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July 1972

THE SIMULATION OF VEHICLE PERFORMANCE IN SURF

by

John Dalzell

Prepared under
Contract DAAE07-69-C-4370
(DL Project (3700/425)

STEVENS INSTITUTE OF TECHNOLOGY
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Details of illustrations in this document may be better studied on microfiche

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ABSTRACT

This study is part of an overall program on the interpretation of performance tests of amphibious vehicles in surf. By "surf" is meant the zone near-shore wherein waves are actually breaking—that is, the zone where the analytical treatment of water waves is least tractable and, consequently, least satisfactory. By "simulation" is meant the production of "surf" in a tank facility and the operation of a model vehicle in this surf. This report is presented in two parts: Part One is a survey of available knowledge of surf, the implications for model simulation and a preliminary application to existing Davidson Laboratory facilities. Part Two is a presentation of results of initial experiments on model surf generation at the Davidson Laboratory. The broad conclusion from the study is that quite reasonable simulations may be achieved to model scale. Practical model construction problems with military amphibious vehicles may dictate model scales and thus surf scales which are at the limit or beyond the capability of installed Davidson Laboratory equipment. It is suggested, however, that the production of the required surf conditions in such cases would be technically feasible and relatively economical.

KEYWORDS

Surf

Simulation

Amphibious Vehicles

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NOTATION

C_b	Breaker Celerity
C_o	Wave Celerity
d_w	Backwash Depth
d_b	Breaker Depth
d	Water Depth
g	Gravitational Constant
H_b	Breaker Height
H_o, H	Deep Water Wave Height
$\tilde{H}_b$	Significant Breaker Height
$\tilde{H}_{1/3}$	Significant Wave Height
L_o, L	Deep Water Wave Length
L_b	Breaker Length
m	Beach Steepness
N	Number of Waves
P	Plunge Distance
R	Run-up
T	Wave Period
T_b	Breaker Period
$\tilde{T}_b$	Average Apparent Breaker Period
$\approx{T}$	Average Period of Waves Entering Breaker Zone
$\approx{T}_B$	Average Period of 1/3 Highest Breakers
Y_B	Crest Elevation
α_B	Breaker Angle (with shore)
α_o, α_n	Angles Defining Beach Slew

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PART ONE

SURVEY AND IMPLICATIONS

I. DISCUSSION

The attractions in the model approach are considerable:

- Technically, it is not possible to order up desired conditions in full scale testing, and, in the absence of an agreed upon analytical model for extrapolation, comparisons between vehicles are bound to suffer from the element of chance.
- Full scale testing in extreme conditions is very hazardous.
- Where the vehicle is relatively large, expensive or apt to be built in large numbers, the model approach is economically attractive for the investigation of surf performance before construction.

The source material on surf and surf-related phenomena is moderately large. However, very little engineering material is to be found in the marine literature. Most of what has been done has been in support of "Coastal Engineering" (beach erosion) efforts. Proceedings of the various Conferences on Coastal Engineering and the Journal of Geophysical Research are the most fruitful literature sources.

The results of a sampling of the literature through Fall of 1970 are noted in the Bibliography. The first 65 citations are roughly in chronological order. In addition to the standard hydrodynamics texts (Stoker[18], Wehausen[22]) two engineering texts can be recommended: Wiegel[34] and Ippen[39]. There are three citations on tests of vehicles in full scale and model surf[14,15,53] and eleven for field observations of surf[3,11,17,19,20,21,32,38,50,52,62]. Studies of model surf in the laboratory are touched upon in fourteen citations[5,6,8,16,30,31,33,44,45,46,48,54,60,64]. The remaining 33 citations seem largely analytical and fully two-thirds of these deal with the transformation of waves from deep into shallow water-up to, but not including, the surf zone.

II. SURF IN TWO DIMENSIONS

Much of the analytical work in the field and most observations are couched in two-dimensional terms. In this section of the report it will be assumed that all waves are long-crested and that all beaches have parallel contours normal to the direction of wave advance.

A. Beach Topography

Figure 1 after Wiegel[34] illustrates beach terminology. The "surf zone" is generally defined as the region inshore of the position where the waves just start to break. Long-shore bar formation is associated with breaking waves and thus the inshore region of Figure 1 and the surf zone may be considered about the same. Beaches do not necessarily have long-shore bars; these are formed by wave action depending on previous wave history over time periods as short as weeks. Wiegel points out that the width of the surf zone may be influenced by the tide when long-shore bars or steps are present. At low water waves may first break over the bar, reform and break again on the beach face; at high tide they may break elsewhere. Thus the approximate location of the surf zone indicated in Figure 1 could be displaced by many factors.

Figure 2, also from Wiegel[34] illustrates the range of beach slopes commonly found. The beach topography apparently depends on the size of sediment available and upon the wave "climate."

B. Observations of Breaking Waves on Beaches in Wave Tanks

Much of the terminology and most of the practically useful results have come directly or indirectly from experiments in wave tanks. This type of experiment involves the generation and propagation of simple (usually periodic) waves onto beaches of various slopes. Qualitatively, and sometimes quantitatively, the results have been related to full scale surf.

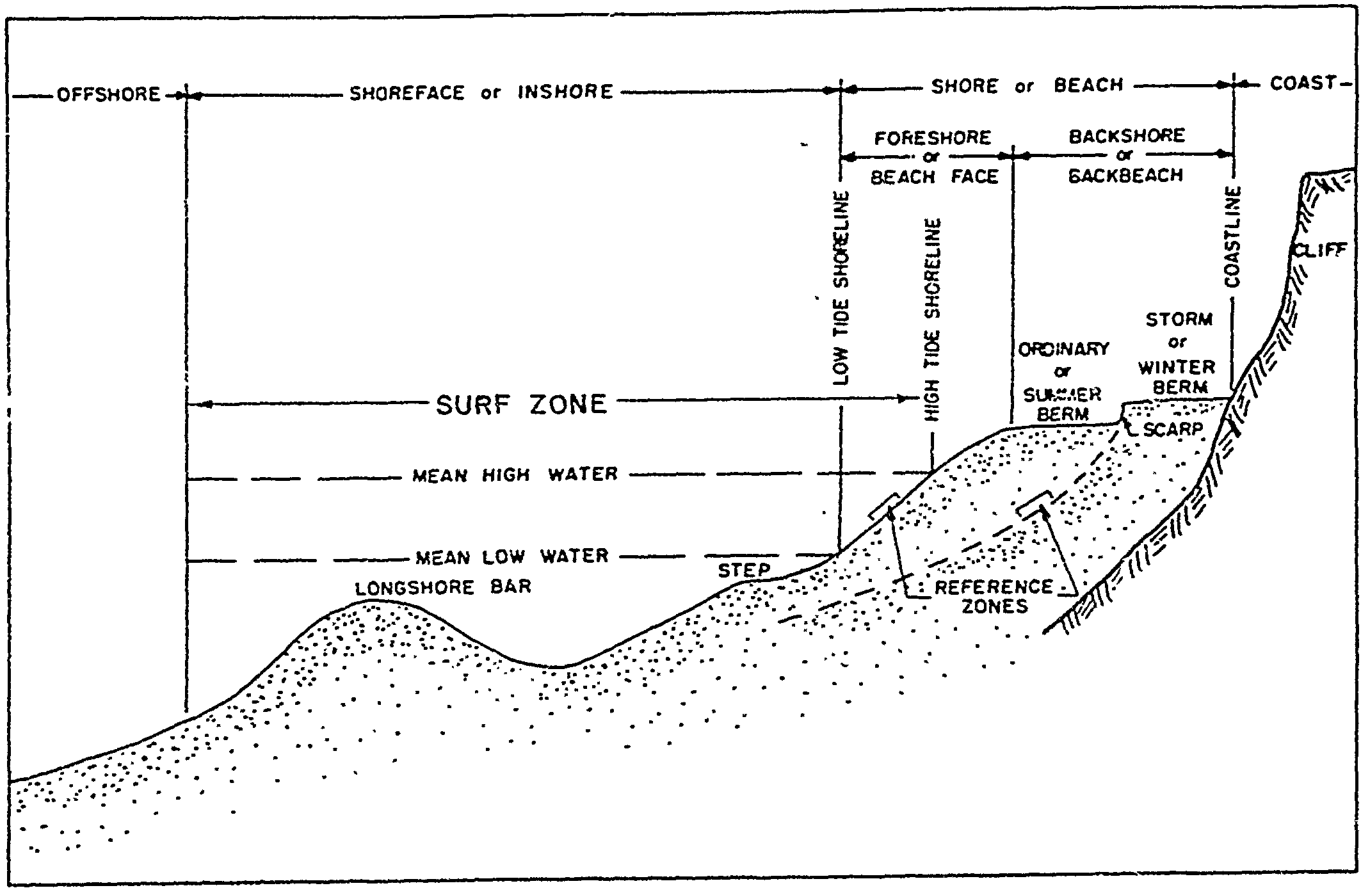

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FIGURE 1. TERMINOLOGY ASSOCIATED WITH A SHORE PROFILE[54]

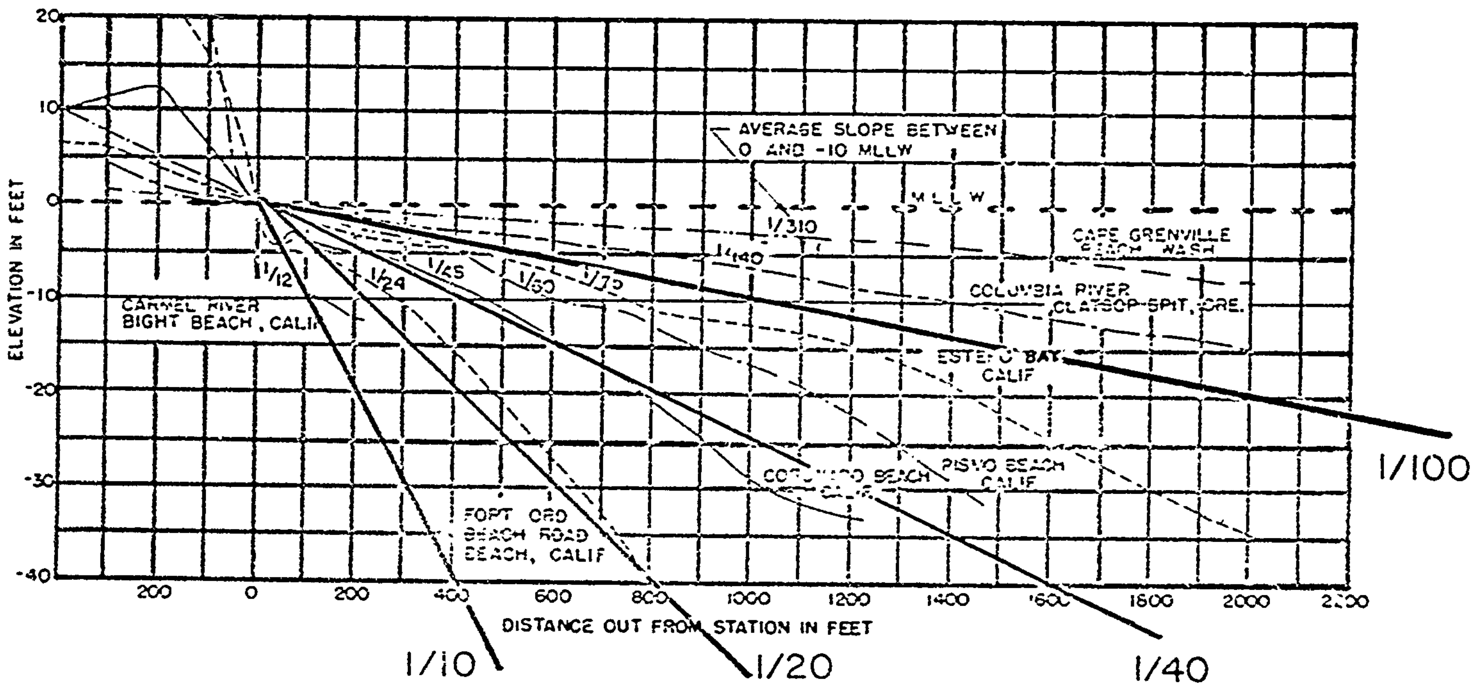

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FIGURE 2. TYPICAL PACIFIC COAST BEACHES SHOWING THE WIDE RANGE OF BEACH SLOPES THAT ARE COMMONLY FOUND[34]

Events in the "surf zone" of a laboratory beach under the influence of incident periodic waves from deep water depend upon combinations of the following parameters:

- Deep water wave period or length (T, L_o)
- Deep water wave height (H_o)
- Beach steepness (m)

Figure 3 from Galvin[54] is a good recent illustration of the variation of the sequence of events after breaking. As shown, breakers are classified into four types:

- Spilling: Bubbles and turbulent water spill down the front face of wave. The upper 25% of the front face may become vertical before breaking.
- Plunging: Crest curls over a large air pocket. Smooth splash-up usually follows.
- Collapsing: Breaking occurs over the lower half of the wave. There is a minimal air pocket and usually no splash-up. Bubbles and foam are present.
- Surging: The wave slides up beach with little or no bubble production. The water surface remains almost plane.

The influence of the various beach parameters were correlated with breaker type by Galvin[54]. Figure 4 is a presentation of the type of surf observed at a beach as a function of offshore and inshore parameters. If the type of surf is plotted against the offshore parameter, $\frac{H_o}{L_o m^2}$ (where H_o, L_o and m have been defined above), the transition between surging-collapsing and plunging surf occurs at about 0.09, and the transition between plunging and spilling surf occurs at 4.8. If the type of surf is plotted against the inshore parameter, $\frac{H_b}{gmT^2}$ (where H_b is the breaker height, g is the gravitational constant, and m and T have been defined above), the transition between surging-collapsing and plunging

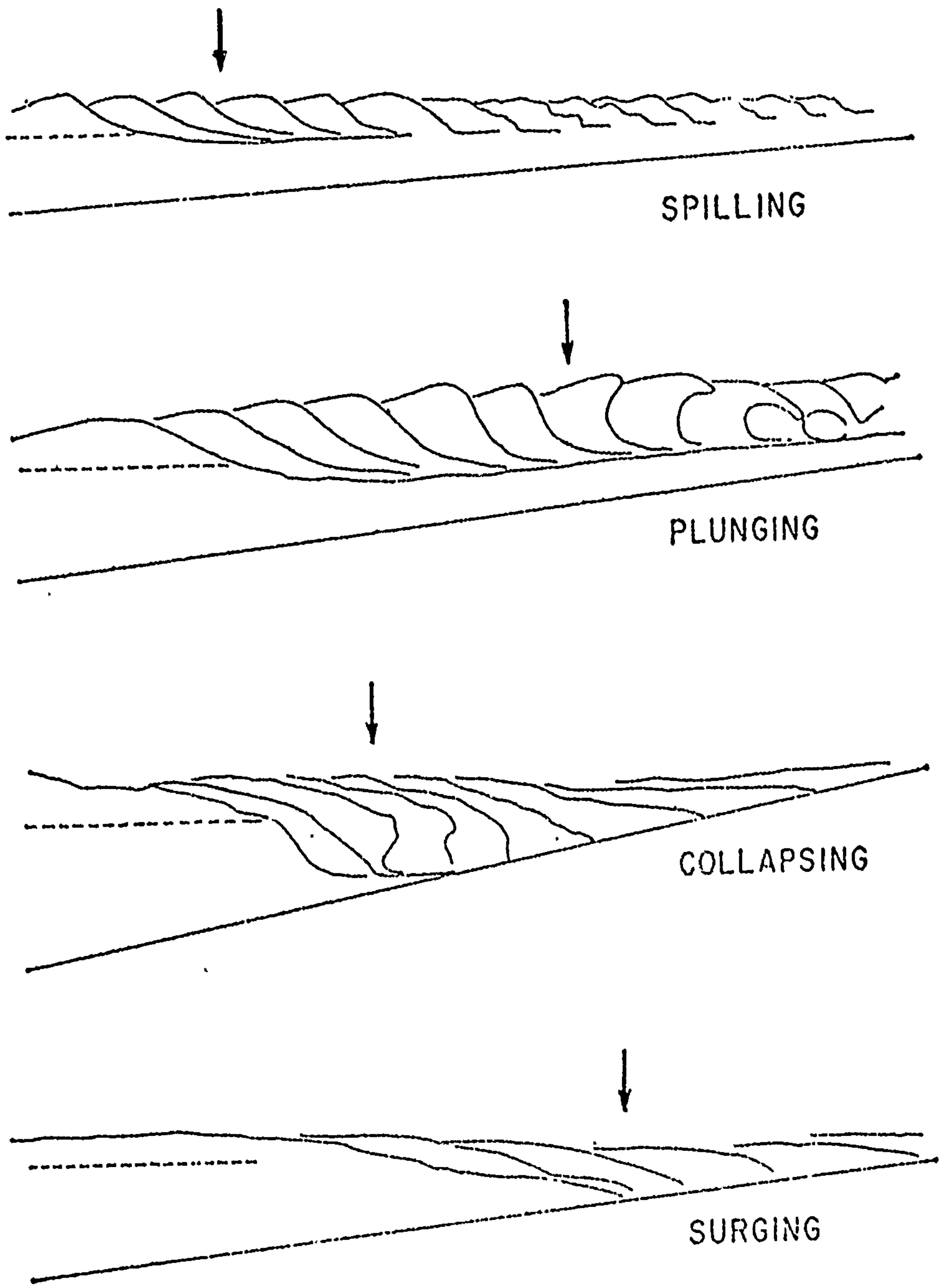


FIGURE 3. PRINCIPAL BREAKER TYPES.
DASHED HORIZONTAL LINE IS THE "STILL WATER LEVEL."
ARROWS LOCATE THE DEFINED BREAKING POINT.[54]

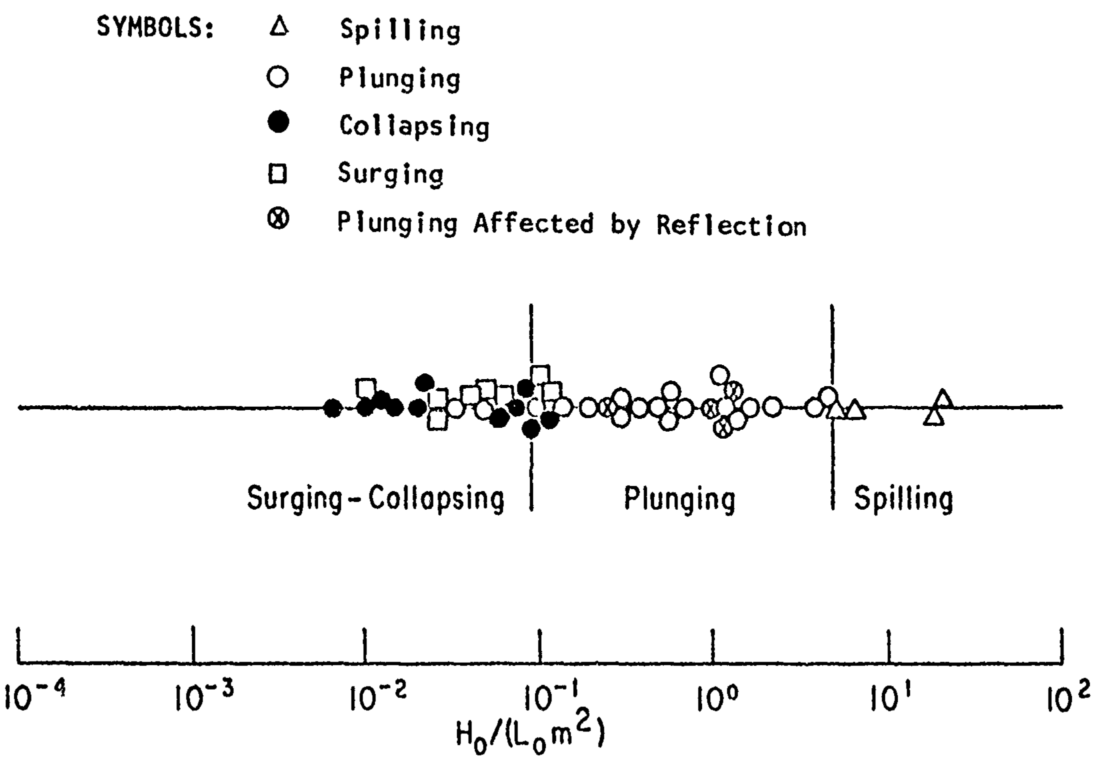


Figure 4a. As a Function of the Offshore Parameter

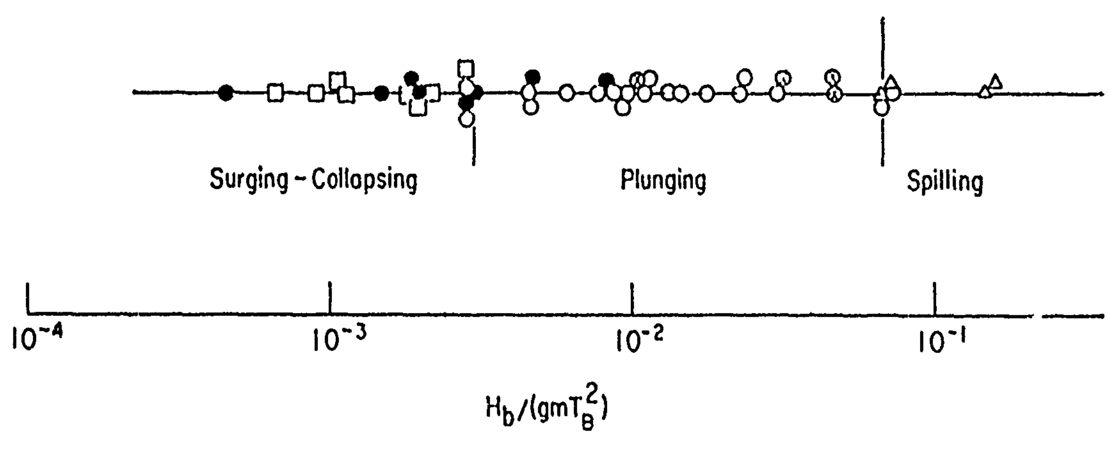


Figure 4b. As a Function of the Inshore Parameter

FIGURE 4. OBSERVED BREAKER TYPES[54]

surf occurs near 0.003, and the transition between plunging and spilling surf occurs at 0.068. These values are not definite cut-off points, and the type of breakers grade continually into one another. Relatively small variations in period and in some cases the reflections from previous waves can alter the type. In the field, successive combinations of adjacent types are ordinarily observed on the same beach at about the same time due to wave variability.

