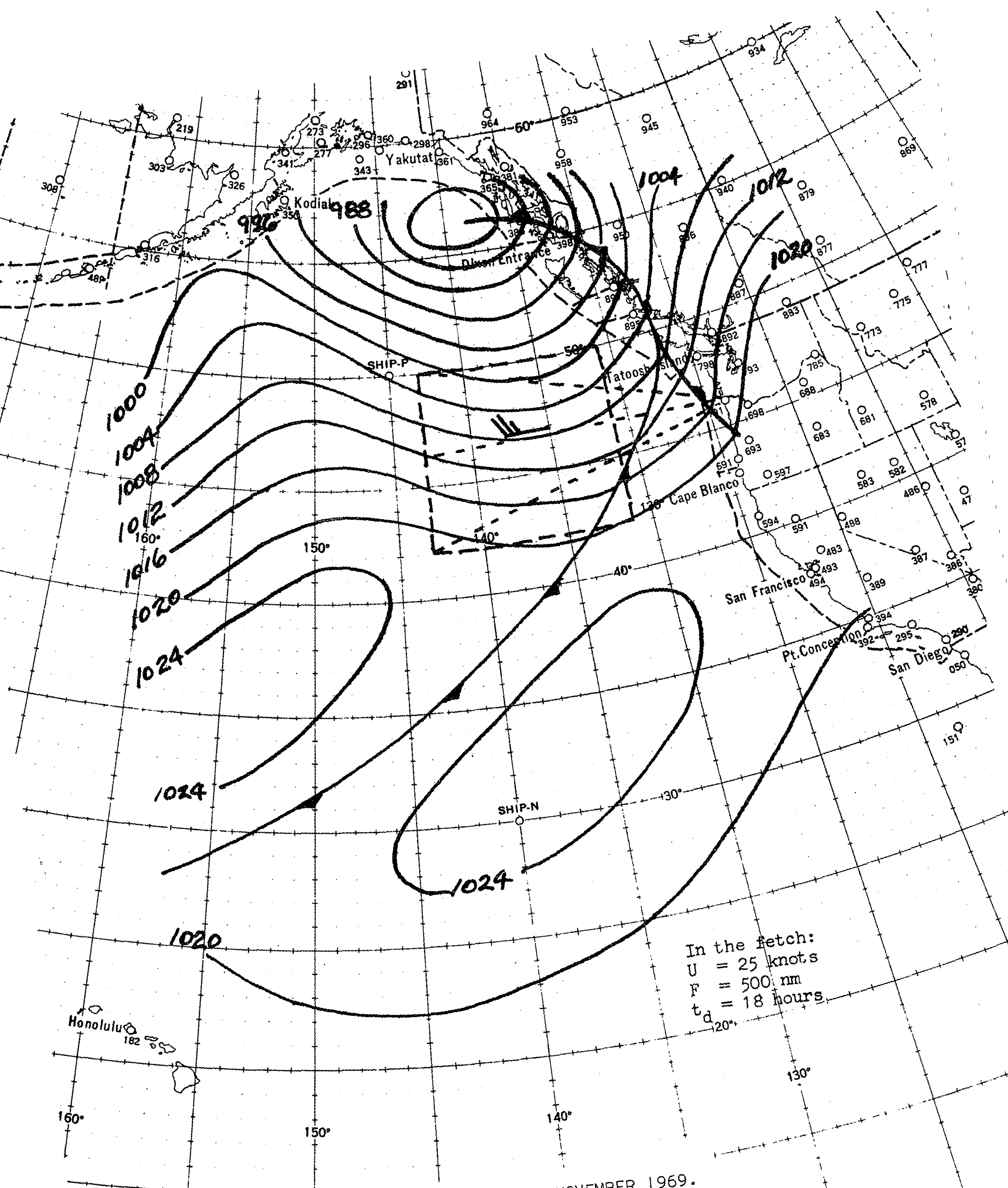



FIGURE 31. SURFACE CHART 0600Z 23 NOVEMBER 1969.