Of the options between offshore characteristics and inshore, the later involving breaker height, appears to be technically better for use in this simulation study.

The question of the definition of breaker height for each classification arises. Generally, breaker height is defined as the difference between the maximum water surface elevation at the position on the beach where breaking starts and the minimum water elevation when the preceding trough passed that point. The position where breaker height is ordinarily measured is indicated in Figure 3 by arrows. Figure 5 shows various other surf notations which ordinarily refer to spilling or plunging breakers. It may be noted that the terminology shown in Figure 5 involves, for the most part, a description of the wave profile. Run-up distances are maxima and do not necessarily occur for the same wave as that which generated the maximum breaker height.

Figure 6 (Wiegel[34]) is among the most useful results from the laboratory studies. It summarizes an analysis of Iverson's data[6] and relates breaker height indices, breaking depth and beach slope to deep water wave height and period. The breaker index, H_b/H_o relates the deep water, unrefracted wave height to breaker height. This is a primary index in forecasting. These, then, are the gross parameters which must be accounted for in a model simulation.

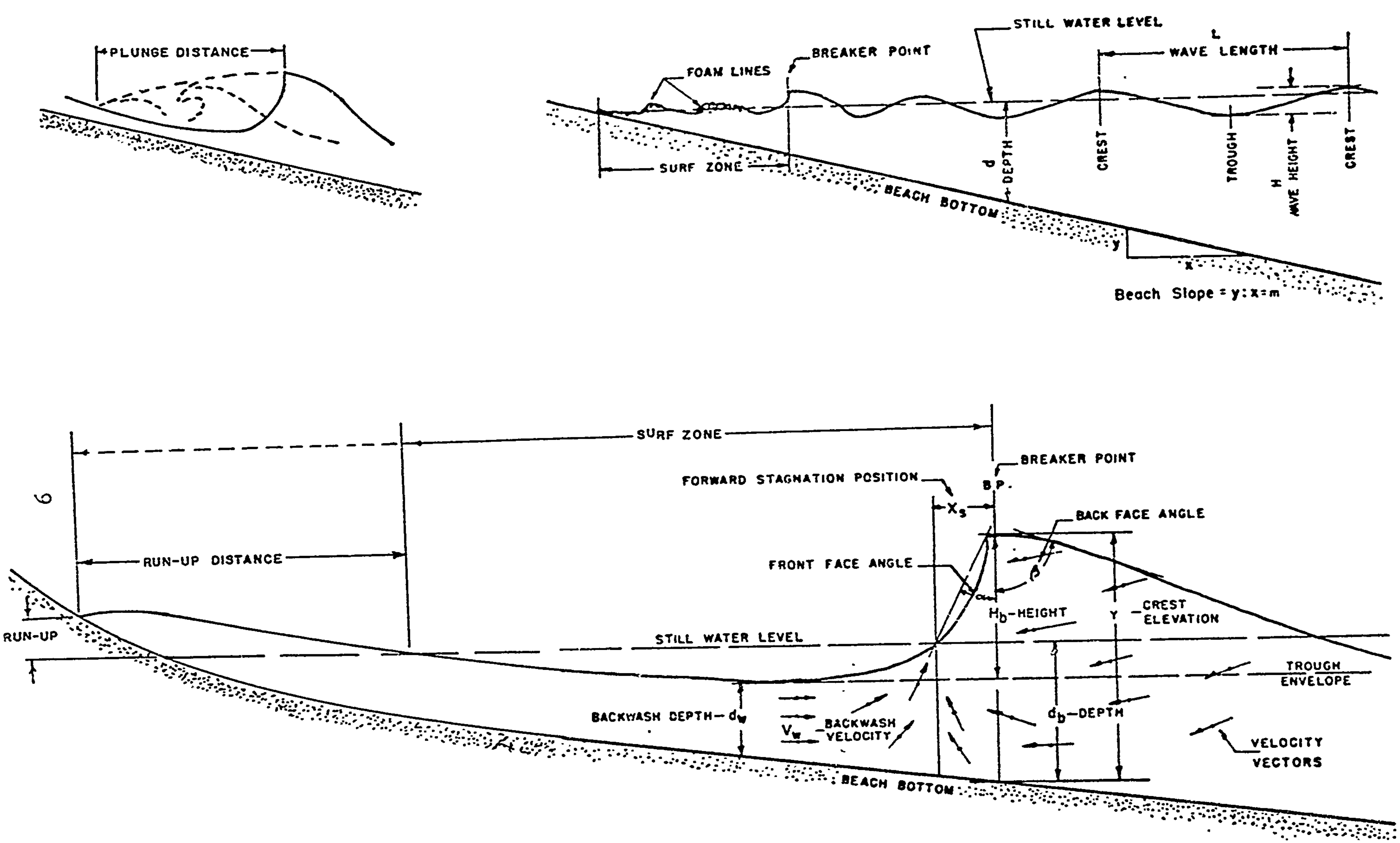
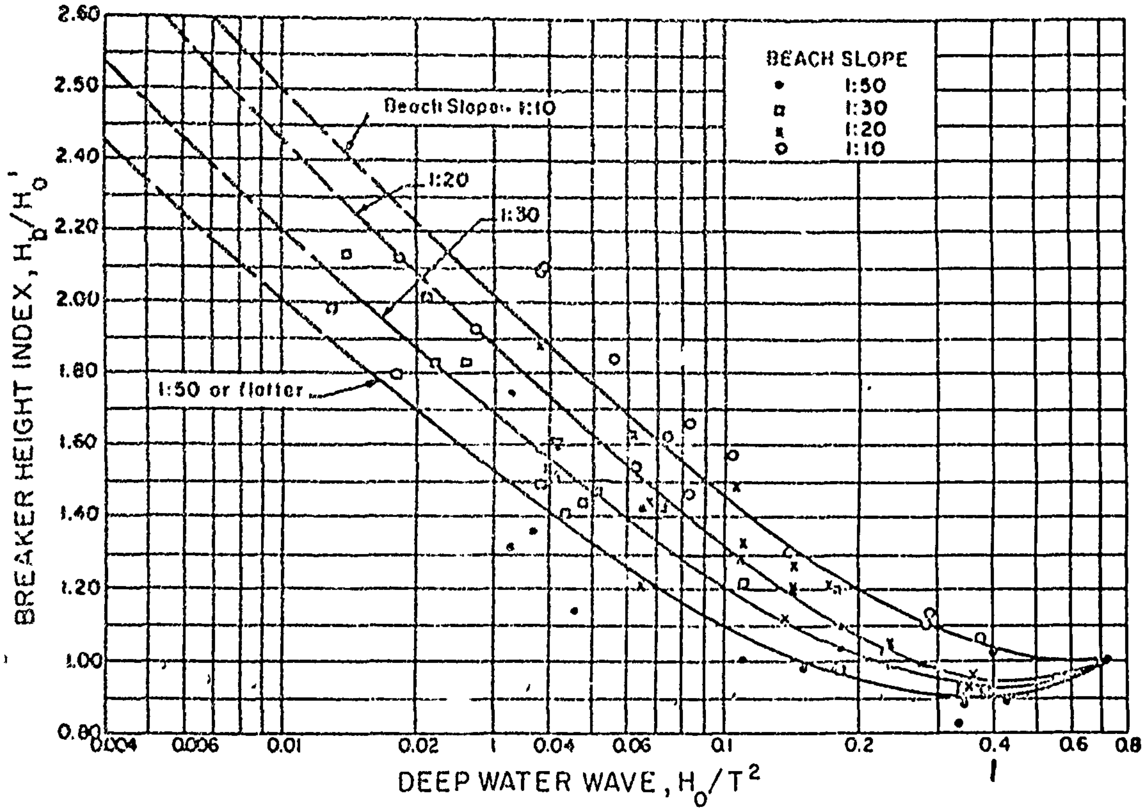


FIGURE 5. TERMINOLOGY ASSOCIATED WITH SURF[6]



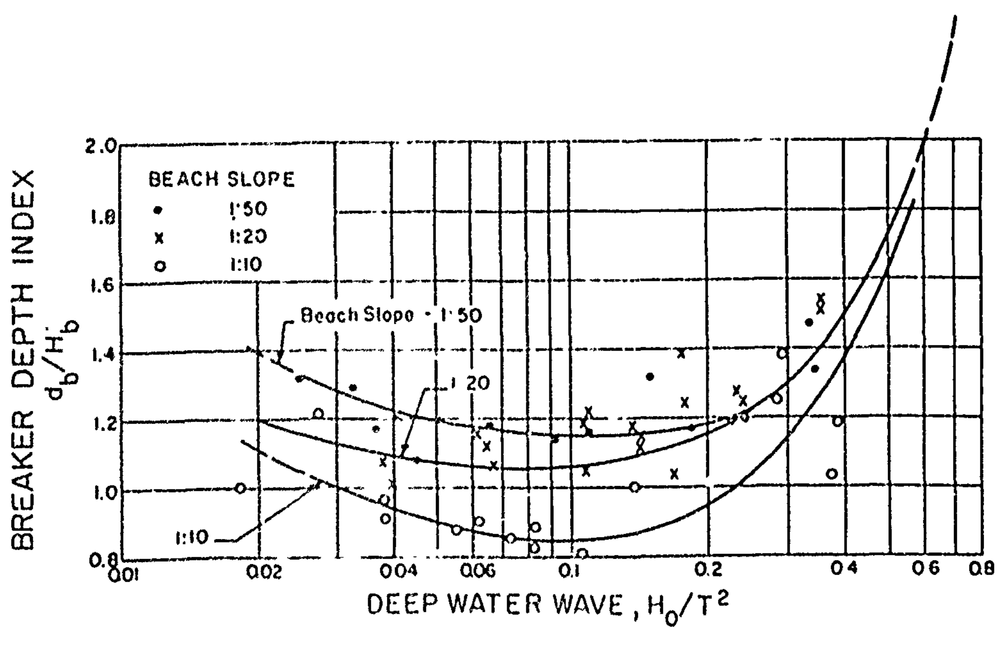


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FIGURE 6. BREAKER HEIGHT AND DEPTH RELATIONSHIPS[34]

Some of Iverson's data has been replotted on a base of Galvin's inshore parameter, (Figure 7). If the definitions of breaker height are the same in both investigations, it is clear that Iverson's data pertains to plunging and spilling breakers. Because of the nature of the process and the lack of unifying methods of analysis, laboratory results have a wide scatter. The parameter d_b defines the surf zone given a beach slope. Figure 7 indicates that d_b/H_b varies from 1 to 1.4 for slopes flatter than 1/20. From solitary wave theory this value should be 1.28.

Backwash depths, d_w (Figures 5 and 7) tend to be around half the breaker height for plunging surf; about equal to the breaker height for spilling surf.

Iverson's data yields magnitudes for some of the other parameters in Figure 5:

Back Face Angle:	from 70^o to 85^o
Front Face Angle:	from 40^o to 60^o
Backwash Velocity:	from 0.1 to 0.5 $\sqrt{gY_B}$
Crest Velocity:	from 0.6 to 1.1 $\sqrt{gY_B}$
Crest Elevation (Y_B):	from 0.6 to 2.2 H_b

Run-up (R) is very little documented for slopes from 1/10 to 1/100. Data in Wiegel[34] indicates that, for values of deep water wave steepness likely to produce plunging surf, run-up will be less than half H_b.

Galvin[52] reports that the minimum horizontal distance traveled by the crest of a plunging wave from the breaker position to touchdown point is about twice breaker height. The distance can increase to $4H_b$ as beach slope decreases to less than 1/20. From these observations, it is apparently possible to produce breakers which travel quite a long distance on composite slope beaches. A transition from 1/20 to flat, then back to 1/20, might result in a significantly increased surf zone.

It should be emphasized that the above parameters are noted only at time of breaking, or, in the case of run-up, at a maximum. After the breaker point, the "wave height" decays. Some model data is in the literature (Horikawa[45] and Nakamura[46]).

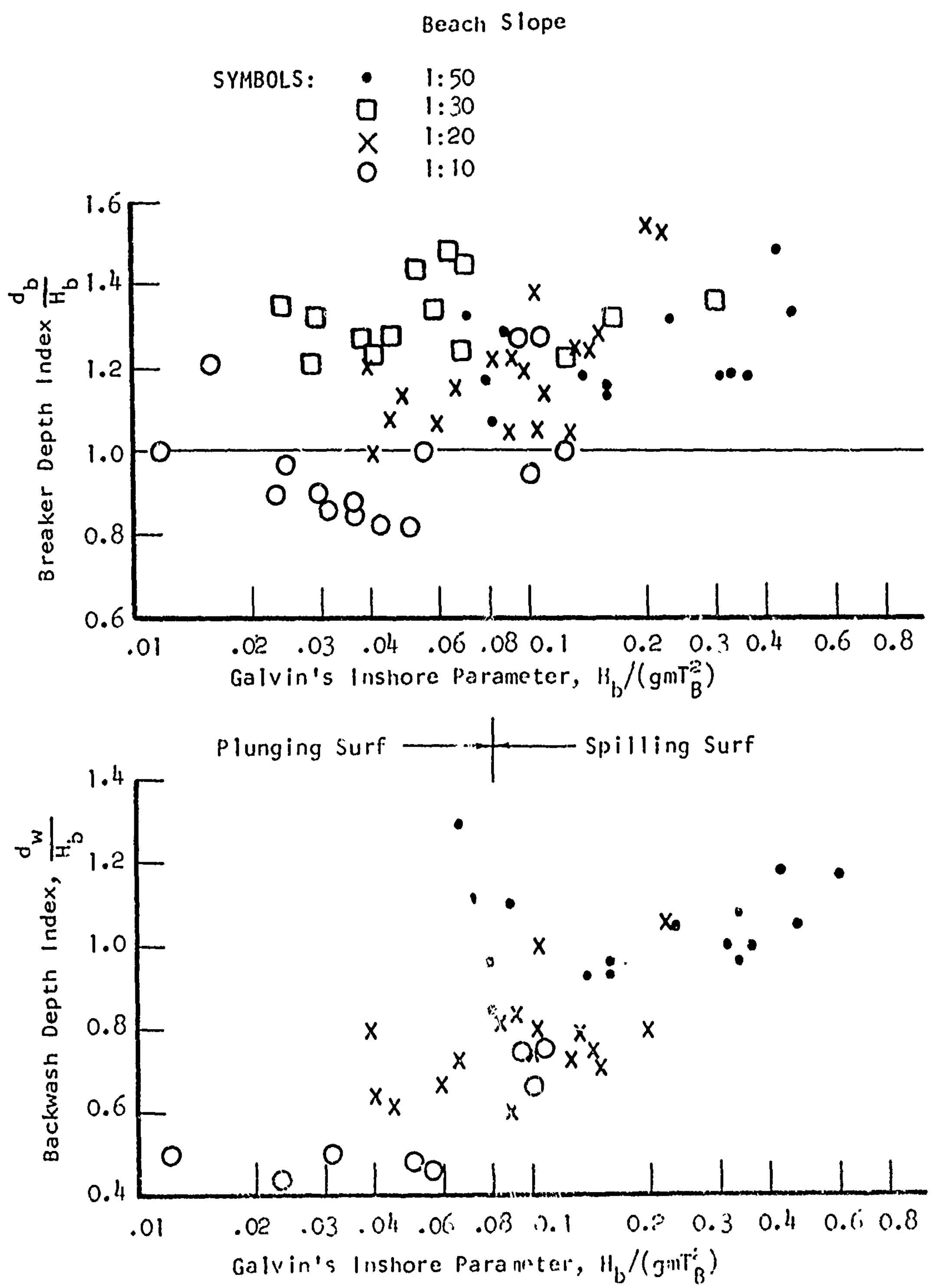


FIGURE 7. A REPLOT OF IVERSON'S DATA
ON GAVIN'S[54] INSHORE PARAMETER

Figure 8 from Iverson[6] is an early study of the velocity field in the wave during breaking, which has been reproduced over and over in the literature. The figure shows a velocity mapping at an instant of time for four waves about to break.

C. The Analytical Treatment of Periodic Waves

In the mathematical study of surf, finite amplitude wave theory is necessary almost by definition. These theories are complicated by the importance in shoaling water of the water depth and the wave height itself. Because of the difficulties many analysts have regarded one or another of the parameters to be small to obtain restrictive solutions. At least three finite amplitude theories have been utilized. The situation is summed up by Ippen[39] in Figure 9. Exact regions of validity of each theory are not well established. In fact, Ippen asserts that limitations on accuracy of results are often imposed by the analytical method in which parameters are determined rather than being inherent in the theory.

On the whole, it appears that transformation of the celerity (L/T), and steepness (H/L) and height is accounted for by linear theory to water depths of $d/L \approx 1/5$—at least within experimental scatter which, as has been noted, is relatively large. Linear theory also seems a reasonable approximation up to d/L of about 1/10 (Eagleson[16]). In the region $\frac{1}{5} > \frac{d}{L} > \frac{1}{10}$, a second approximation of Stokes' wave theory was found to correlate reasonably well with experimental data.[13]

Galvin[54] summarized the state of theory in 1968 as follows:

> "...Existing theories which deal with waves as they approach breaking...or with waves after breaking has produced a bore of assumed properties...or they assume special conditions that produce no breaking at all... There has been little theoretical study of the structure of the breaking process itself, but promising results are contained in numerical solutions being developed...by Harlow[66]."