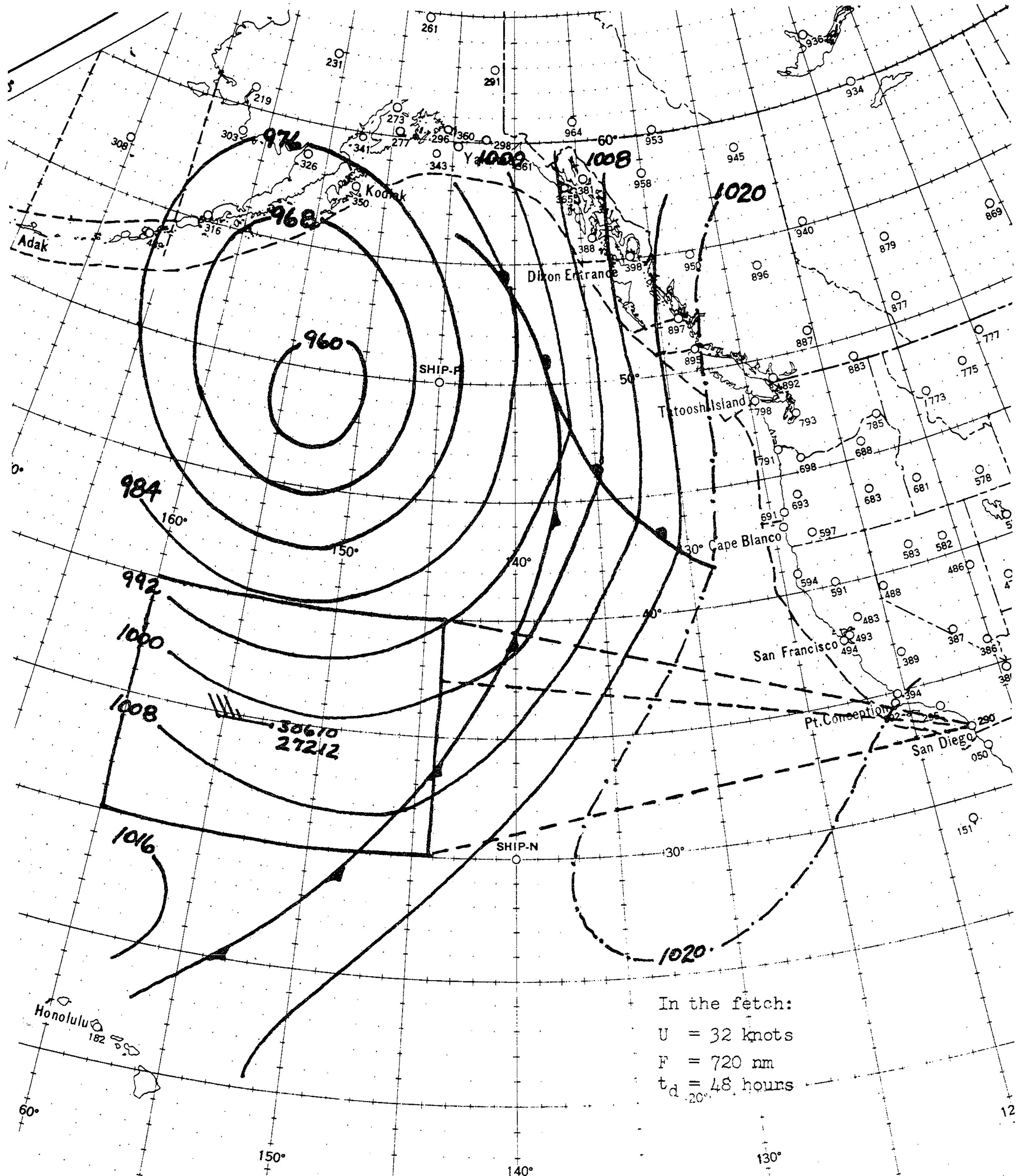



FIGURE 32. SURFACE CHART 0600Z 2 DECEMBER 1969.

## SEA AND SWELL WORKSHEET

FETCH # ____________ CHART DATE 02/0600Z MONTH December 1969

*****************************************************************************

### FETCH

1. Wind speed over fetch: $U$ = 32 KTS
2. Length of fetch: $F$ = 720 N.M.
3. Duration of winds: $t_d$ = 48 HRS.

*****************************************************************************

### SEA IN FETCH

4. Enter Figure 5 with U (step 1) and F or $t_d$ (step 2 or 3) whichever comes first while going across graph from left to right and record:

   $H_F$ = 21 FT
   $T_F$ = 13 SECS.
   $F_{min}$ = 600 N.M.

*****************************************************************************

### SWELL AFTER DECAY

5. Measure decay distance D: D = 1200 N.M.
6. Enter upper portion Figure 7 with $T_F$ (step 4) and D (step 5) - move horizontally across to $F_{min}$ (step 4) then vertically to $T_D/T_F$ — $T_D/T_F$ = 1.23
7. $T_D/T_F$ from step 6 and $T_F$ (step 4) compute $T_D = T_F \times$ 1.23 : — $T_D$ = 16 SECS.
8. Enter lower portion of Figure 7 with $H_F$ (step 4) to D (step 5) - move horizontally across to $F_{min}$(step 5) then down to $H_D/H_F$: — $H_D/H_F$ = 0.38
9. With $H_D/H_F$ (step 8) and $H_F$ (step 4) compute $H_D = H_F \times$ 0.38 : — $H_D$ = 8 FT.
10. Enter Figure 8 with $T_D$ (step 7) and D (step 5) to find $t_D$ (travel time): — $t_D$ = 50 HRS.
11. Add $t_D$ (step 10) to Date/Time of map for ETA of swell: — ETA 04 / 0800Z

FIGURE 33

SURF FORECAST WORKSHEET

BEACH NAME ________ BEACH SLOPE 1:30 ETA SURF 04/0800Z

**************************************************************************

FROM OBSERVED OR FORECAST SWELL

1. Deep water wave height: $H_o$ = 8 FT
2. Deep water wave period: $T_o$ = 16 SECS
3. Angle between deep water wave and depth contours: $a_o$ = 60 DEGS

**************************************************************************

SURF COMPUTATIONS

| Step | Enter Figure | With | And Read |
|---|---|---|---|
| 4 | 10 | $H_o$ from step 1 and $T_o$ from step 2 | $H_o/T_o^2$ .031 |
| 5 | 11 | $H_o/T_o^2$ from step 4 | $H_b/H_o$ 1.70 |
| 6 | 12 | $H_o$ from step 1 and $H_b/H_o$ from step 5 | $H_b$ 14 Ft. |
| 7 | 13 | $H_o/T_o^2$ from step 4 and Beach Slope from heading | Breaker type Plunging |
| 8 | 14 | $H_o/T_o^2$ from step 4. If $H_o/T_o^2$ <.01 go to next step | d /H 2.0 |
| 9 | 15 | $H_o$ from step 1 and $d_b/H_o$ from step 8 or use $d_b$= $1.3H_o$ if $H_o/T_o^2$ <.01 | $d_b$ 16 Ft. |
| 10 | 16 | $d_b$ from step 9 and Beach Slope from heading | Width of surf zone 160 Yds. |
| 11 | 17 | $d_b$ from step 9 and $T_o$ from step 2 | $L_b$ 360 Ft. |
| 12 | 18 | $L_b$ from step 11 and Width of Surf Zone from step 10 | No. Lines Surf 1 - 2 |
| 13 | 19 | $d_b$ from step 9 and $T_o$ from step 2 | $d_b/L_o$ .013 |
| 14 | 20 | $a_o$ from step 3 and $d_b/L_o$ from step 13 | $a_b$ 15 Degs.<br>$K_d$ 71 |
| 15 | 21 | $H_b$ from step 6 and $K_d$ from step 14 | $H_b$ corrected for refraction<br>cor $H_b$ 9.9 Ft.<br>Max $H_b$ 18.5 Ft. |
| 16 | 22 | $a_b$ from step 14 and Beach Slope from heading. $H_b$ from step 15 and $T_o$ from step 2 | Longshore current<br>Kts. |

FIGURE 34

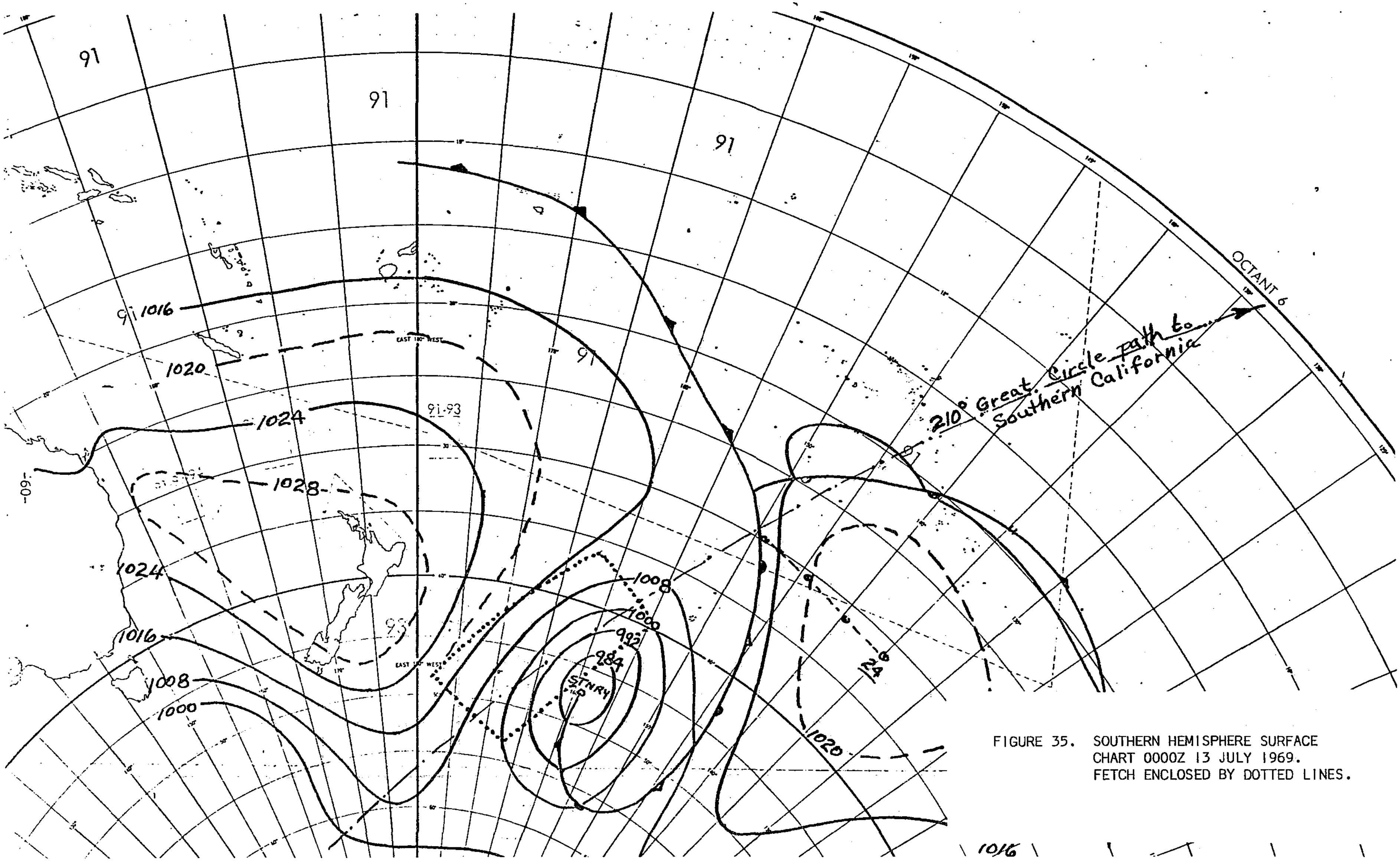



FIGURE 35. SOUTHERN HEMISPHERE SURFACE CHART 0000Z 13 JULY 1969. FETCH ENCLOSED BY DOTTED LINES.