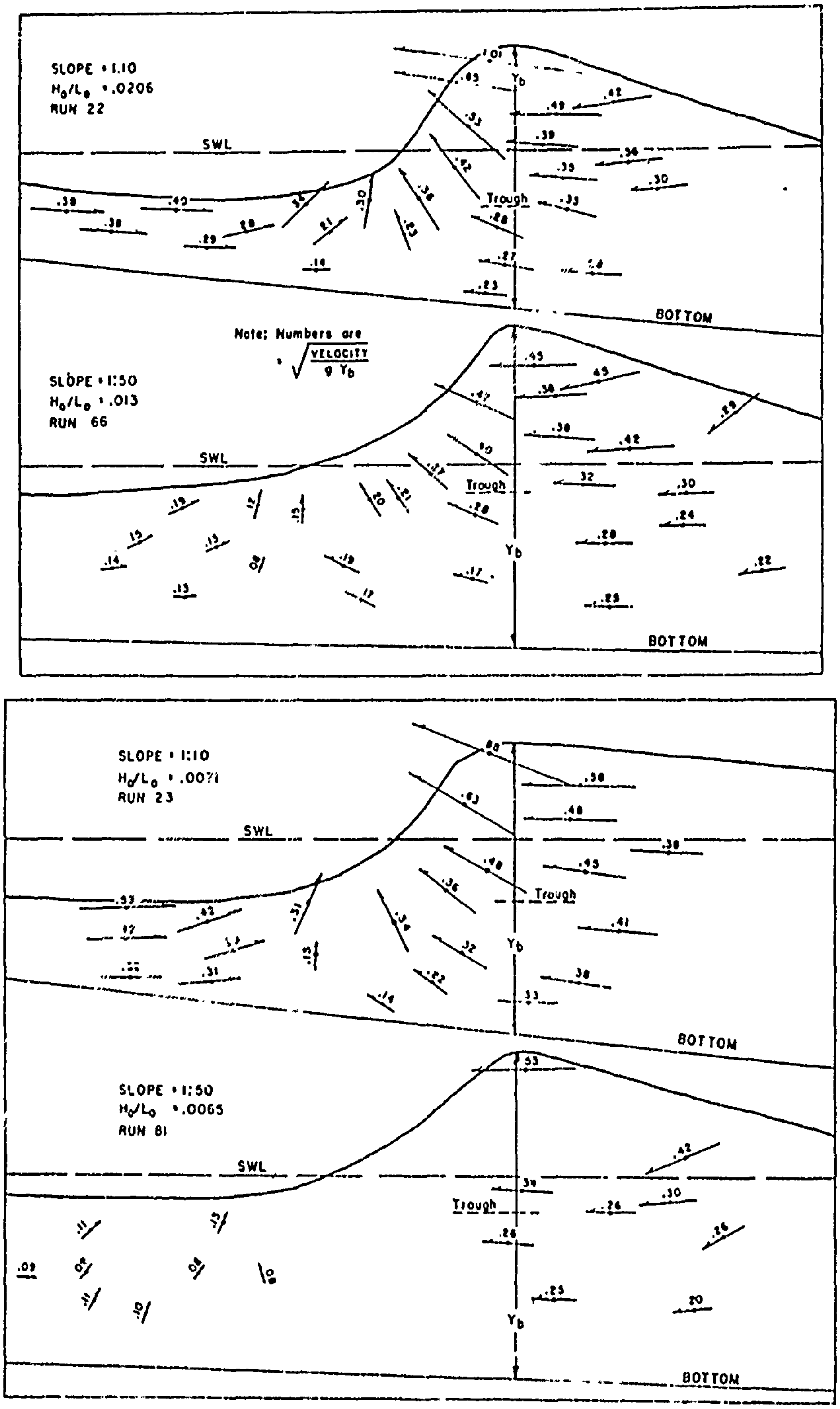


FIGURE 8. VELOCITIES IN SURF AT BREAKING POINT[6]

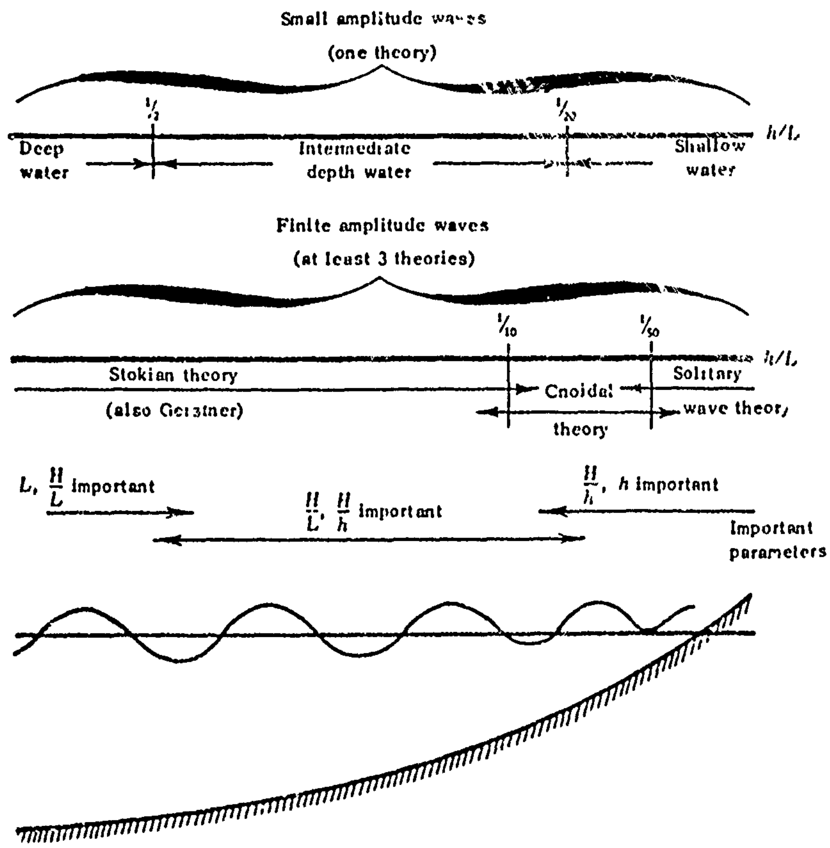


FIGURE 9. CLASSIFICATION OF FINITE AMPLITUDE WAVES[39]

1. Variations over time scales which are long with respect to vehicle transit time. This variability is essentially that of the statistics of the incident sea state.

2. Short term (wave to wave) variability.

Figure 10 indicates the monthly average wave conditions on 27 California beaches recorded by Szuwalski[67] and Galvin[50] for nine months of 1968. The breaker heights are monthly averages of 30-60 observations as are the average periods. The data is remarkable for its lack of correlation between average height and period as well as for the relatively narrow range of period averages. Figure 11 is a subset of the same data. This time the individual observations which went into the average statistics for one beach is presented. The lack of correlation between breaker period and height is even more evident. Figure 12 is a similar plot of observations from various investigators at various locations[50,53]. It is again evident that breaker height and period are not well correlated for the same beach.

The "significant wave" point of view in wave forecasting[34] gives rise to a correlation of average period and height for deep water waves by:

$$\tilde{H}_{1/3} \approx 0.25\ \tilde{T}^2$$

Classical theory for progressive deep water waves of maximum steepness yields:

$$H \approx 0.71\ T^2$$

These lines are plotted on Figures 11 and 12 for comparison. The surf apparent periods are much longer for two reasons:

1. Surf period is the time interval between successive recognizable breakers in a (hopefully) small area just inside the breaker zone. Small waves which do not break or are swallowed up or overtaken in the general confusion are not counted. Thus $\tilde{T}_B$ is not necessarily a measure of the number of crests and troughs passing a fixed point.

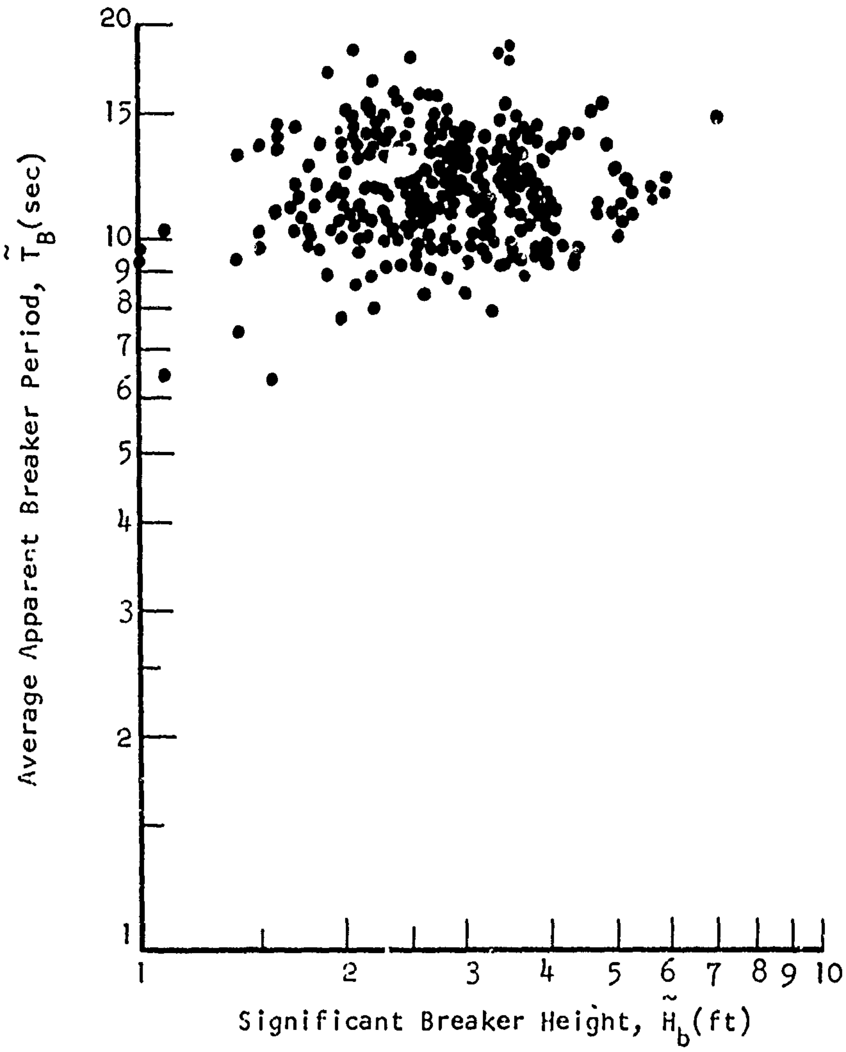


FIGURE 10. MONTHLY AVERAGE SURF CONDITIONS AT 27 STATIONS ON THE CALIFORNIA COAST BETWEEN APRIL and DECEMBER, 1968. EACH POINT REPRESENTS AN AVERAGE OF 30 TO 60 OBSERVATIONS PER MONTH[67]

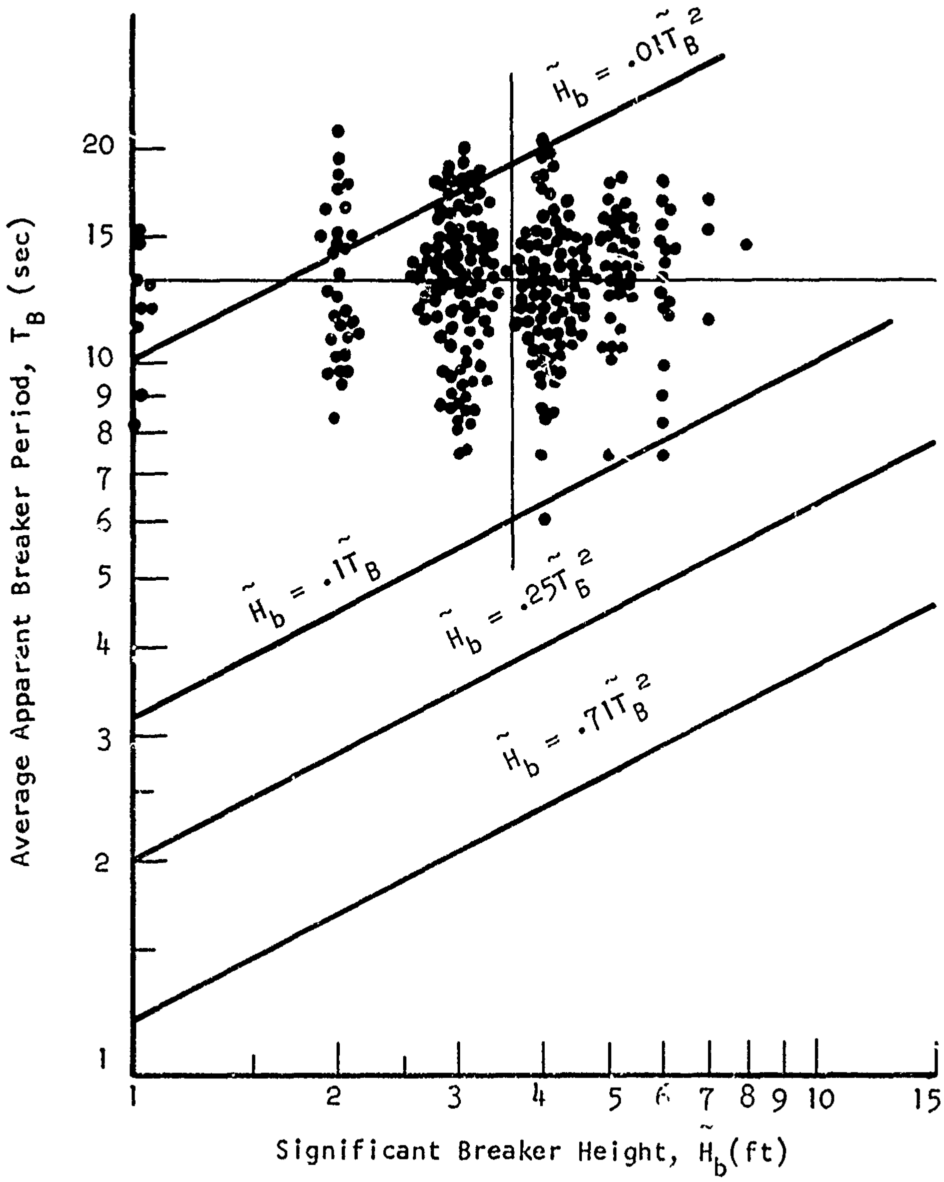


FIGURE 11. SURF OBSERVATIONS AT MANCHESTER STATE BEACH, CALIFORNIA BETWEEN APRIL AND DECEMBER, 1969. EACH POINT IS A VISUAL ESTIMATE OF BREAKER HEIGHT AND THE TIMED AVERAGE FOR TEN WAVES.[67]

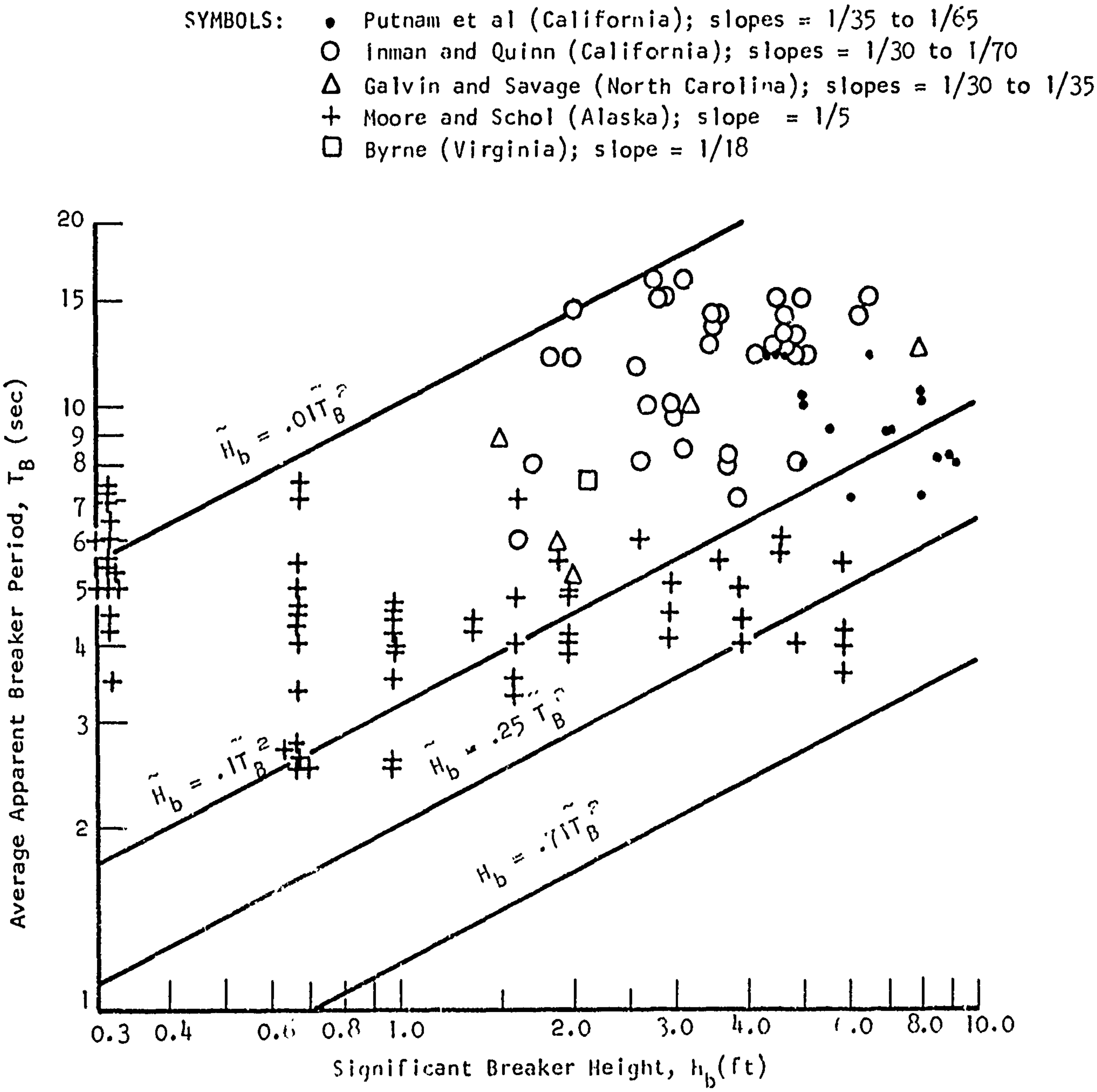


FIGURE 12. SURF OBSERVATIONS
AT VARIOUS LOCATIONS[50,53]

2. The waves reaching real beaches are the residuals of every storm in the ocean. Dispersion and wave decay act so as to lengthen the average period of swell.

Inshore, from the transition from deep to shallow water, the waves and their statistics start to be modified by the bottom in a non-linear way. The dispersive properties of the wave field are modified. The prediction of the wave spectrum just outside the breaker zone can apparently only be done by assuming no interaction between frequencies. That is, the spectrum of the incident waves may be broken into a finite number of sinusoids, each may be propagated as a periodic wave, and then the sum taken as an approximation to the spectrum in shallow water. The statistics of this process are not known and its basic validity may be questioned.

For this reason, the concentration in the literature is upon the significant wave concept—a replacement of the random process by an "equivalent" sinusoid. This point of view may be quite adequate for studies of beach erosion, etc. But, to the extent that the significant wave concept is misleading in deep water ship motions, it will also be misleading in problems of vehicles in surf. Nevertheless, the significant wave approach is inherent in most of the existing data and must be used in order to make progress. Because of the complexity and probable defects of analytical approaches, the characterization of surf for simulation purposes must be based upon observable parameters in the surf zone as found in nature.

F. Definition of Gross "Surf States"

To study the feasibility of model simulation, numerical ranges of the parameters describing long term surf variability are required. These will be defined as a measure of "surf state."

The simulation envisioned is dynamic and time must be taken into account. The gross parameters defining "surf state" (two-dimensional) will be taken as:

$\tilde{T}_b$ - Average apparent breaker period (average time between breakers)

$\tilde{H}_b$ - Significant breaker height (assumed to be the quantity reported as average height)

The reason for this choice is practical—it is about the only common description.

Tentatively, it must be concluded on the basis of data in hand, that about any physically plausible combination of breaker height and period (and some combinations which are not plausible) may be reported.

G. Surf Variability (Short Term)

From the data furnished us by Byrne, histograms of his estimates of breaker height and periods were constructed (Figure 13). The breaker height data is not consistent with a Rayleigh distribution as might be hoped. Furthermore, the period distribution does not resemble anything common. These data fragments illustrate that a realistic simulation of surf must be capable of considerable short-term variability. The rms deviation from the mean of period is about 25% of the mean and that of height about 35%. This breaker height variability is consistent with the rough rules presented by the U.S. Hydrographic Office[19]; the period variability is consistent with the data of Wiegel[34] for deep water waves.

In order to produce natural appearing surf in the tank, data on the variability of surf in the mid-range of significant breaker height should be obtained. In particular, distributions for as many as possible of the descriptive variables of Figure 5 should be extracted. Further, to do quantitative correlations with measurable quantities in a model simulation, some idea of the frequency spectrum and the distribution of maxima of water elevation at various points on the beach should be obtained.

H. Surf for Military Vehicles

From the point of view of military amphibious vehicles, what is meant by "surf"? Thus far, specifications seem only to be on breaker height and, typically, that it be of "plunging" type. The vehicles involved in amphibious operations are likely to range upward from 20 feet in length. Therefore, it is unlikely that breakers less than about 3 feet in height would be very important to any aspect of their behavior. It seems reasonable also to assume that 15-foot breakers are sufficiently rare so as to put some limit at the other end of the scale.