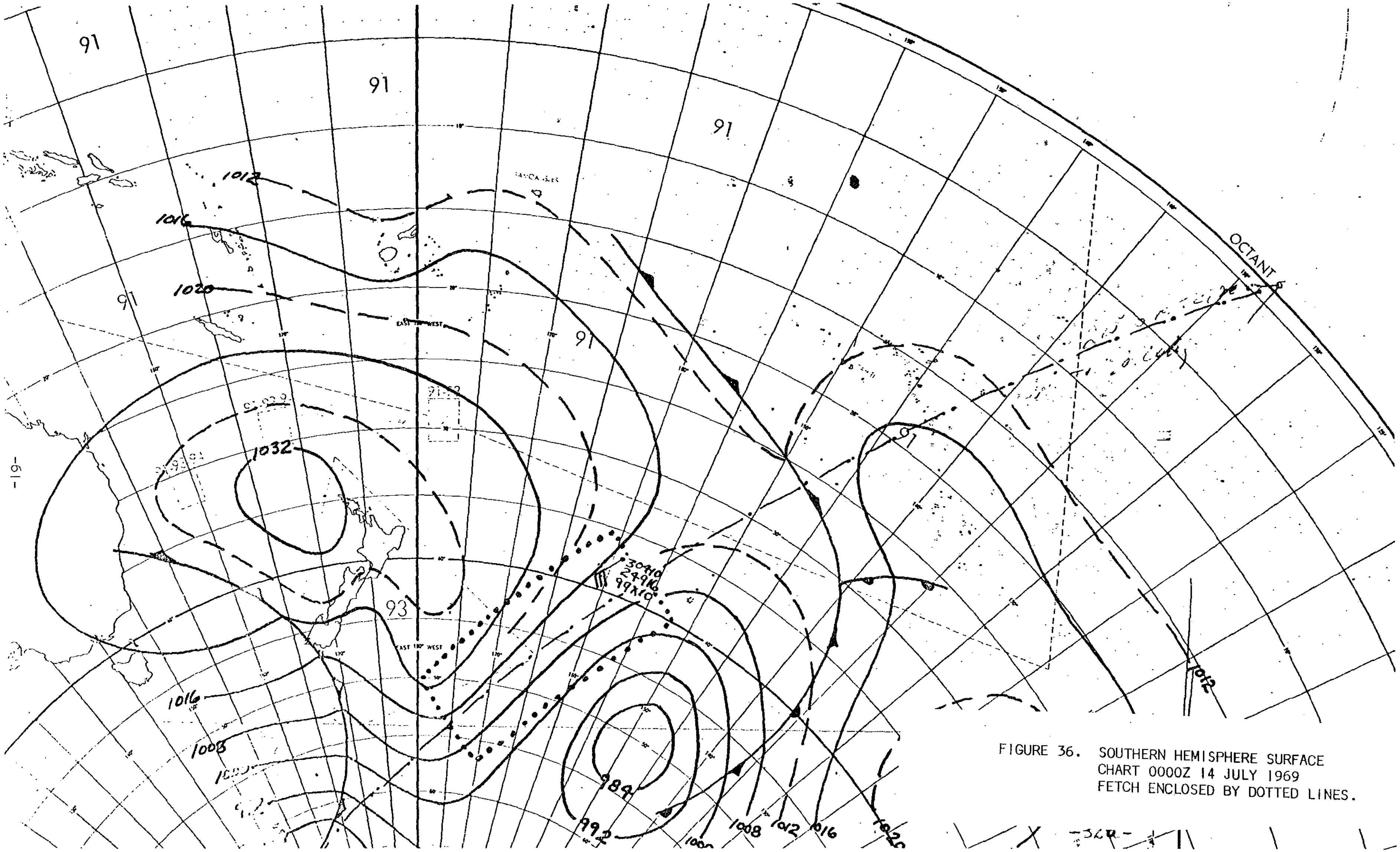



FIGURE 36. SOUTHERN HEMISPHERE SURFACE CHART 0000Z 14 JULY 1969 FETCH ENCLOSED BY DOTTED LINES.

SEA AND SWELL WORKSHEET

FETCH # S.H. CHART DATE 14/0000Z MONTH July 1969

*****************************************************************************

FETCH

1. Wind speed over fetch: $U$ = 36 KTS

2. Length of fetch: $F$ = 1000 N.M.

3. Duration of winds: $t_d$ = 36 HRS.

*****************************************************************************

SEA IN FETCH

4. Enter Figure 5 with U (step 1) and F or $t_d$ (step 2 or 3) whichever comes first while going across graph from left to right and record:

$H_F$ = 26 FT

$T_F$ = 14.3 SECS

$F_{min}$ = 600 N.M.

*****************************************************************************

SWELL AFTER DECAY

5. Measure decay distance D: $D$ = 4800 N.M.

6. Enter upper portion Figure 7 with $T_F$ (step 4) and D (step 5) - move horizontally across to $F_{min}$ (step 4) then vertically to $T_D/T_F$ — $T_D/T_F$ = 1.38

7. $T_D/T_F$ from step 6 and $T_F$ (step 4) compute $T_D = T_F \times$ 1.38 : — $T_D$ = 19.8 SECS

8. Enter lower portion of Figure 7 with $H_F$ (step 4) to D (step 5) - move horizontally across to $F_{min}$(step 5) then down to $H_D/H_F$: — $H_D/H_F$ = 0.22

9. With $H_D/H_F$ (step 8) and $H_F$ (step 4) compute $H_D = H_F \times$ 0.22: — $H_D$ = 5.7 FT

10. Enter Figure 8 with $T_D$ (step 7) and D (step 5) to find $t_D$ (travel time: — $t_D$ = 160 HRS

11. Add $t_D$ (step 10) to Date/Time of map for ETA of swell: — ETA = 20/1600Z

FIGURE 37

SURF FORECAST WORKSHEET

BEACH NAME Newport BEACH SLOPE 1:30 ETA SURF 20/1600Z

****************************************************************************

FROM OBSERVED OR FORECAST SWELL

1. Deep water wave height: $H_o$ = 5.7 Ft
2. Deep water wave period: $T_o$ = 19.8 Secs
3. Angle between deep water wave and depth contours: $a_o$ = 60 Degs

****************************************************************************

SURF COMPUTATIONS

| Step | Enter Figure | With | And Read |
|---|---|---|---|
| 4 | 10 | $H_o$ from step 1 and $T_o$ from step 2 | $H_o/T_o^2$ .016 |
| 5 | 11 | $H_o/T_o^2$ from step 4 | $H_o/H_o^2$ 2.0 |
| 6 | 12 | $H_o$ from step 1 and $H_b/H_o$ from step 5 | $H_b$ 11 Ft |
| 7 | 13 | $H_o/T_o^2$ from step 4 and Beach Slope from heading | Breaker type Plunging |
| 8 | 14 | $H_o/T_o^2$ from step 4. If $H_o/T_o^2$ .01 go to next step | $d_b/H_o$ 2.9 |
| 9 | 15 | $H_o$ from step 1 and $d_b/H_o$ from step 8 or use $d_b$ = 1.3$H_o$ if $H_o/T_o^2$ .01 | $d_b$ 16 Ft |
| 10 | 16 | $d_b$ from step 9 and Beach Slope from heading | Width of surf zone 160 Yds |
| 11 | 17 | $d_b$ from step 9 and $T_o$ from step 2 | $L_b$ 450 Ft |
| 12 | 18 | $L_b$ from step 11 and Width of Surf Zone from step 10 | No. Lines Surf 1 |
| 13 | 19 | $d_b$ from step 9 and $T_o$ from step 2 | $d_b/L_o$ .008 |
| 14 | 20 | $a_o$ from step 3 and $d_b/L_o$ from step 13 | $a_b$ 11 Degs<br>$K_d$ 71 |
| 15 | 21 | $H_b$ from step 6 and $K_d$ from step 14 | $H_b$ corrected for refraction<br>cor $H_b$ 7.8 Ft<br>Max $H_b$ 14 Ft |
| 16 | 22 | $a_b$ from step 14 and Beach Slope from heading. $H_b$ from step 15 and $T_o$ from step 2 | Longshore current 1.5 Kts |

FIGURE 38

TABLE I

SOUTHERN CALIFORNIA'S MAJOR BEACHES WITH BEACH ORIENTATION AND EXPOSURE WINDOWS

Rincon and Solimar
Orientation: 303° to 123°
(refraction around small points bring surf onto beaches from 180°)
Window: 276° to 255°

Point Hueneme
Orientation: 332° to 152°
Windows: 285° to 268°
224° to 199°
190° to 155°

Zuma Beach
Orientation: 320° to 240°
Windows: 285° to 274°
263° to 220°
212° to 170°

Malibu-Surfrider
Orientation: 270° to 90°
Windows: 252° to 225°
217° to 176°

Santa Monica Beach
Orientation: 312° to 132°
Windows: 264° to 230°
223° to 189°

Redondo Beach
Orientation:
North of King Harbor 337° to 157°
South of King Harbor 5° to 185°
Windows: 272° to 240°
234° to 206°