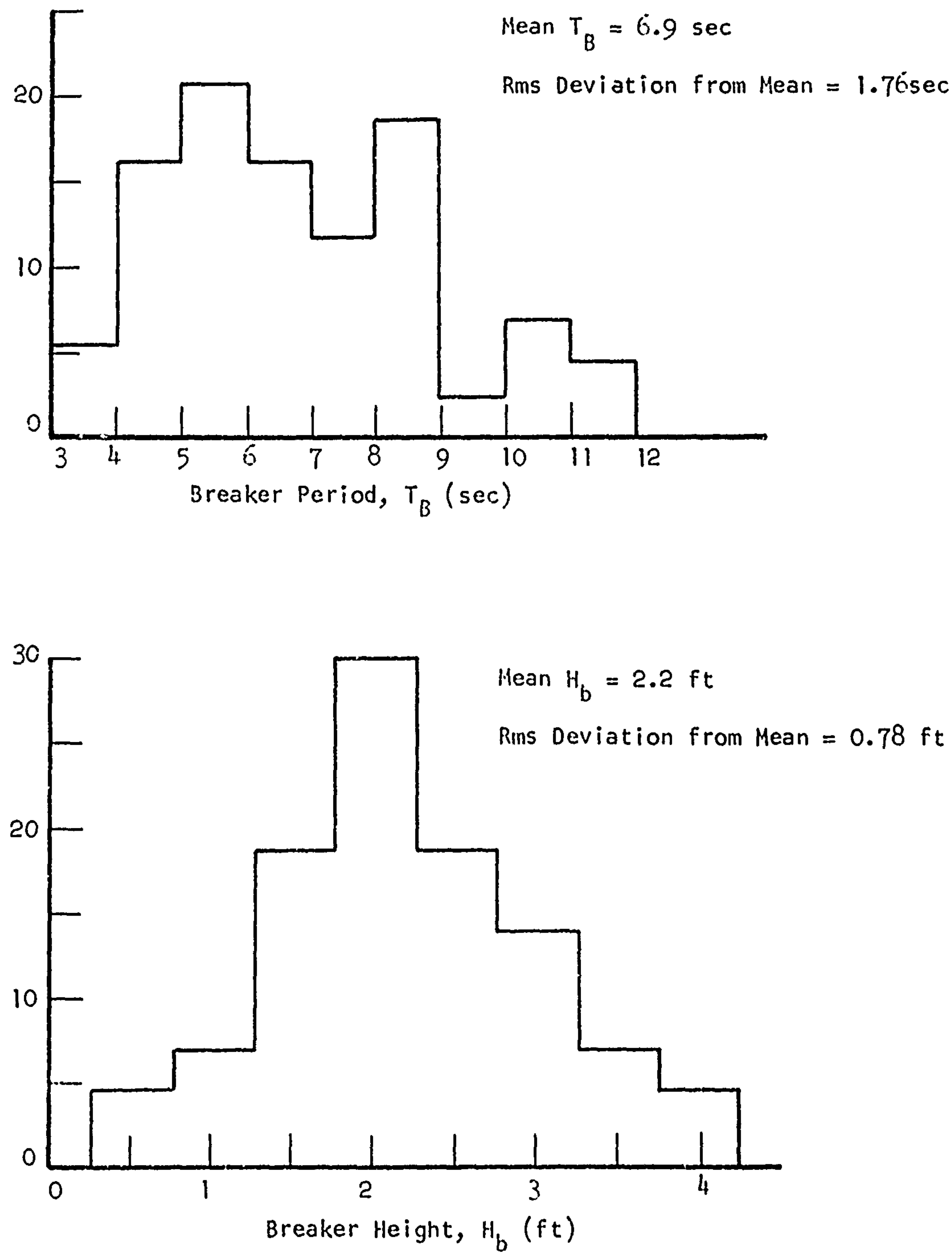


FIGURE 13. VARIABILITY OF BREAKER HEIGHTS AND PERIODS. HISTOGRAMS FROM A 43 WAVE SAMPLE FROM RUN #33 BY BYRNE[53]

Thus, part of the surf state range specification for vehicle interaction purposes is assumed to be:

$$3 \text{ ft} < \tilde{H}_b < 15 \text{ ft}$$

It is clear from the data in hand that average breaker periods of 17 seconds are not uncommon. It is also clear from the data in hand that a lower limit on breaker period averages of 7 seconds for breakers in excess of 3 ft would exclude only the data of Moore-Schol[50] (which was quite possibly obtained with different rules for observing breaker period). The combination of 7 second periods and breaker height of 15 feet might be implausible but at the moment there is no reason to suspect that the combination could not happen.

Thus, for military vehicles, we are interested in the range:

$$7 \text{ sec} < \tilde{T}_b < 17 \text{ sec}$$

The net result is a two-dimensional range of parameters related to "military" surf state.

III. SURF IN THREE-DIMENSIONS

A. Refraction

In the qualitative discussion of "two dimensional" surf, the incident wave was assumed to be the residual effects of many wind-driven seas. In a real surf the dominant direction of these incident waves may be nearly anything within $\pm 90^{\circ}$ of the normal to the beach. Further, the waves arriving at an angle are refracted as well as transformed in length.

Considerable effort has long been made in the computation of refraction of sinusoidal waves (see Wiegel[34]). Fairly simple considerations lead to acceptable results for engineering purposes up to the breaker zone. The tendency is for the wave crests to turn parallel to the shore. Analytical work on beaches with flat, parallel contours (LeMehaute[41]) indicates that the angle of the wave crest with the shore line at breaking may be up to 40° or 50°, depending on the analytical breaking criterion. Observations of the average angle of breaking waves in the field range up to 45°. However, both laboratory and field data (Galvin[50]) indicate that a more prevalent range of angle in the breaking zone is between 0° and 20°.

B. Nearshore Circulation

Nearshore circulation is caused by the shoreward mass transport of water due to wave motion which carries water through the breaker zone in the direction of wave propagation. This water must go somewhere and thus flows parallel to the coast (longshore currents) are established in both directions. Periodically, this longshore current encounters another traveling in the opposite direction. At that point both turn seaward (the rip current). Beyond the surf zone the current fans out (the rip head) to replace the water mass transported shoreward by the surf. The sketch by Shepard and Inman[11] to illustrate this phenomenon is presented in Figure 14. The prediction of longshore currents, the spacing of rips, etc., is yet a disputed matter. Field observations have resulted in measured

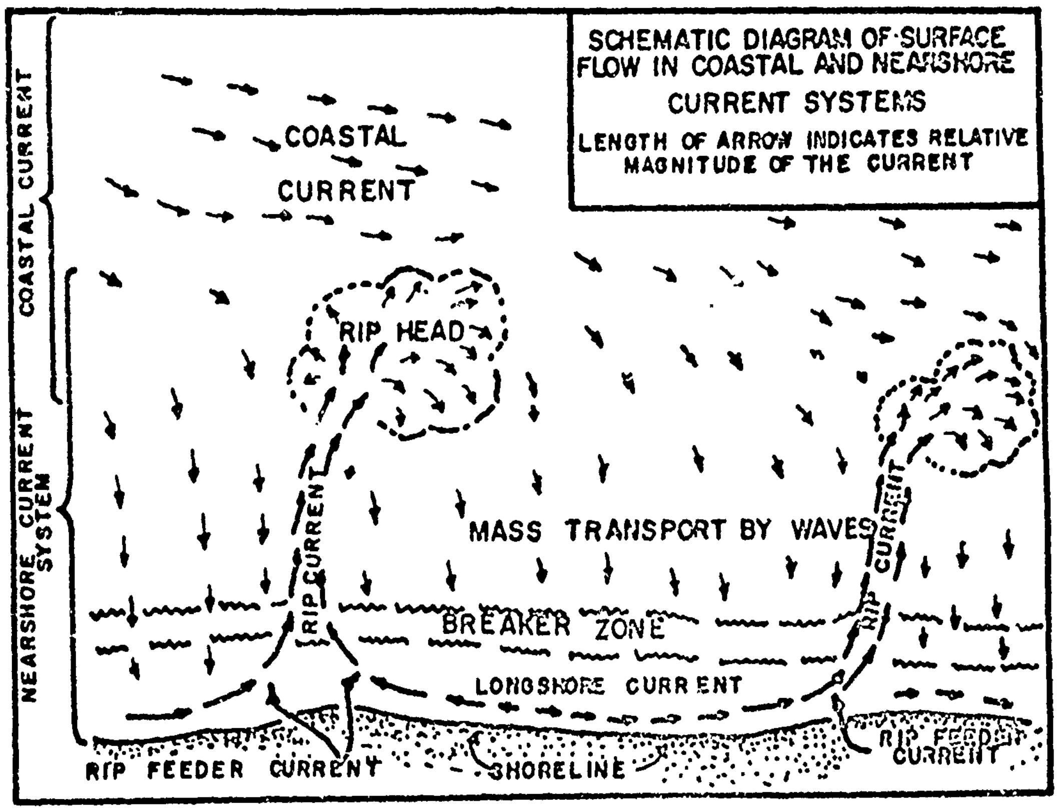


FIGURE 14. NEARSHORE CIRCULATION

longshore currents slightly above 4 ft/second (Galvin[50]). These measurements, however, are difficult to obtain in the presence of the large fluctuations in water velocity normal to the beach due to the breaking waves. The indications seem to be that the current is fairly uniform across the flow. The magnitude and direction, as may be surmised from Figure 14, varies with distance from the rips.

C. Importance of Three-Dimensional Effects on Simulation

One of the more difficult aspects of handling of vehicles in surf is the avoidance of broaching. The simulation of lateral fluid motion must be important to the subject.

Any swimmer in moderate bathing type surf can notice how far along the beach it is possible to drift while swimming nominally in and out of the surf zone. This is essentially the effect of the longshore current (as well as how the current is measured). Model measurements by Galvin and Eagleson[50] indicate that the magnitude of this current does not vary greatly as a function of distance normal to the beach.

There are clearly substantial lateral velocity fluctuations in a wave breaking at an angle and in the subsequent run-up and backwash. It is also clear that breaker heights tend to be lower in a rip current.

On the basis that longshore and rip currents involve spatially large velocity fields with respect to vehicle sizes of interest, it may be hypothesized that they affect the behavior only secondarily; that is, the longshore current would produce a steady lateral drift but no appreciable yaw moments, and a rip current would help retraction and hinder landing but again, not impose direct yaw moments.

On the other hand, the very fact that waves break at an angle is an indication of an important transient lateral asymmetry of flow relative to an object held stationary.

The main conclusion is that the only three-dimensional effect worth simulating is the angle of breaking relative to the beach.

IV. SIMULATION OF SURF

A. Specifications

From the above considerations, six basic specifications of model "military" surf may be postulated:

1. Significant breaker heights:

$$3 < \tilde{H}_b < 15 \text{ feet}$$

2. Average breaker periods:

$$7 < \tilde{T}_b < 17 \text{ seconds}$$

3. Breaker type:

Plunging, since experience[14,68] indicates this type to be most hazardous.

4. Beach topography:

Flat and straight with constant slope in the surf zone. May steepen at the beach face to angles of 15°. Underwater slope, from 1/10 to 1/100 in the surf zone. The effect of long shore bars is probably to lower breaker height near shore; thus there does not appear to be a necessity to simulate long-shore bars in present state-of-the-art.

5. Breaker angle (the approximate angle in the horizontal plane which the breaking wave crest makes with shore):

$$0 < \alpha_B < 20^{\circ}$$

6. Variability:

Undetermined or none until full scale observations yield a definitive scheme.

According to Wiegel[34] and Galvin[50] the first four specifications are not independent (see Section II). For flat beaches, Galvin gives a surf classification scheme based on the parameter H_b/gmT_b^2. Assume that it is desired to simulate surf arising from a swell with a fairly narrow frequency band of energy. Specification 3 requires plunging surf, specification 4 indicates a flat beach and specifications 1 and 2 give ranges of surf state parameters.

If Galvin's data (Figure 4) is good for all slopes (he tested only 1/5, 1/10, 1/20), the breaker types may be estimated as follows:

Type of Surf	Range of H_b/gmT_b^2
Surging	less than .0022
Plunging and Surging	from .0022 to .0063
Plunging	from .0063 to .04
Plunging and Spilling	from .04 to .1
Spilling	greater than .1

Application of the above ranges is facilitated by Figure 15 in which contours of constant H_b/gT_b^2 are shown for the full surf-state range. Combinations of given beach slopes with the contours of Figure 15, allows the estimated types of breakers to be outlined as areas on a T_b vs H_b plot. This has been done for beach slopes between 1/5 and 1/100 in Figure 16, 17 and 18. In these figures, the range of surf zone width has been estimated by assuming (from Figure 7):

$$d_b = 1.3\ H_b$$

$$\text{surf zone width} = d_b/m$$

Thus:

$$\text{surf zone width} = 1.3\ H_b/m$$

It seems clear from the figures that the majority of surf states of interest will not be predominately plunging on beaches of $m = 1/40$ and flatter (Figure 18). Within the surf state parameters given, the best certainty of obtaining plunging waves seems to be with a beach slope of 1/10. Galvin[50] noted that the classification scheme of Wiegel and Patrick[14] puts the transition between plunging and spilling at higher wave steepness for beach slopes of 1/20. This means, in effect, that use of their criterion would make a much larger portion of the plot for $m = 20$ more definitely plunging.