Huntington Beach
Orientation: 310° to 130°
Windows: 276° to 260°
200° to 155°

Seal Beach
Orientation: 320° to 120°
Windows: 245° to 238°
192° to 154°

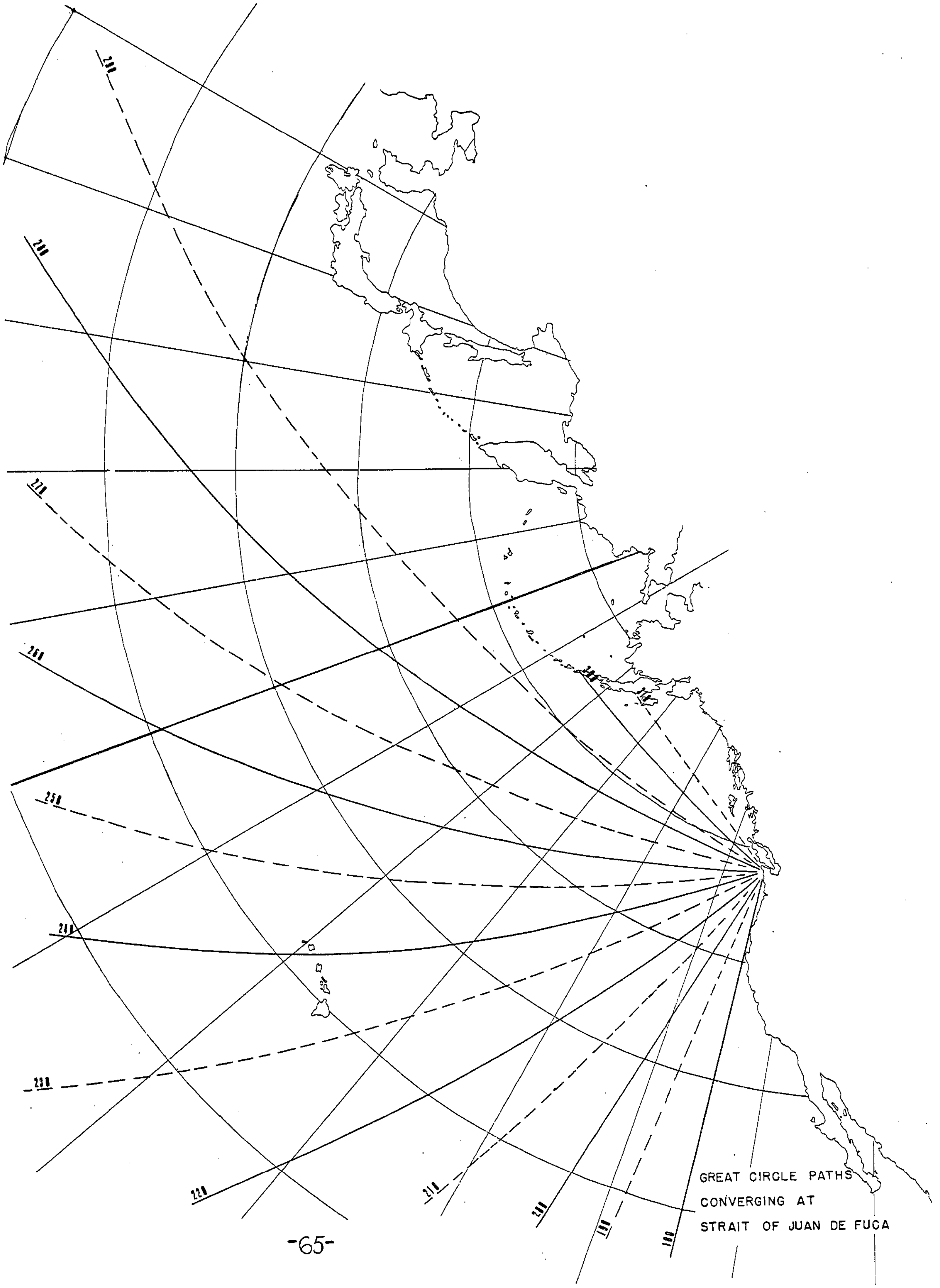
Newport Beach
Orientation:
North of pier 330° to 150°
South of pier 295° to 115°
Windows: 278° to 262°
204° to 156°

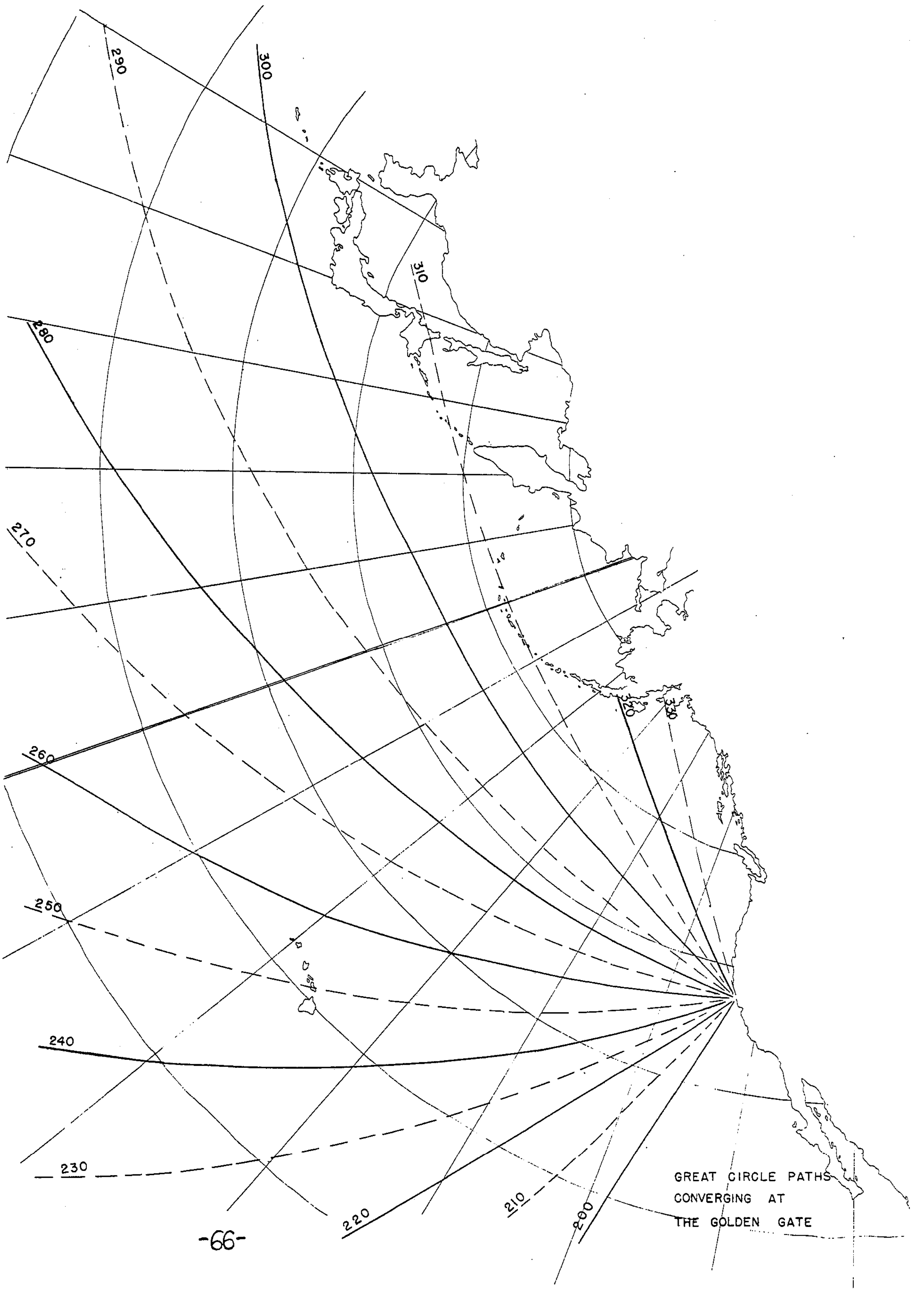
San Clemente Beach
Orientation: 321° to 141°
Windows: 283° to 276°
259° to 246°
225° to 165°

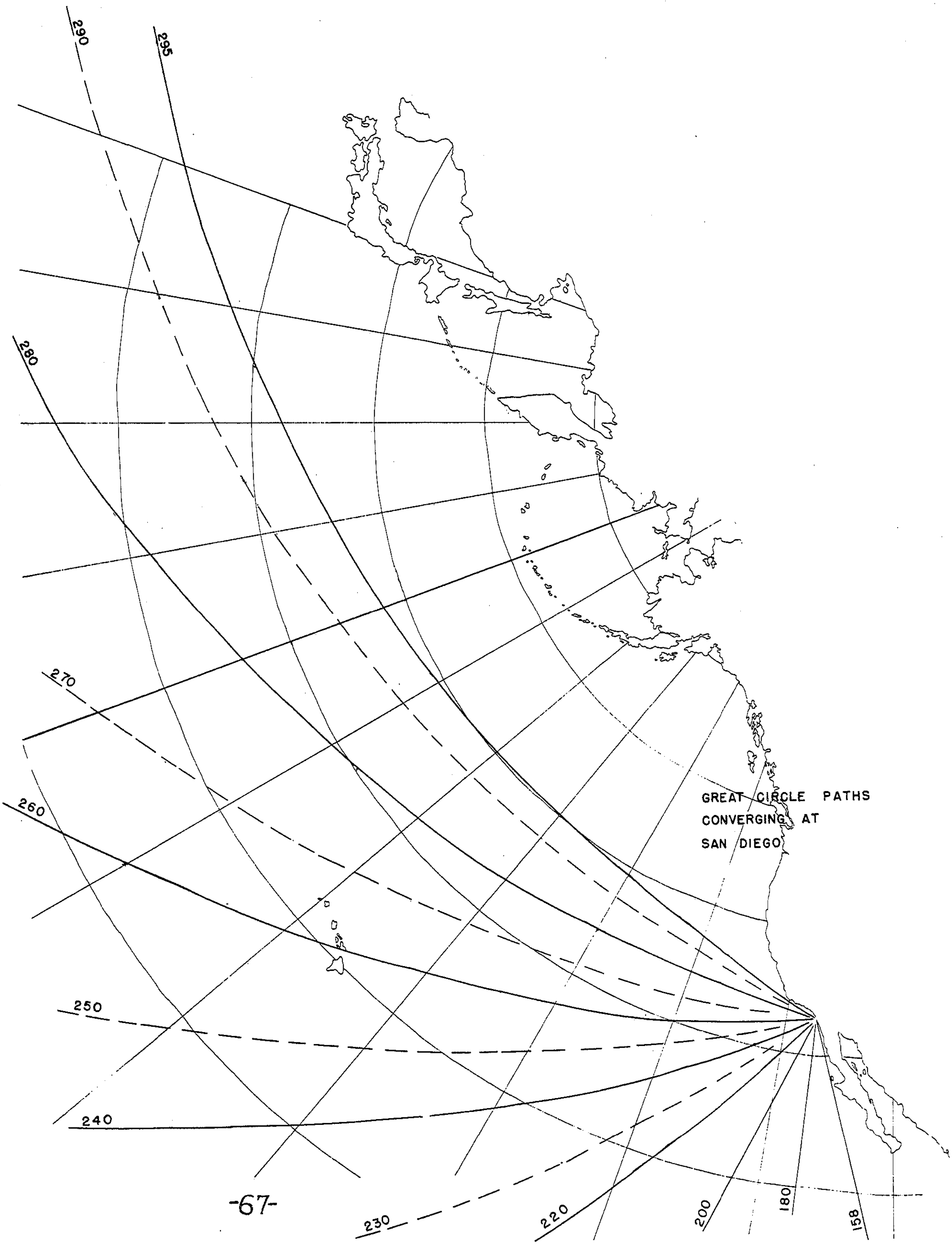
Oceanside Beach
Orientation: 334° to 144°
Windows: 276° to 262°
244° to 176°

Del Mar Beach
Orientation: 340° to 160°
Windows: 288° to 279°
278° to 274°
261° to 194°