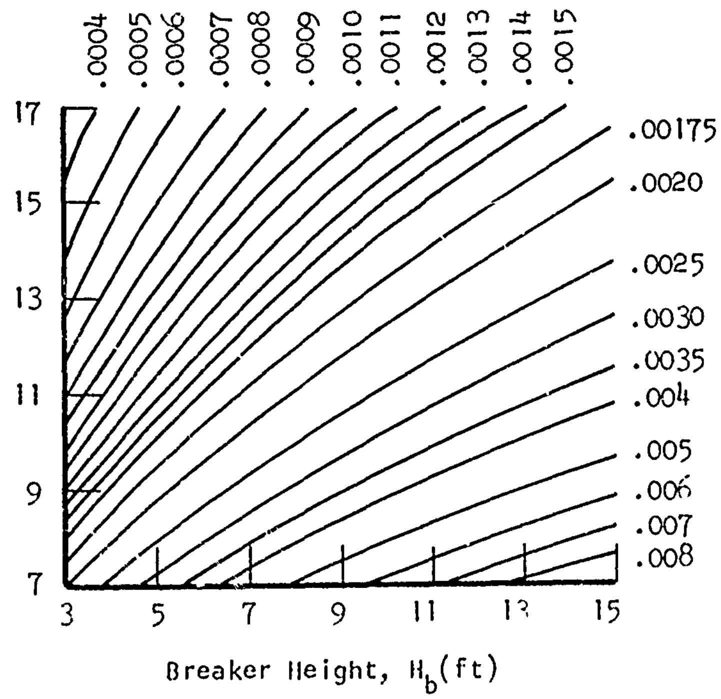


FIGURE 15. CONTOURS OF CONSTANT $H_b/(gT_B^2)$

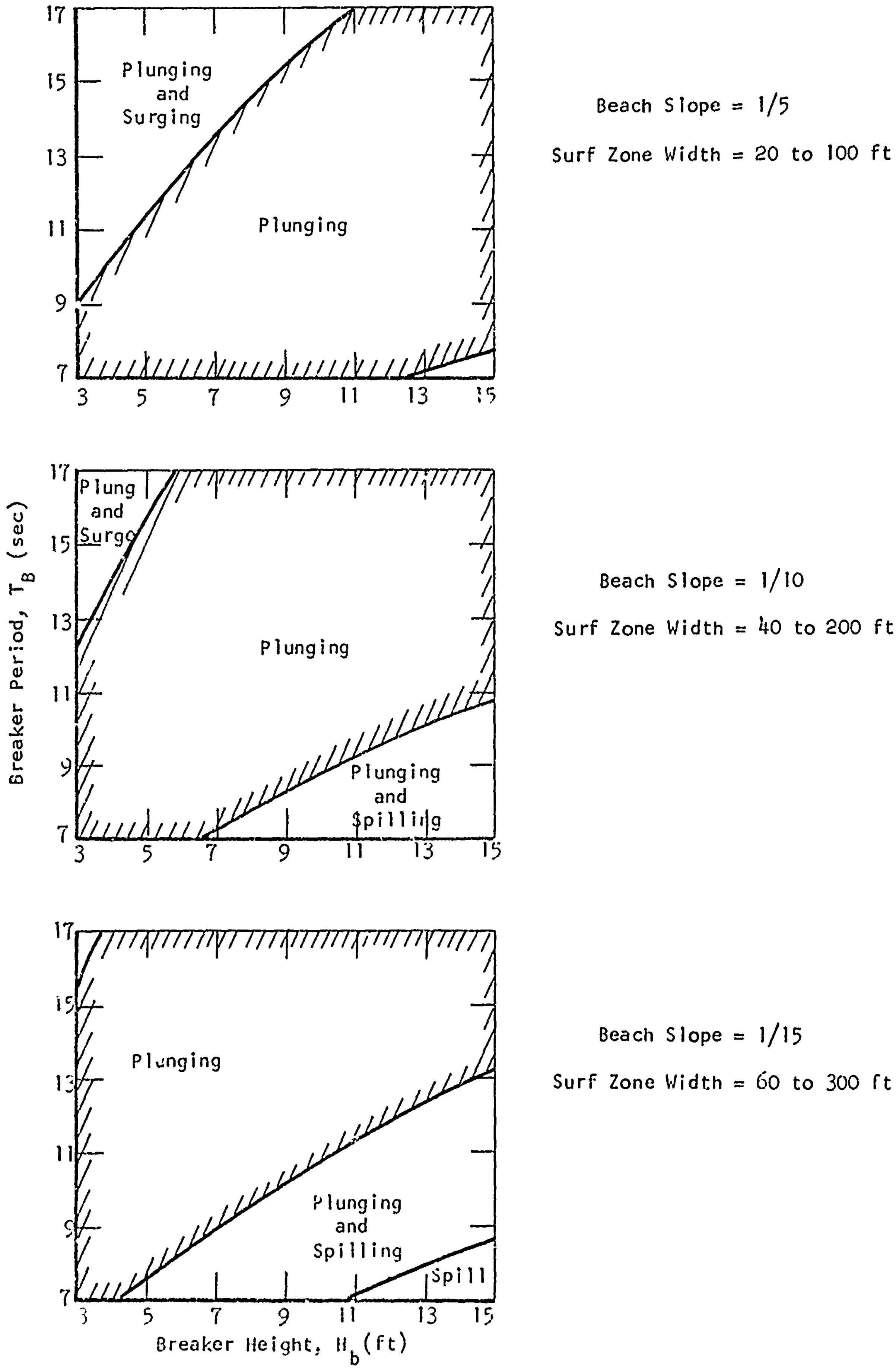


FIGURE 16. BREAKER TYPES FOR VARIOUS BEACHES, 1/5 to 1/15

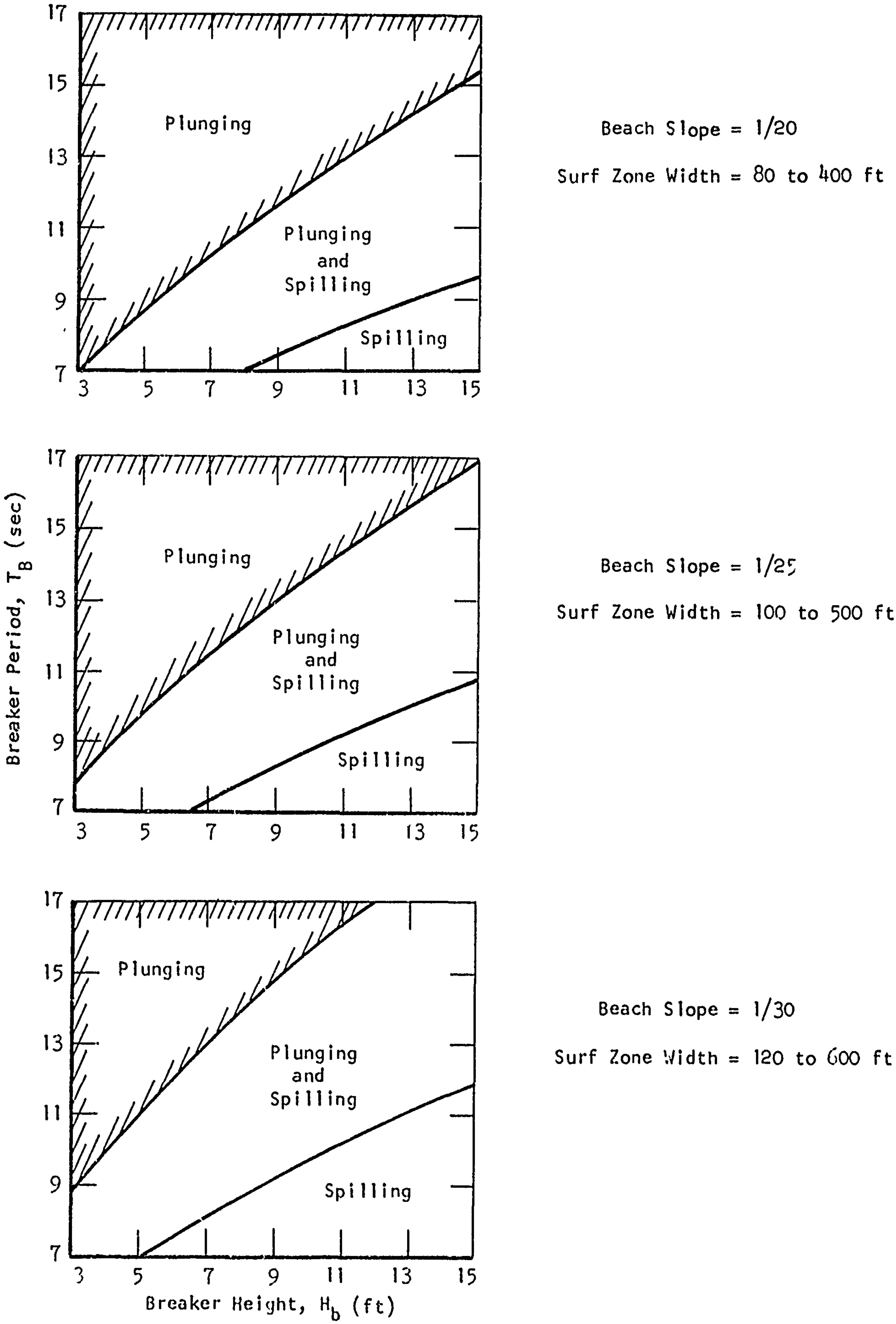


FIGURE 17. BREAKER TYPES FOR VARIOUS BEACHES, 1/20 to 1/30

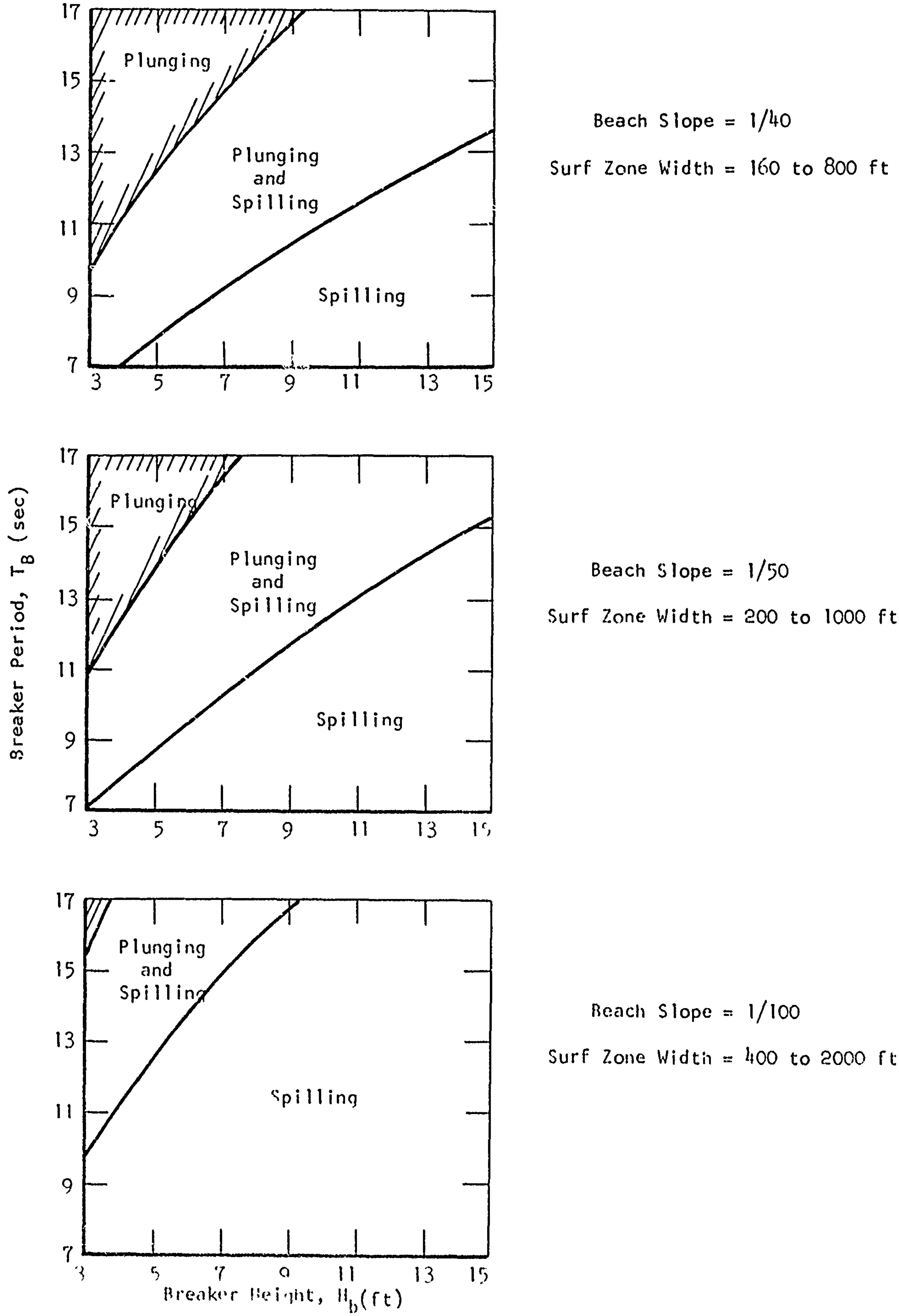


FIGURE 18. BREAKER TYPES FOR VARIOUS BEACHES, 1/40 TO 1/100

The width of the surf zone is also important in the simulation of vehicle vehavior. As the beach steepens, the nominal surf zone decreases. A nine foot breaker of 11 or 12 second period, is the midpoint of the surf state range. According to Figures 16 and 17, such a breaker would be plunging on both 1/10 and 1/20 beaches, but a vehicle would be subjected to the breakers for twice as long on the less steep beach.

It appears, on the basis of data now in hand, that the interesting range of beach slopes is narrower than in specifications 4; that is, it is from about 1/10 to 1/25 or 1/30.

B. Scales

In earlier sections, it was assumed that the full-scale vehicles would be of lengths greater than 20 feet. Considering amphibious operations in general, vehicles much in excess of 100 feet would not be common. A small-end limit on scale ratios of 1/30 would result in a reasonable size towed model in these cases. The difficulties of construction and operation of self-propelled and tracked models below a 1/10 scale are probably very great. Thus an anticipated reasonable model scale range is from 1/10 to 1/30 (resulting in models $2\frac{1}{2}$ to 5 feet in length).

The pioneering has been done on model testing in surf (Iverson and Crooke[15]). Approximate correlation with full scale was obtained for pitch motion. Scale effects will, of course, be present, since sea water will be simulated by fresh water. These, it must be hoped, will be small or explainable. As far as scale effects on the waves are concerned, the proportionately larger surface tension in the model simulation will have at least a qualitative effect.

The production of foam is apparently much enhanced by sea water. The persistance of foam or small bubbles in fresh water is apparently about 2/3 that in salt (Monaham[48]). The size of the bubbles entrained should be about the same for both model and full scale, which means that foam in the model will probably not be produced, nor will it persist in anything like the full scale manner. Qualitative observations on a model scale similar to those envisioned indicate, however, that foam of some sort is produced and the "green" part of the model breaker will be very much like full scale.

Scale effects on the propagation of the waves after breaking are probably not provable either way with the data at hand. Froude's scaling laws should apply.

C. Simulation Range

The specifications cited earlier in this section may be translated into a desirable range of model surf parameters. The upper end of H_b and T_b are determined by 1/10 scale; the lower end by 1/30 scale. The results are as follows:

Model H_b from 1 to 18 inches

Model T_b from 1 to $5\frac{1}{2}$ seconds

This range is summarized in Figure 19 where contours of $H_b/g\ T_b^2$ are shown.

The period range shown in Figure 19 is the range required to produce "regular" surf. Since $\tilde{T}_b$ is the apparent period of the breakers, this range may not be the range required to produce an irregular surf.

D. Application to Simulation in Existing Davidson Laboratory Facilities

Assuming that regular surf, two-dimensional, is required, a limit is placed on simulation capability by the long-period wavemaker capability. Using the Davidson Laboratory Tank 3 wavemaker calibration curve corrected to deep water conditions, the maximum breaker height was estimated for 1/10, 1/20, 1/30 beach slopes using the data in Figure 6 and assuming ± 8 inches of plunger stroke to be available.

The results are plotted in Figures 20, 21 and 22 for three beach slopes. Estimated breaker type is included in a fashion identical to that of Figures 16, 17 and 18.

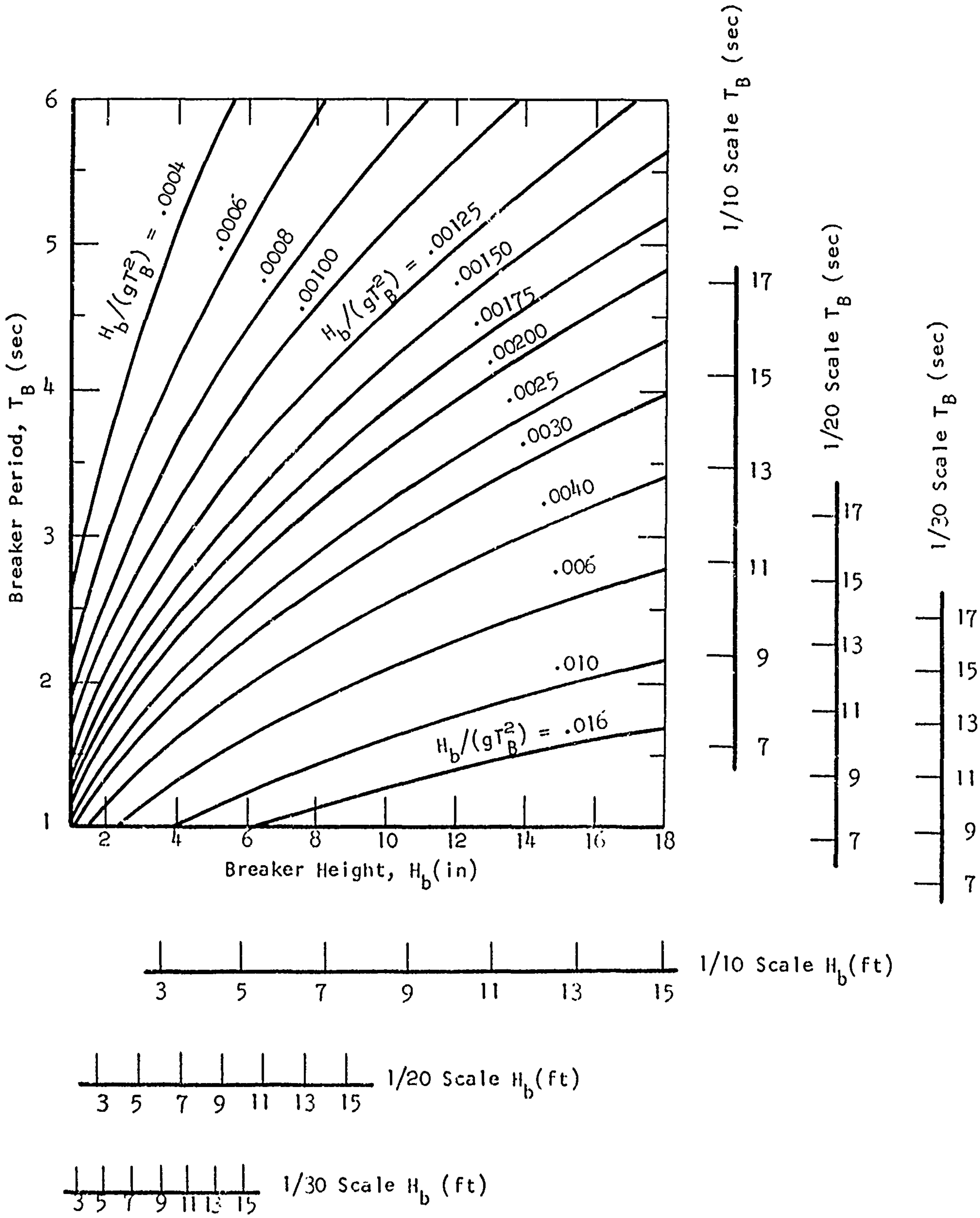


FIGURE 19. CONTOURS OF CONSTANT $H_b/(gT_B^2)$ FOR SCALE MODEL WAVES

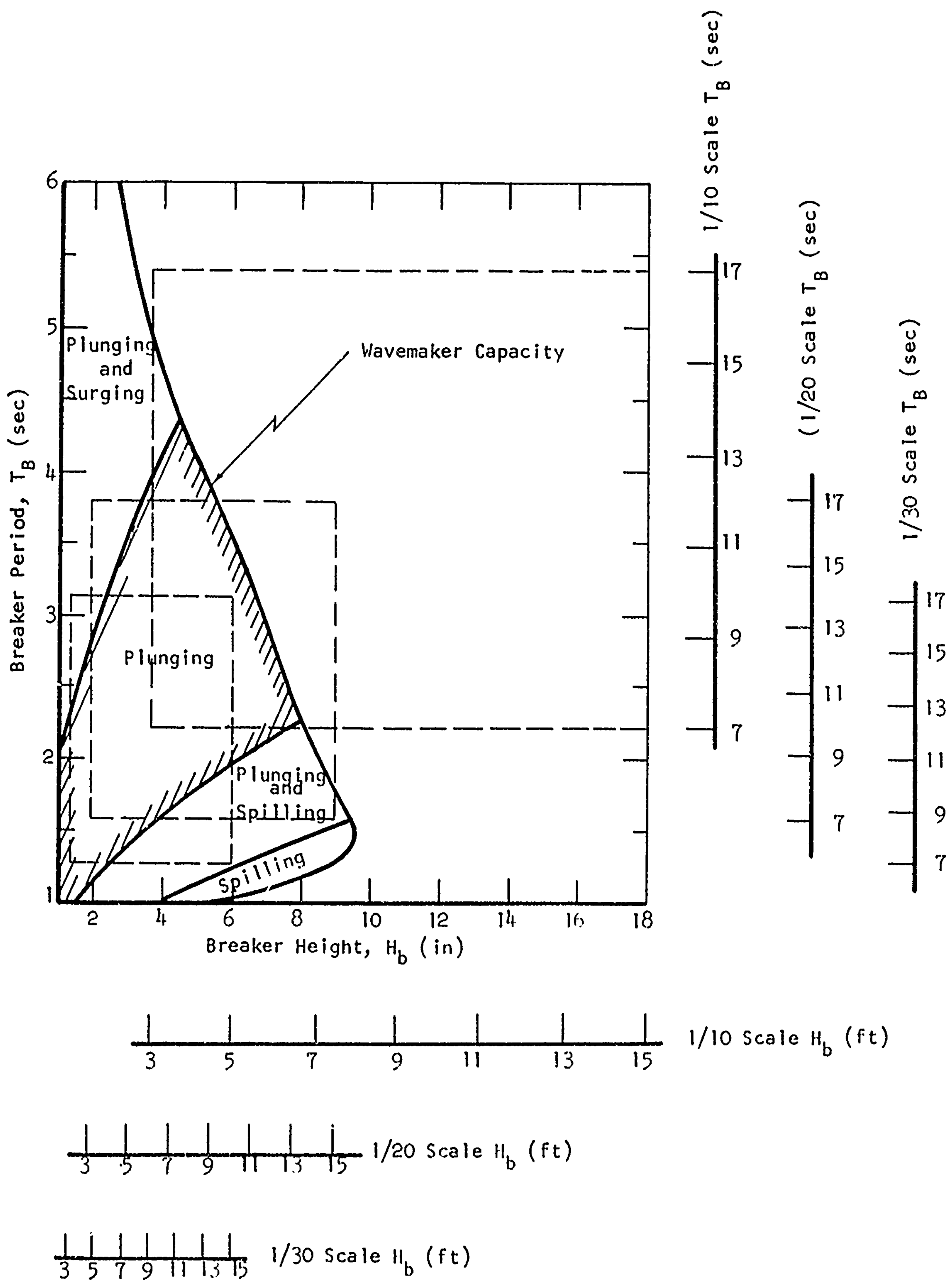


FIGURE 20. SIMULATION RANGE OF BREAKER TYPES FOR TANK 3 WAVEMAKER ON 1/10 SLOPE BEACH

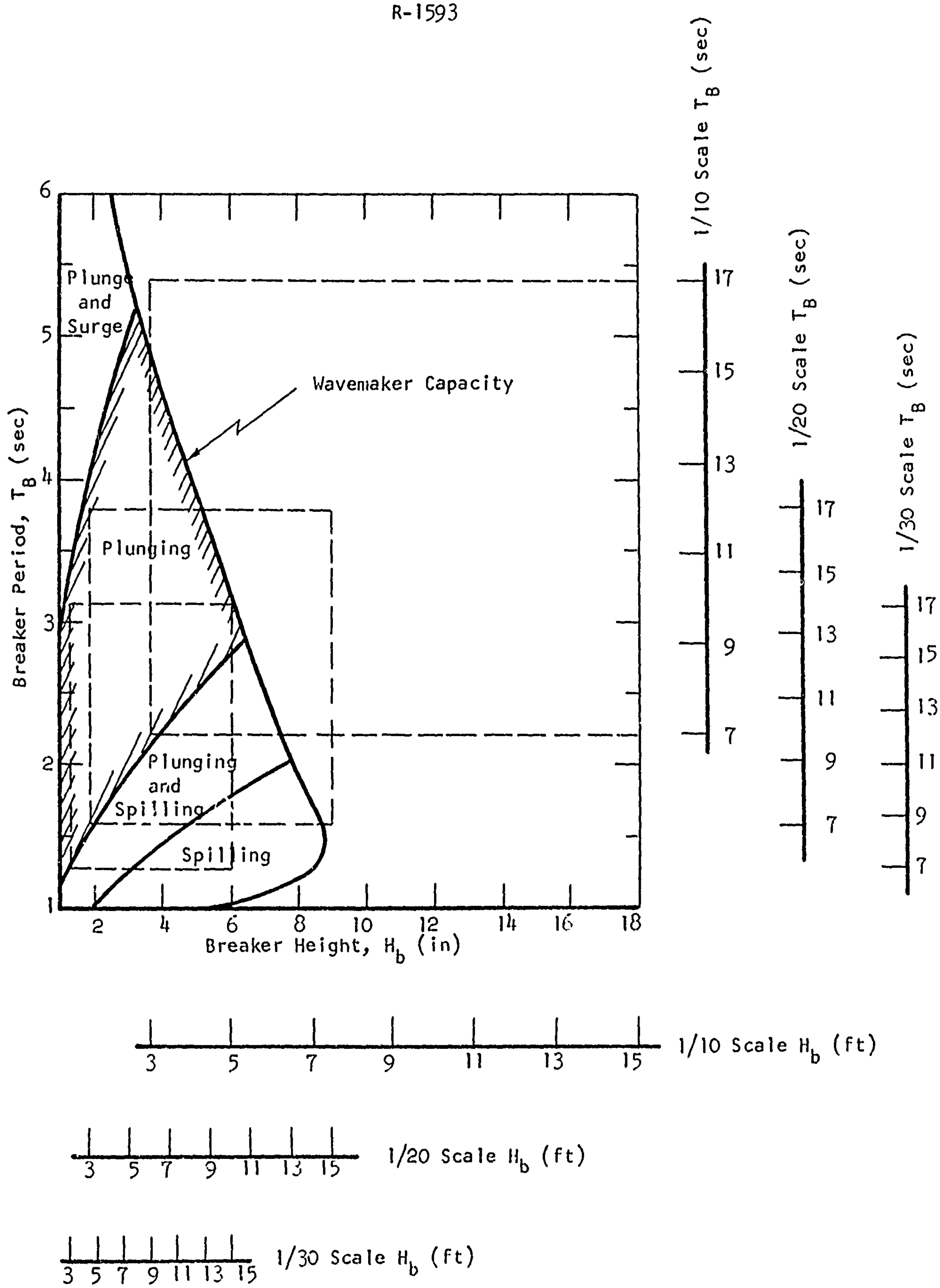


FIGURE 21. SIMULATION RANGE OF BREAKER TYPES FOR TANK 3 WAVEMAKER ON 1/20 SLOPE BEACH

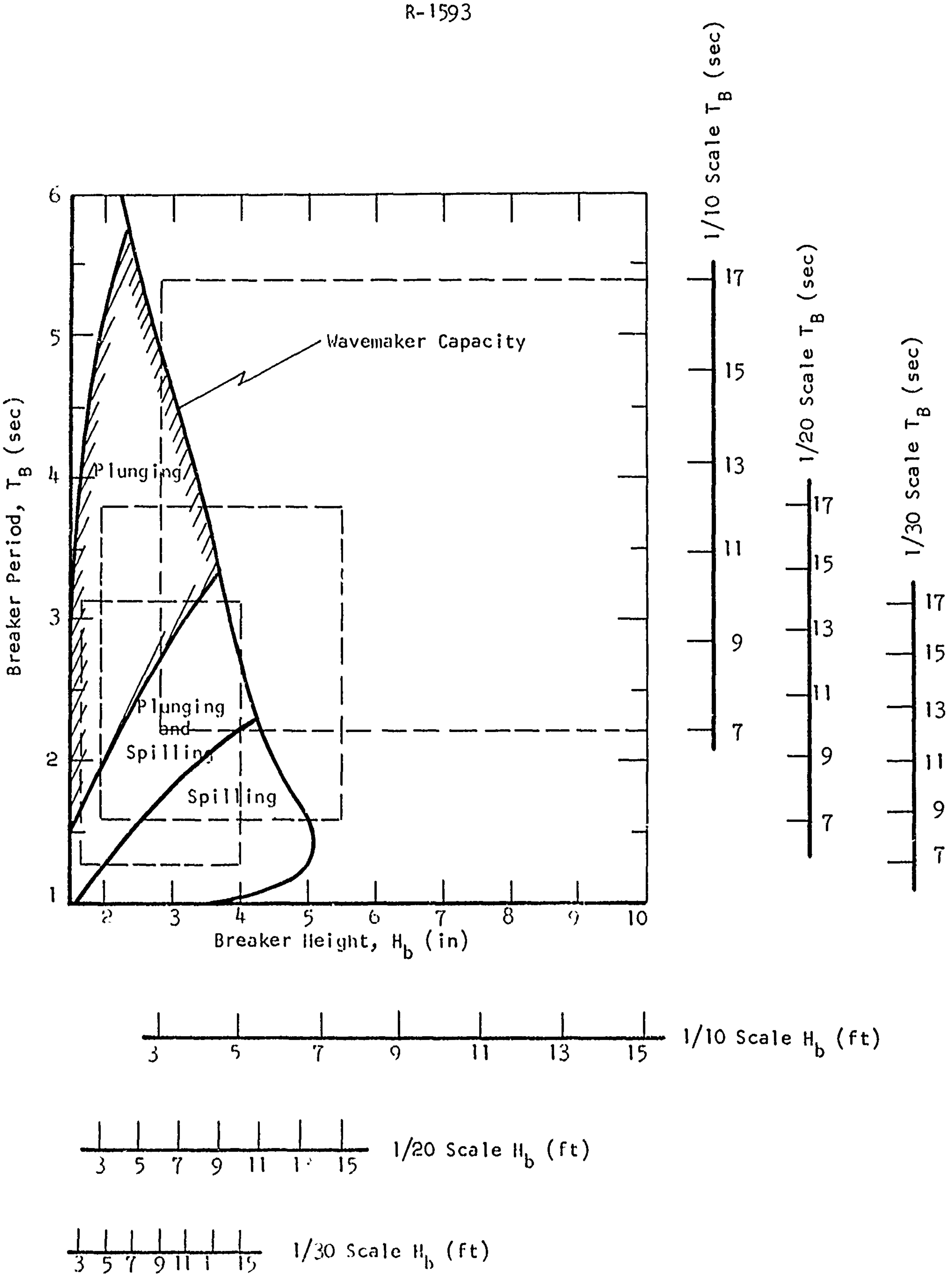


FIGURE 22. SIMULATION RANGE OF BREAKER TYPES FOR TANK 3 WAVEMAKER ON 1/30 SLOPE BEACH

It was clear from the results that an interesting range of surf characteristics might be obtained at scales around 1/20 and smaller (H_b to 8 or 9 feet). At 1/10 scale, plunging breakers less than 5 feet might be possible. This was not a very good result in the sense that scale ratios for amphibious vehicles (powered) would best be from 1/15 to 1/10. However, it appeared that initial simulation efforts could be conducted in DL Tank 3. (To obtain the full simulation range, a special wavemaker would be required.)