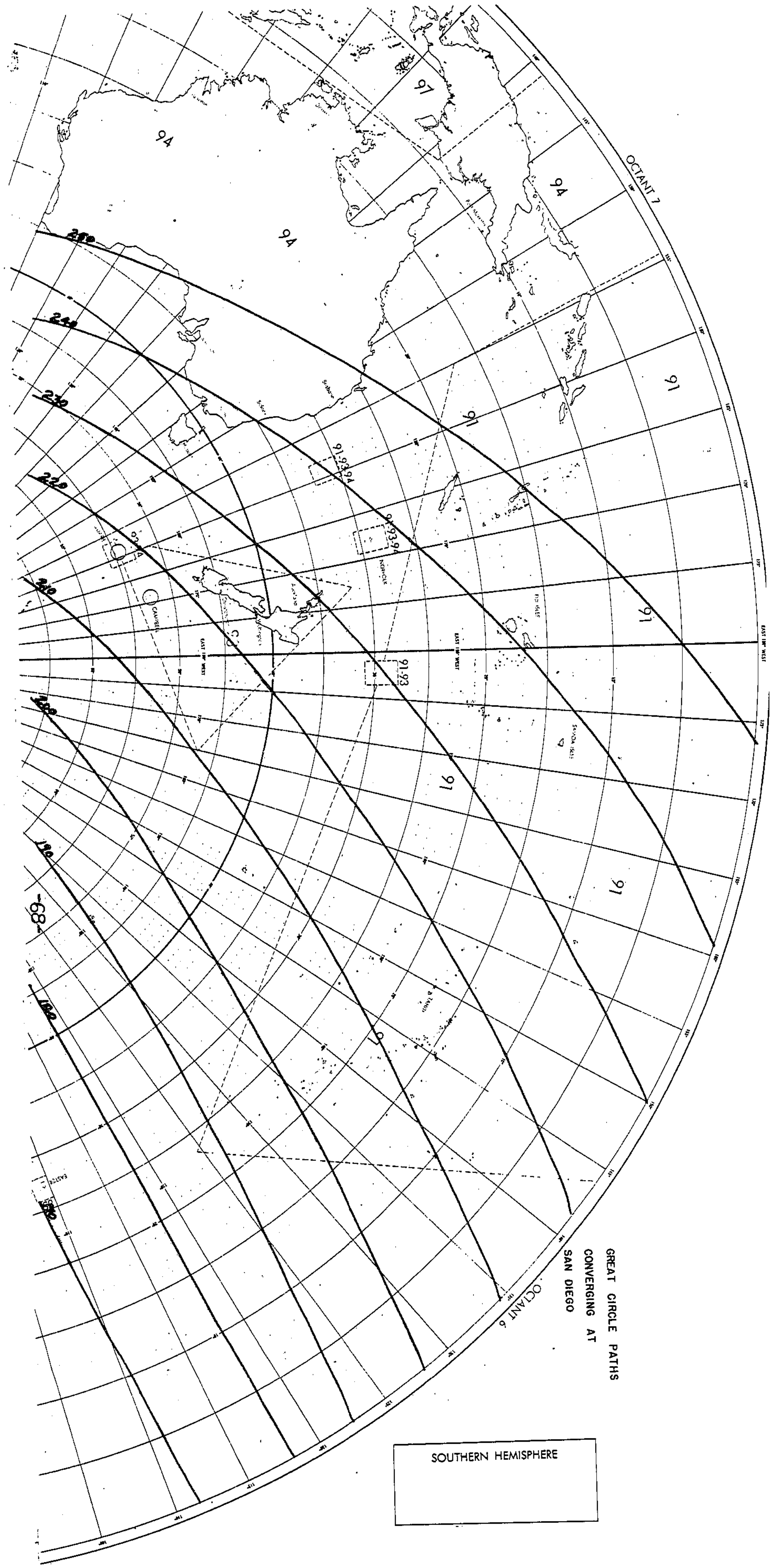
Mission Beach
Orientation: 340° to 160°
Windows: 295° to 285°
273° to 188°


GREAT CIRCLE PATHS
CONVERGING AT
STRAIT OF JUAN DE FUCA


290
300
310
280
270
260
250
240
230
220
210
200
320
330
GREAT CIRCLE PATHS
CONVERGING AT
THE GOLDEN GATE



290
295
280
270
260
250
240
230
220
200
180
158
GREAT CIRCLE PATHS
CONVERGING AT
SAN DIEGO




GREAT CIRCLE PATHS
CONVERGING AT
SAN DIEGO

SOUTHERN HEMISPHERE

Western Region Technical Memoranda (Continued):

No. 27 Objective Minimum Temperature Forecasting for Helena, Montana. D. E. Olsen. February 1968. (PB-177 827)

No. 28** Weather Extremes. R. J. Schmidli. April 1968. (PB-178 928)

No. 29 Small-Scale Analysis and Prediction. Philip Williams, Jr. May 1968. (PB-178 425)

No. 30 Numerical Weather Prediction and Synoptic Meteorology. Capt. Thomas D. Murphy, U.S.A.F. May 1968. (AD-673 365)

No. 31* Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky. July 1968. (PB-179 084)

No. 32 Probability Forecasting in the Portland Fire Weather District. Harold S. Ayer. July 1968. (PB-179 289)

No. 33 Objective Forecasting. Philip Williams, Jr. August 1968. (AD-680 425)

No. 34 The WSR-57 Radar Program at Missoula, Montana. R. Granger. October 1968. (PB-180 292)

No. 35** Joint ESSA/FAA ARTC Radar Weather Surveillance Program. Herbert P. Benner and DeVon B. Smith. December 1968. (AD-681 857)

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No. 45/1 Precipitation Probabilities in the Western Region Associated with Winter 500-mb Map Types. Richard P. Augulis. Dec. 1969. (PB-188 248)

No. 45/2 Precipitation Probabilities in the Western Region Associated with Spring 500-mb Map Types. Richard P. Augulis. Jan. 1970. (PB-184 434)

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No. 50 Statistical Report of Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona 1969. Wayne S. Johnson. April 1970. (PB-191 743)

* Out of Print
**Revised