The production of waves which do not break all along the crest at the same time was believed important to the simulation. In order to make the waves break at an angle some refraction is necessary. Ideally, to refract the waves properly, the tank must be curved along the orthogonals to the refracted crest lines, an impossibility. An approach, which it is felt would produce small breaking angles is as follows:

1. Assume a plane beach of slope m to be rotated α_o^o within the tank (see Figure 23). The equations of the resulting rotated beach are:

$$Z = X(m\cos\alpha_o) - Y(m\sin\alpha_o)$$

Trace along Y = 0: $Z_o - Xm\cos\alpha_o$

$Y = W$: $Z_W = Xm\cos\alpha_o - Wm\sin\alpha_o$

Contours normal to tank centerplane

$$Z = \text{constant} - Ym\cos\alpha_o$$

Approximating this surface with rectangular sections spanning the tank would depend on an ability to twist each section. If a 1/20 slope is assumed and a 15^o skew angle, α_o, the drop from the high to low side of the beach is about 1-3/4 inches in 12 feet, which is not a large amount even if all twist had to be achieved in 10 or 12 feet of tank.

2. Assume for small skew angles that the waves will refract reasonably without training walls.

3. Defining α_b to be the breaker angle in water of depth $d_b = 1.3\ H_b$; and assuming that linear theory holds:

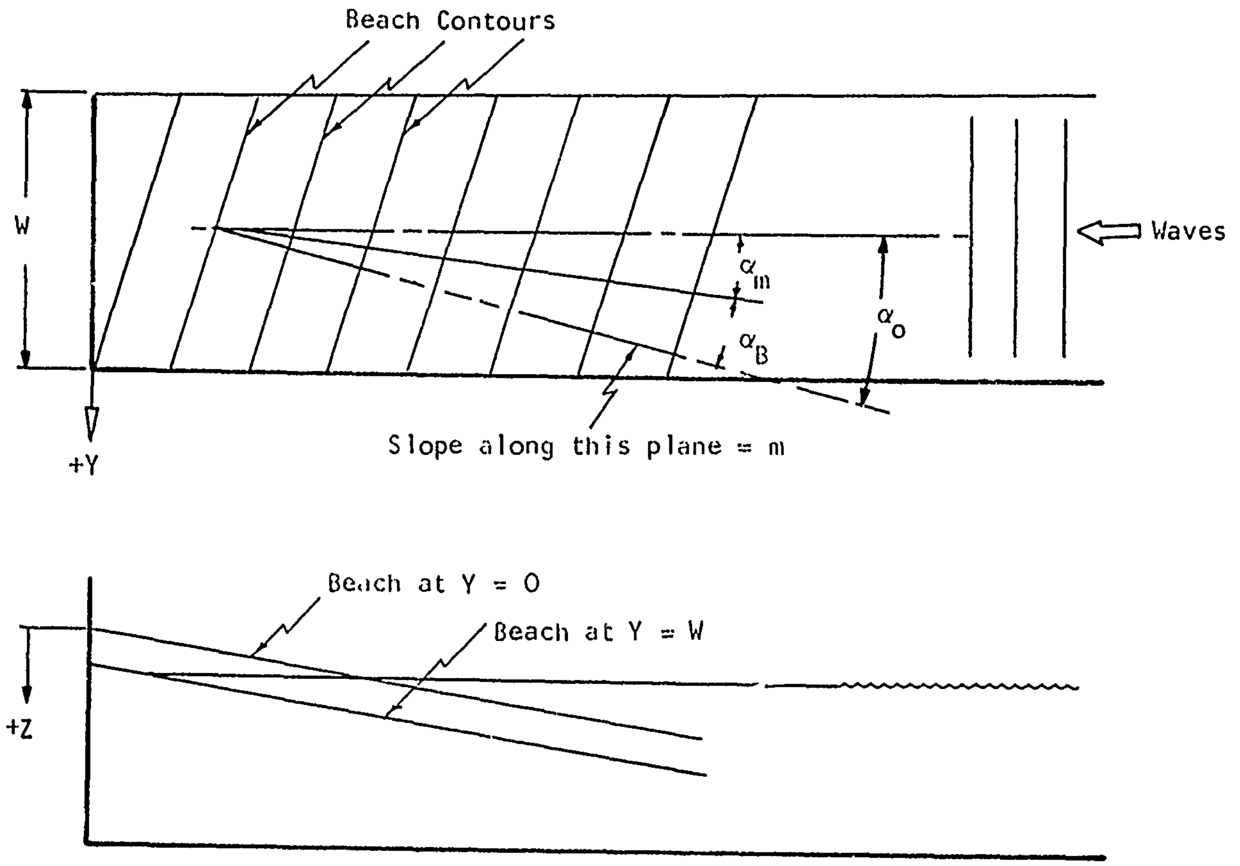


FIGURE 23. SKEWED BEACH

$$\frac{\sin \alpha_b}{\sin \alpha_o} = \frac{C_b}{C_o} = \tanh \frac{2\pi(1.3)H_b}{L_b}$$

Solution of this relationship is possible as a function of the parameter H_b/gT_b^2. By comparing Figures 19 and 21, an interesting range of H_b/gT_b^2 is:

$$.001 < \frac{H_b}{gT_b^2} < .004$$

4. Having the solutions for $\sin \alpha_b/\sin \alpha_o$ the angle α_m can be computed for given values of α_o and H_b/gT_b^2. The angle α_m is the estimated angle of the breaking crest relative to tank centerline (the nominal path of the model).

The results of such a computation are shown in Figure 24 for a 1/20 slope beach (superposed essentially on Figure 21). The computed angle of breaking was empirically proportional to α_o, not analytically. The effect of no training walls should have the effect of decreasing breaker height on the high side and increasing it on the low side of the beach. If the skew angle is small, say 5^o, the arithmetic says that waves would break at about 3^o to the tank centerline.

An important point about the design of a beach installation in a tank is the probable importance of continuing it to the tank bottom in some way. All of the generated wave energy must be transformed in order to achieve maximum breaker height. Figure 25 indicates the arrangements used by Iverson[6]. In order to do the experiments with a fixed length of beach, he made approach slopes of about 1:6. There is no indication of the effect of the transition on the waves. The approach slope of 1/6 is probably the best information available for practical design purposes.

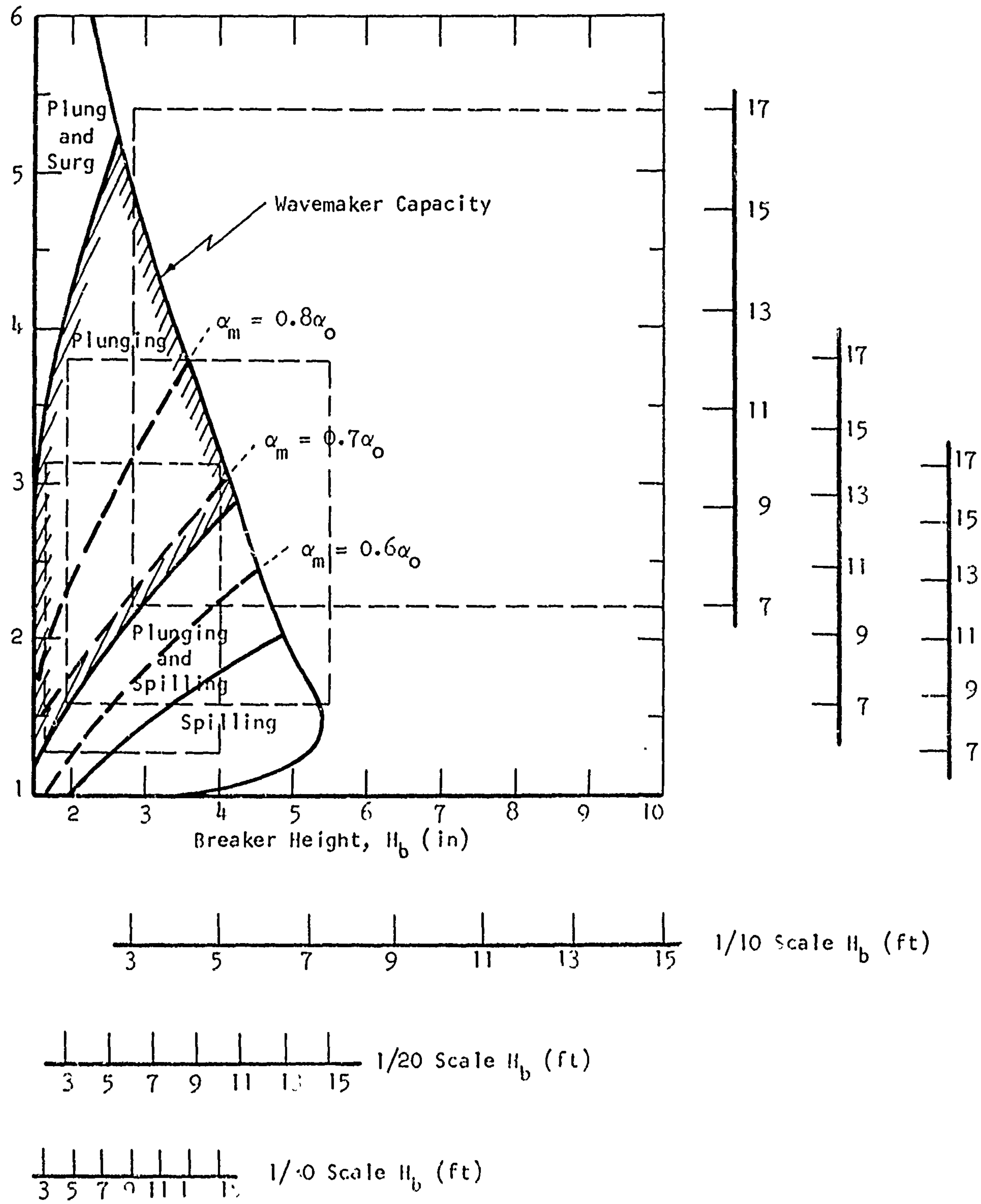
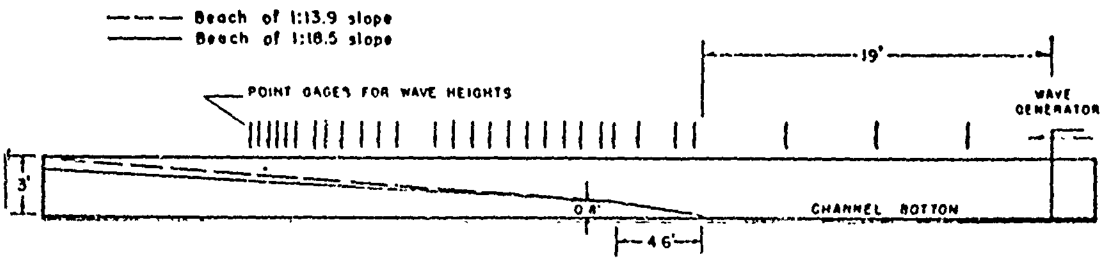
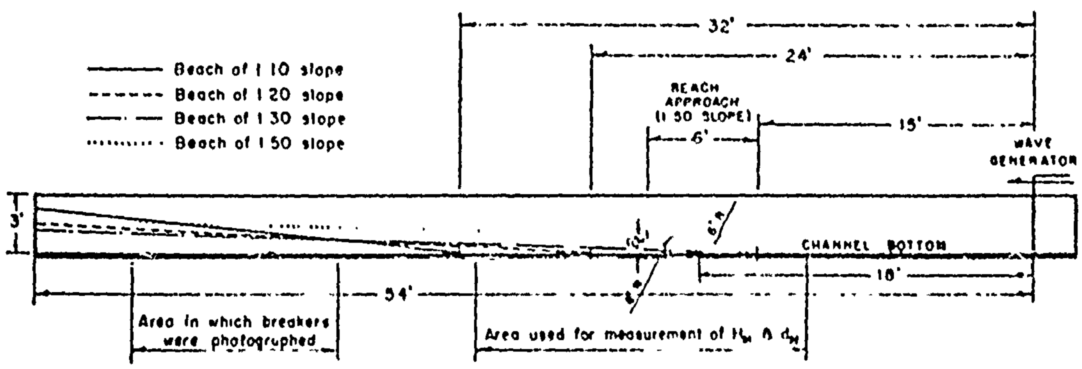


FIGURE 24. SIMULATION RANGE OF BREAKER [illegible]
FOR TANK 3 WAVEMAKER ON 1/20 SLOPE BEACH
AND SKEW ANGLES, α_o, BETWEEN 5^o AND 15^o



CHANNEL ARRANGEMENT FOR WAVE HEIGHT TRANSFORMATION STUDIES



CHANNEL ARRANGEMENT FOR BREAKER STUDIES

FIGURE 25. BEACH ARRANGEMENTS USED BY IVERSON[6]

For the Davidson Laboratory Tank 3 the wave maker limits maximum breaker height (Figures 20, 21, 22), and thus the surf zone. Consequently, for a trial beach installation the surf zone was estimated to start in one-foot of water. A reasonably economical initial beach design thus involves a straight beach of any given slope extending to a two-foot depth, then a transition to the bottom on a 1/6 slope. The run-up area will be important in some cases. No more than a six-inch rise above the waterline seemed necessary for the initial Tank 3 installation.

V. SUMMARY AND CONCLUSIONS TO PART ONE

For vehicle motion and control purposes, the state of surf technology appears to be about in the same state as deep water wave technology was 20 years ago. The reason is the formidable analytical difficulties inherent. There is no recognized stochastic approach to surf similar to that available for deep water waves. Surf is specified by significant breaker height and sometimes an average apparent breaker period and general type. Data on short term variability of breaker height, apparent period, breaking depth and a host of other descriptive parameters, is nearly totally absent because, for the most part, those who study surf are interested in beach processes which take place at a relatively slower rate.

The objective of this part of the study has been to summarize for engineering purposes what is known and/or conventionally assumed, what may be of importance to vehicle control and motion, and whether or not simulation is feasible.

The essential results are contained in Section IV where numerical facility requirements are outlined and applied to existing Davidson Laboratory facilities.

The broad conclusion from this part of the study was that simulation to reasonable model scales might be anticipated. It should be emphasized that the pioneering work was done many years ago and on a very small scale. The questions remaining about simulation are related more to adequacy precision and economy than to feasibility.

An exploratory investigation of the techniques and problems in producing model surf was recommended.

PART TWO
LABORATORY EXPERIMENTS

I. INTRODUCTION

Preliminary tests on techniques and problems in the production of model surf were carried out in Tank 3 of the Davidson Laboratory from 27 July through 3 August 1970.

The general objectives were as follows:

o To learn how to install and adjust the beach--and assess qualitatively the breaking waves produced.

o Make measurements so as to allow comparison of periodic surf performance with prior estimates and develop a calibration technique.

o Obtain preliminary measurements of irregular surf for quantitative comparison with full-scale data and for calibration purposes.

o Produce motion pictures and stills of model surf for qualitative comparison with full scale.

o Investigate beach slew as a means of causing waves to break at an angle.

II. BEACH SLOPED AT 1:10

A. Geometry and Initial Installation

The experiments were started with the nominal 1/10 beach because it was the shortest installation and because the results of Part I indicated that the best plunging waves might be obtained at this slope. Figure 26 shows the location and nominal geometry. The overall arrangement was such that the 1/8 transition is constant for other beach slopes. Figure 27 is a sketch of the basic construction. The installation was made up of false bottom sections with the sides filled out by additional pieces of 3/4-inch plywood. Aluminum box-beam "planking" (5" x 1-3/4") was used in the main part of the beach and joined to adjacent false bottom sections with bolted up channel sections.

Fixtures were constructed to hold the beach false bottom and the sides of the planked area down on the 2-inch pipe supports athwart the tank. Six 2 x 4 struts were used to force the transition section false bottoms down into (it was hoped) an elastic curve. Struts to hold down the leading edge on the bottom were also installed. In general, the initial mechanical details were specified with the utmost economy in mind.

B. Observations and Mechanical Modifications

First trials at producing "regular" surf produced breakers about one-fourth the height expected in center and none at all along the tank sides. In the breaker area the total gap between the outermost planks and tank sides was about 3 inches. It was obvious that a very large leakage flow was taking place there. Accordingly, 3/4-inch planks were fitted and clamped along each edge of the beach to cover as much of the gap as possible.

Qualitatively, the results of these modifications were very gratifying. The breaker height doubled and the crest line was more or less straight across the tank. The type of breaker was about as expected,

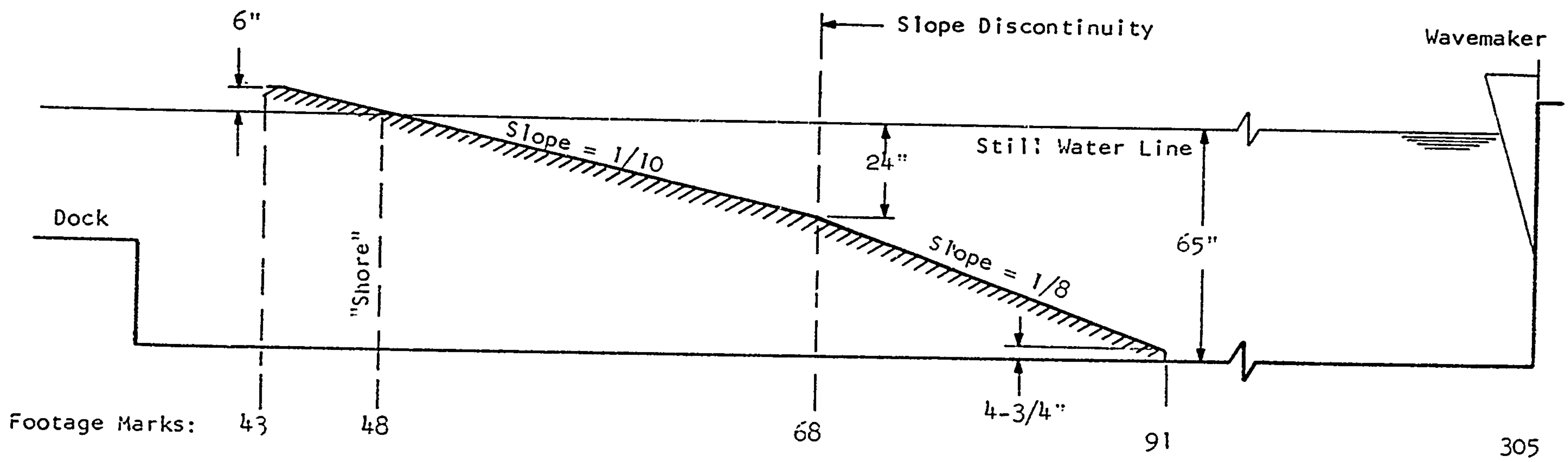


FIGURE 26. NOMINAL LOCATION OF 1/10 SLOPED BEACH IN TANK 3

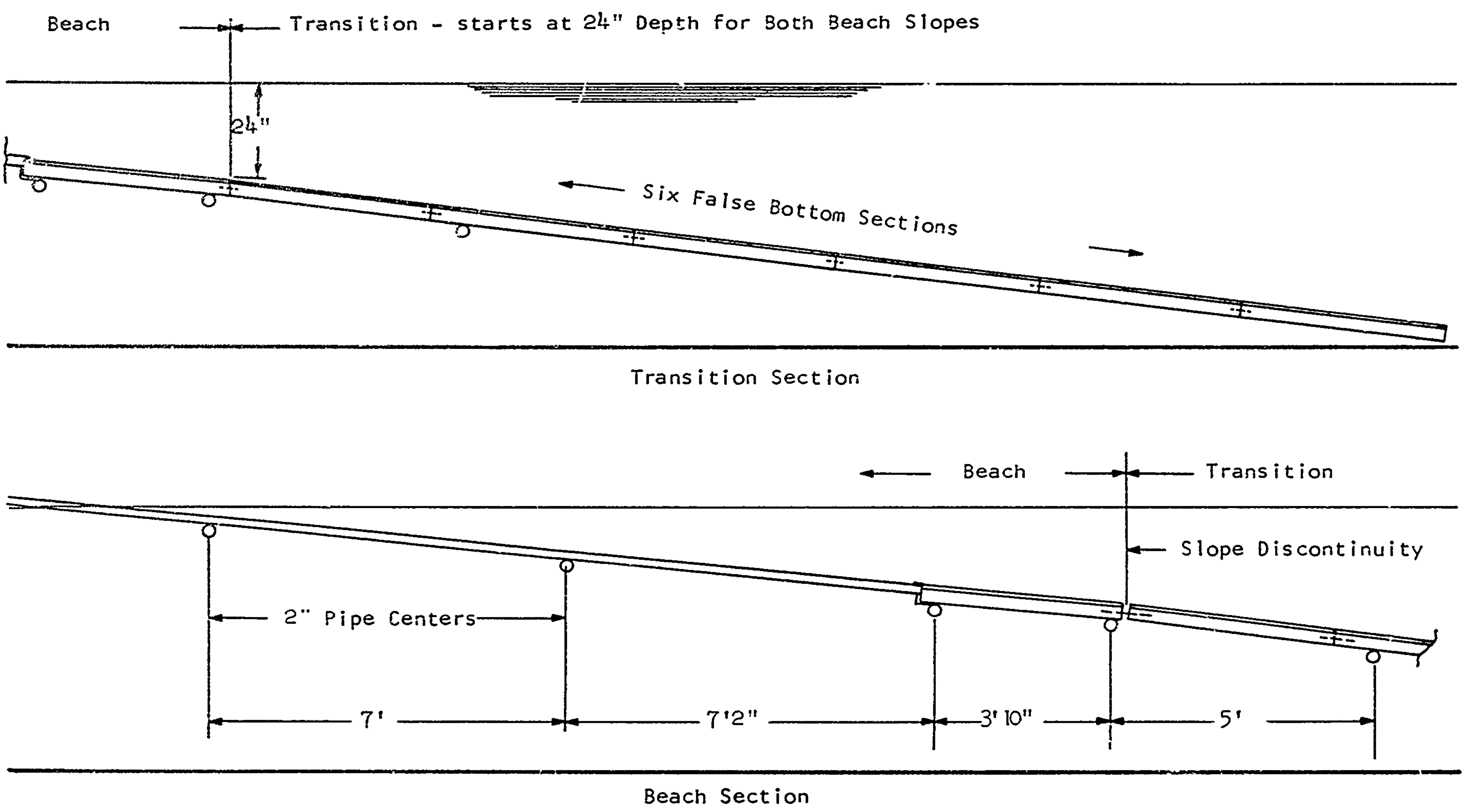


FIGURE 27. BASIC BEACH CONSTRUCTION SCHEMATIC
SHOWN HERE IS THE 1/10 BEACH; 1/20 BEACH HAS
THE SAME TRANSITION, BUT THE BEACH PORTION IS 25 FT LONGER.

though the height remained low and varied over the width of the tank with the lowest point in the center. Deflections in the aluminum plank part of the beach appeared to be about 1/4 inch. Some deflections of portions of unsupported 3/4-inch plywood were very much greater, as were downward deflections of the transition. There was indication of reflection in the incident wave train.

Soundings of the installed configuration were taken and appear plotted in Figure 28. The largest portion of the transition section had a slope of about 1/3 instead of the intended 1/8 and substantial twist. Even if the transition sections remained in contact with the struts holding them down, the 1/3 slope was a possible explanation for the observed reflection and the twist was a possible source of the low breaker height along the tank center.

Accordingly, the transition was forced back into its nominal 1/8 slope by attaching the six hold-down struts to the false bottom joints with eyebolts. Stiffening struts were clamped to the tank sides. Occasion was also taken to plug a one-inch gap across the tank at the beach slope discontinuity.

These changes had the desired effect: the breaking crest was more uniform and a little higher. It was noted that the uppermost section in the transition section was still pumping up and down about an inch due to some slack hinge bolts and lack of positive support of the upper end. A set of auxiliary struts were made up to correct this situation.

Upon completion, more waves were run. After about two minutes of breaking five-inch waves, the crest line angled, distorted and lowered in the center at about the same time as pounding noises came from the beach. Examination showed that two of the strut attachments had failed.

The work to this point had consumed half the budgeted facility time. The extent of the "surf zone" on the 1/10 beach had been observed to be less than expected, and probably not appropriate for five-foot models. It was decided to cease operations on the 1/10 beach and to assemble the 1/20 beach while reworking the supports for the transition section.

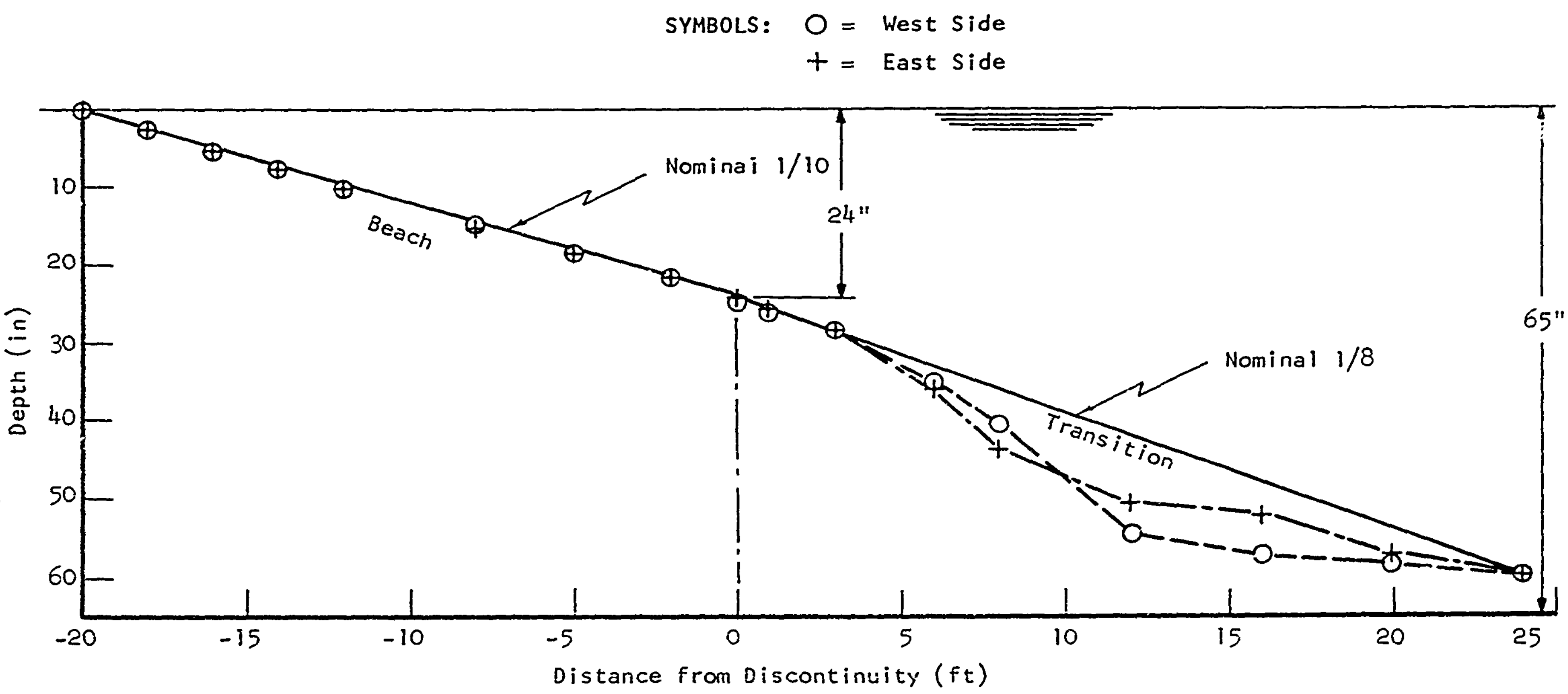


FIGURE 28. SOUNDINGS ON NOMINAL 1/10 BEACH

C. Summary: 1:10 Beach

Several qualitative conclusions may be drawn from these mechanical misfortunes:

- Sealing and leakage area or porosity of beach surface of about 3% completely fouled up the breaker. The leakage area finally achieved was probably about 1/4%. The corresponding figure for the transition section was probably about 1%. Even these figures may be too high for best test results.

- Dynamic beach deflection also fouls up breakers. There is no good measure of the influence; it is felt that spans of unsupported 3/4-inch plywood should not exceed two feet for 5-inch breakers. Overall deflection under load should not be allowed to be greater than 1/4-inch in 12-foot spans.

- Precision in installing the beach is important. Flatness is necessary to about ± 3/16-inch.

- The transition slope of 1/8 seemed not to produce anything obviously unusual at the discontinuity.

- Tension-compression struts or other supports must be provided at at least four-foot spacing on sections made up of false bottoms for 5-inch breakers.

- Quantitative indications of the size of the loads actually experienced are tenuous. A backward computation for the required unit load to generate an observed 1/2-inch panel deflection, puts the loading at approximately 40 lb/ft^2 for 5-inch breakers.

- Indirectly, it appears that the slewing method proposed, may be able to cause waves to break at an angle. Such a result was obtained when one side of the transition broke and sank down.

III. BEACH SLOPED AT 1:20, REGULAR SURF

A. Geometry and Construction

The transition supports were reworked, greatly improving the rigidity of the false bottom joints. Additional struts and clamps were installed to marry the beach more closely to the tank structure. These changes seemed to cure the gross structural problems of the transition.

The 1/20 beach was made by adjusting the slope of the 1/10 beach and adding another false bottom and set of aluminum planks (see Figure 29). The upper end of the beach rested on the permanent Tank 3 wave beach and was weighted down. As with the 1/10 beach, every point which could be held down mechanically, was, and the side gaps were covered with clamped on planks.

Soundings of this beach were taken and are shown in Figure 30. The maximum deviation from nominal was one-inch too low because the two-inch pipe in the transition section was incorrectly set. No corrective action was taken. The majority of the other soundings are within 1/4-inch of nominal.

B. Test Methods and Instrumentation

Motion pictures at 64 frames/sec were obtained of the first set of wave runs. Included were four "regular" waves and three segments of a particular irregular wave program (to be discussed in the next section). A "grid" consisting of 12 rods, was mounted on the tank centerline as indicated in Figure 29. The rods were spaced at one-foot intervals in the direction of wave travel and had alternately colored two-inch bands on either sides of the still waterline.

Three wave probes were utilized in the measurement program following the first set of runs. Probe #1 was a 24-inch resistance wire located near the East (right, looking at the beach from the water) side of the tank at the 250 foot measuring station. Probes #2 and 3 were mounted with

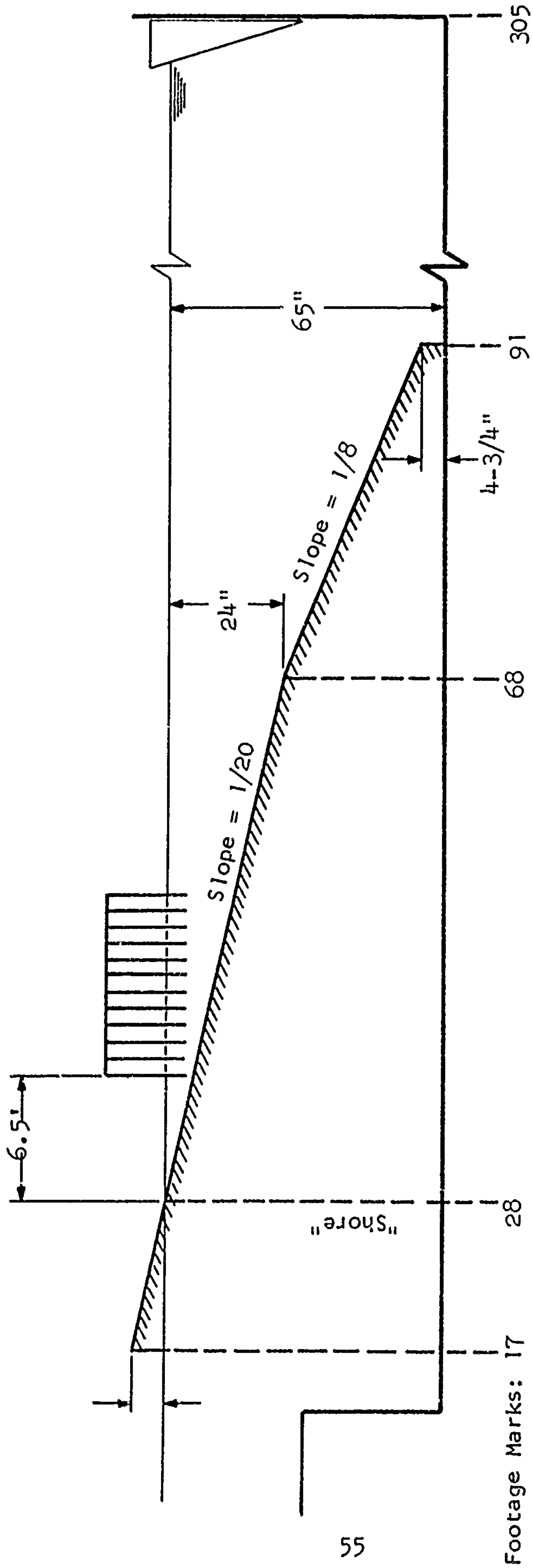


FIGURE 29. NOMINAL LOCATION OF 1/20 SLOPED BEACH IN TANK 3

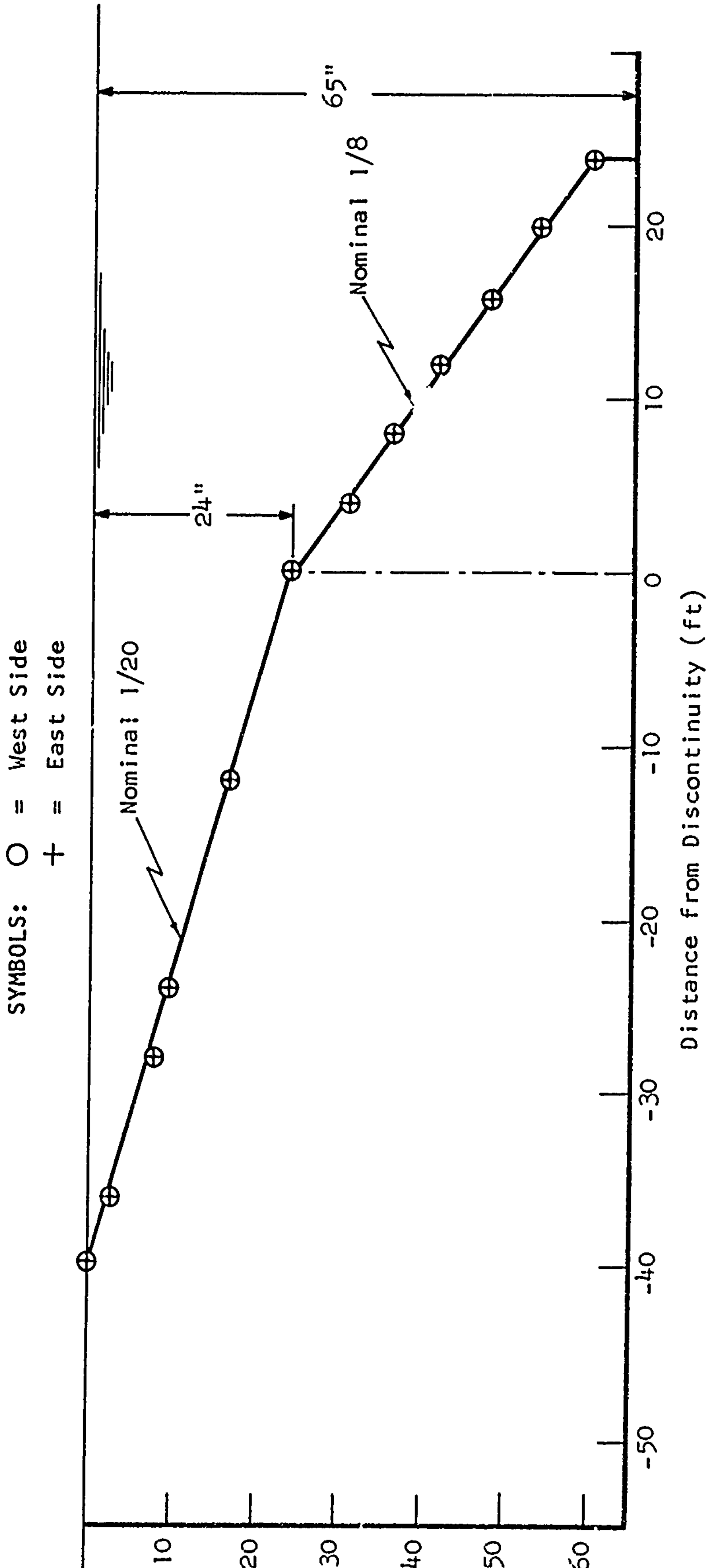


FIGURE 30. SOUNDINGS ON NOMINAL 1/20 BEACH

calibrators on small carriages so that they could be easily positioned along the tank centerline. Probe #2 was a 15-inch resistance type with active bridge. It was set and balanced at 5-inch immersion and calibrated over ± 4-inches in 15 inches water depth. As expected, it was somewhat non-linear in the trough direction. Check calibrations of this probe were made over ± 1-inch range in 7-inch and 10-inch water depths (where records were taken), with no apparent effect of the beach on sensitivity. Probe #3 was a capacitance wire assembled for the occasion. It was used for measurements in 2-inch to 7-inch water depths. Its calibration was also non-linear after a period of being half immersed--a common problem with this type of probe. All three measurements were recorded on an oscillograph. Each record was started before the wave machine was turned on.

A breaking wave changes height as it travels. The quantity most desired was the breaker height, H_b. By definition, H_b is the difference in height between the trough and the crest at the position on the beach where the crest first becomes near vertical and before curl-over or actual breaking occurs. The test technique involved locating Probe #3 at the breaker point by visual estimate. While records were taken, notes were made of the type of breaker and the condition of the crest line (bent, etc.). The still water depth of water at which the records were taken was noted as the breaker depth, d_b.

Fourteen cases of periodic surf were recorded. The period was varied from 1.5 to 4.5 sec for two wavemaker strokes (± 8.2 and ± 5.6 inches), including repeats of conditions for which motion pictures were obtained. Figure 3 is a picture of "typical" plunging surf obtained.

C. Results and Analysis

Figure 31 indicates the observed average breaker heights and periods in the same form as in Figure 21. Included is the previously estimated maximum capacity line. It is clear that maximum periodic breaker heights are about an inch lower than expected at all periods of interest. More discussion on this and upon the mean lines through the data will be advanced subsequently.

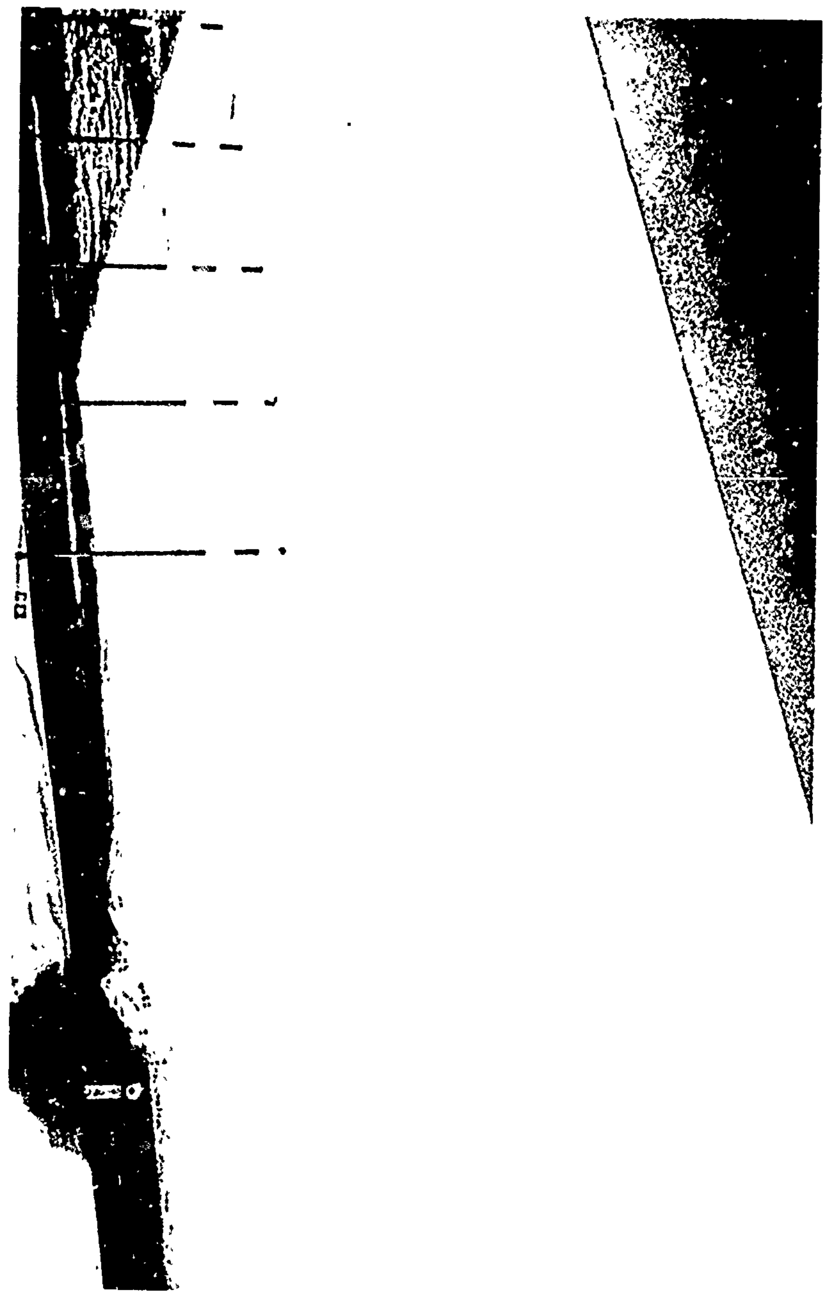


FIGURE 31. "TYPICAL" PLUNGING SURF OBTAINED ON 1/20 BEACH

The first wave test run ($T = 4.5$ sec and stroke = 8.2") was extra long (7 minutes) so that long term variation in breaker height could be observed. No variation greater than that observable in the first two minutes was seen. The remaining runs were one to two minutes in length, depending on period. The breaker height and position varied at least ± 10% from the average. In some runs the variation was much larger and in these cases the plot shows two points with a double arrow between to indicate the range of variation. Visual estimates made during the motion picture session and later from the film, are also included in Figure 32. These estimates tend to be higher than those measured by instruments.

In the worst case ($T = 2.5$ sec) the breakers were beating. At this same period and lower wave maker stroke, crest bending was observed. In the case of $T = 1.5$ sec and stroke = 5.6 inches, crest bending and asymmetrical breaking (about the tank centerline) was observed. Both these periods are close to the two lowest tank free surface modes (deep water). It is not beyond belief that lateral tank modes may be excited and account for some of the variability. The present data are not sufficiently extensive and were not taken carefully enough to allow more than speculation on the sources of variability.

Some comparisons of the observed breakers with other data are possible. Figure 33 is a summary of the classifications of breaker type which were noted during the test. The spots are "plotted" to a base of Galvin's inshore parameter as in Figure 4. The ranges of breaker type noted are also from Galvin. Correlation of breaker type with Galvin's data is rather good as these things go. (The visual classification of breakers in model scale time while looking at them from above, is a rather subjective thing.) For present purposes, the bounds on breaker type presented earlier, may be regarded as confirmed.

Various derived surf indices are shown in Figure 34. Normalization is by breaker height, H_b and the spots are plotted to a base of the inshore parameter. The expression $(Y_b - d_b)/H_b$ in Figure 34a, is the proportion of the breaker height which is above the still waterline. Agreement with Wiegel's average seems good.

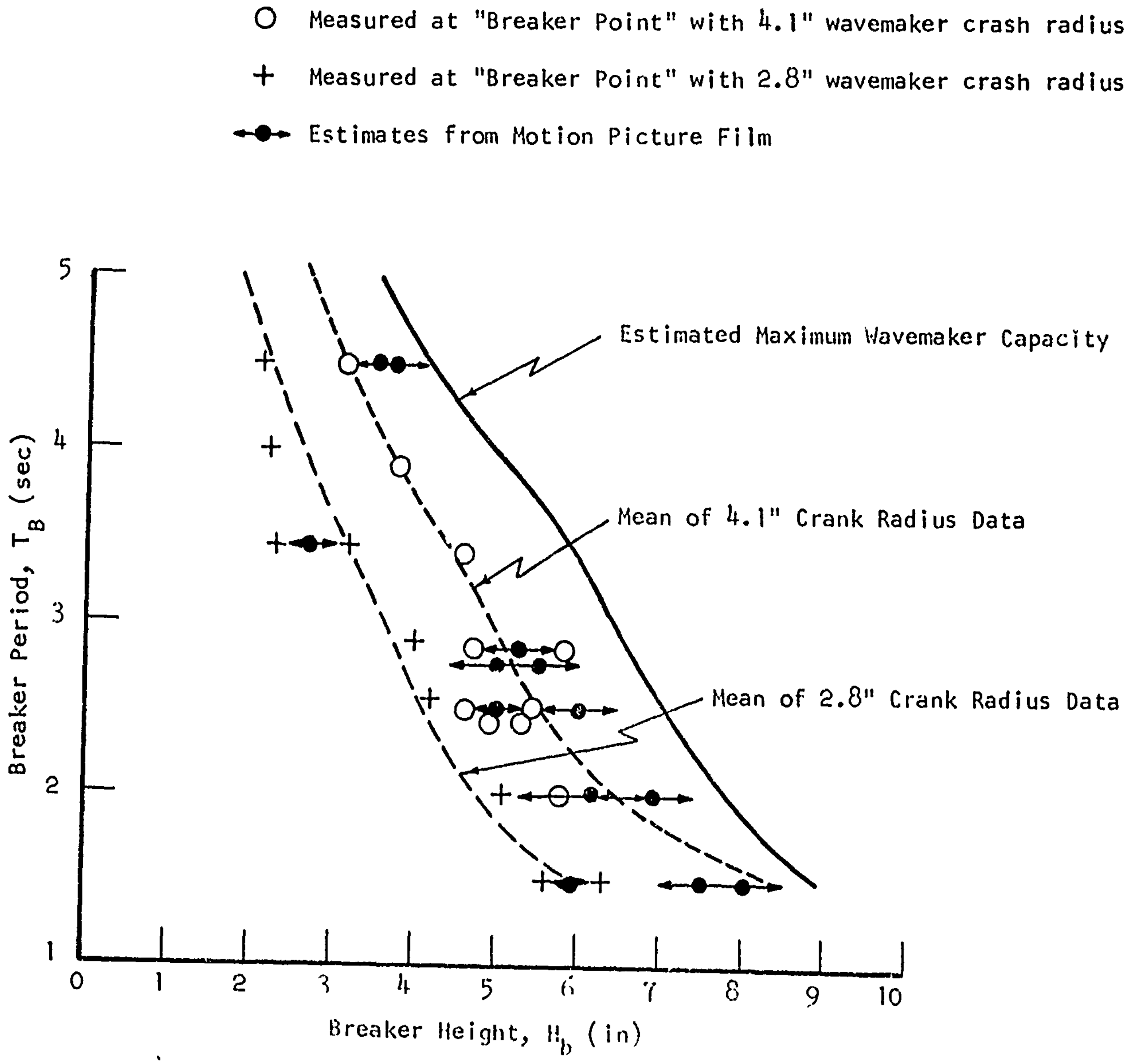


FIGURE 2. OBSERVED BREAKER HEIGHTS
IN TANK 3 WITH 1/20 BEACH

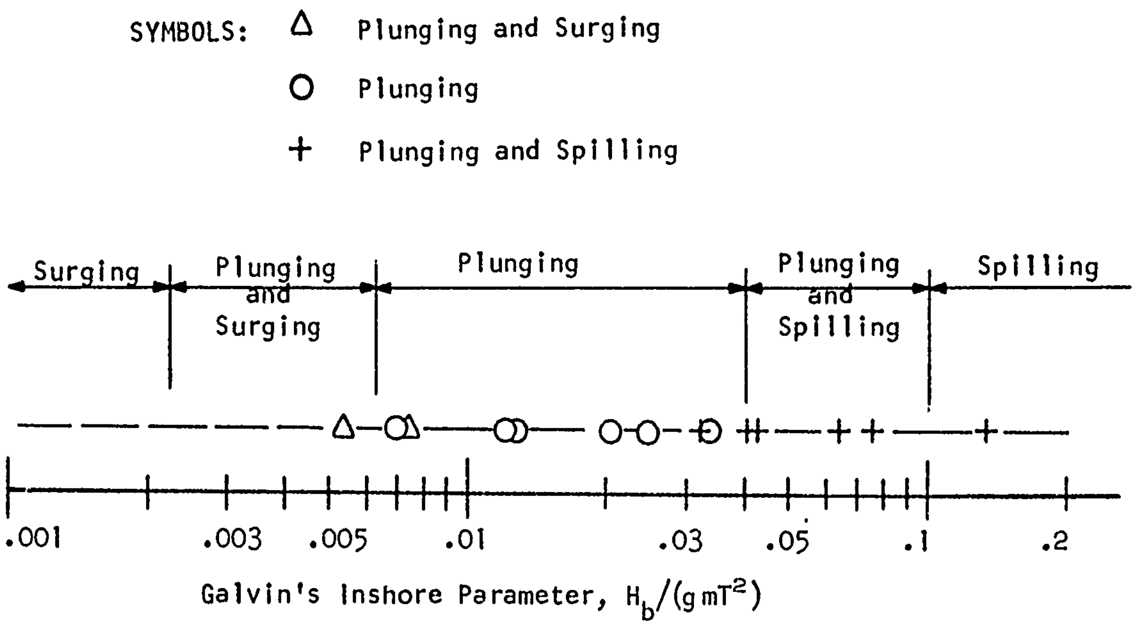


FIGURE 33. COMPARISON OF OBSERVED BREAKERS IN TANK 3 ON 1/20 BEACH WITH GALVIN'S INSHORE PARAMETER

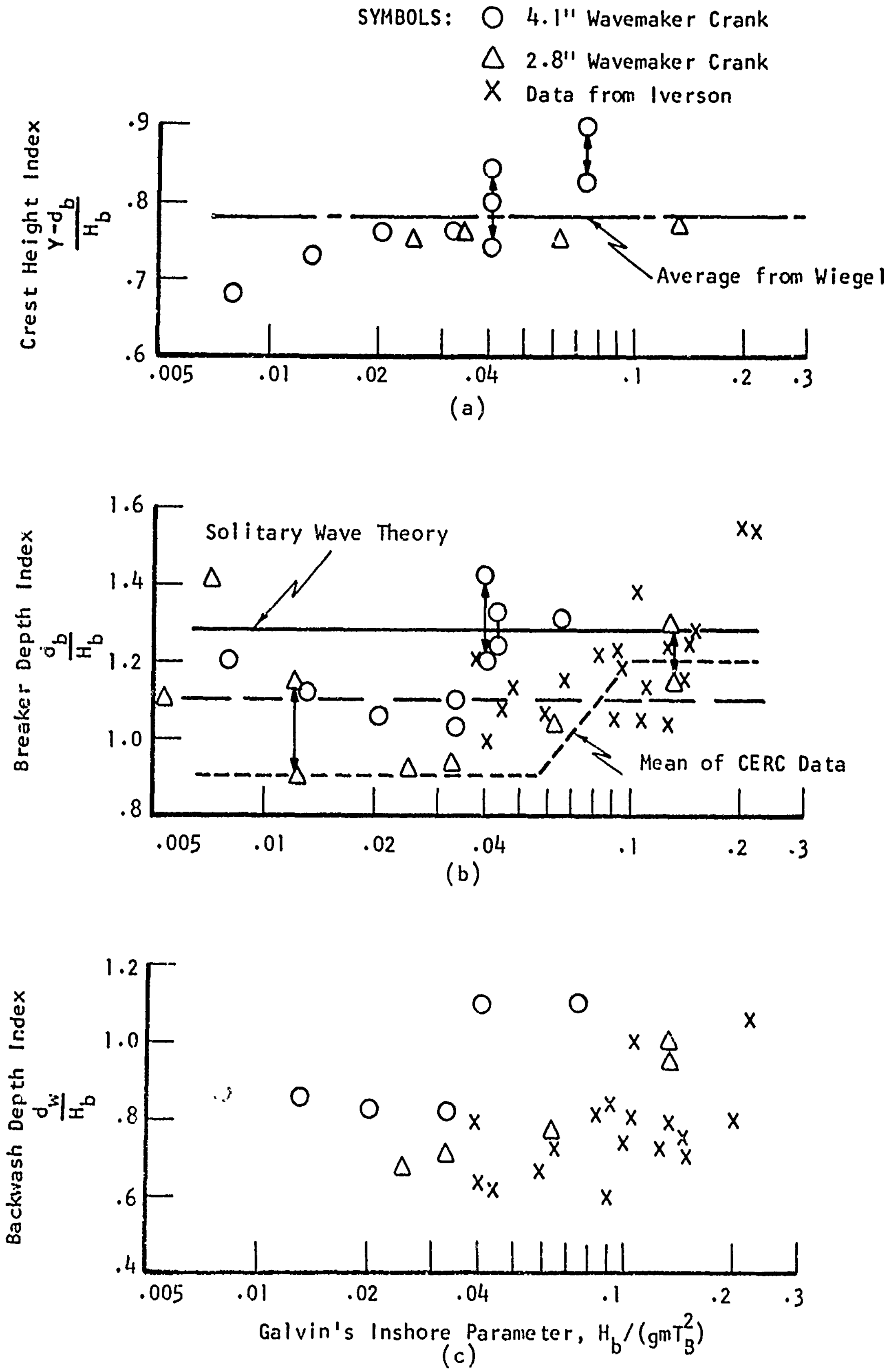


FIGURE 34. COMPARISON OF MODEL SURF DATA ON 1/20 BEACH WITH VARIOUS INDICES.

The breaker depth index d_b/H_b is presented in Figure 34b, along with data from Galvin[52] and Hydrographic Office Publication 234 (Reference 19). Galvin indicates that CERC data shows d_b/H_b to be 0.9 for plunging waves; and 1.2 for spilling. The present good plunging data ($H_b/gmT^2 < 0.03$) tends to agree more with CERC than with the old Hydrographic Office value of 1.28. In any event, the present results compare as well with the various criteria as other investigator's data. For estimating purposes, for the D.L. 1/20 beach, Figure 29, a mean breaker depth index of 1.1 may be assumed (1.1 ± .2 covers all the data). The expression d_w/H_b of Figure 34c is the backwash depth. Present data is compared with that of Iverson for a 1/20 beach.

Generally, the types and proportions of "periodic" breakers which were produced, agree with the data of others. Visual observations and motion pictures provide additional subjective confirmation.

The main disappointment with the results has to do with the lower than predicted maximum breaker heights (see Figure 32). The method of prediction involved three relations:

1. Wavemaker calibration curve (wave height/wave maker stroke vs T).

2. The analytical relations between "deep water" and the 66-inch tank depth.

3. The "breaker index" H_b/H_o vs H_o/T^2 for 1/20 beach. (H_o is "deep water" wave).

Figure 35 is a comparison between the wavemaker calibration curve used to generate Figure 21 and a curve derived from the present test program at a point near the wavemaker. The differences between the two curves, however, are in the wrong direction to explain a deficiency in breaker height. (Higher wave heights than expected were observed.) The corrections for finite depth (Item 2) are relatively small and are tabulated by Wiegel.[34]

Figure 36 shows the observed breaker index (H_b/H_o) on a base of H_o/T^2 as well as the indices used in the earlier predictions. This data explains the deficiency in breaker height. The present data is well below that of Wiegel and the Hydrographic Office.

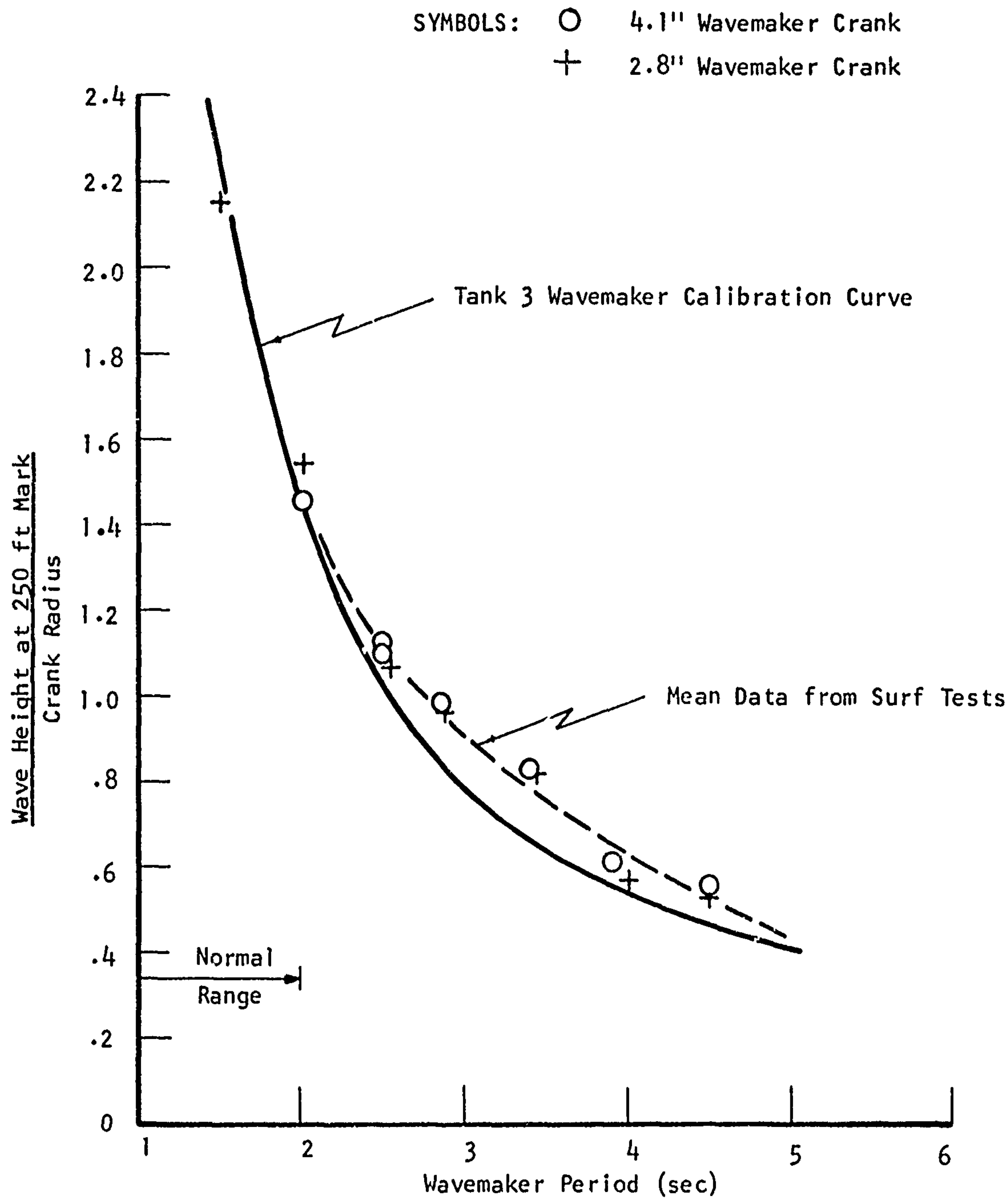


FIGURE 35. OFF-RANGE CALIBRATION OF TANK 3 WAVEMAKER

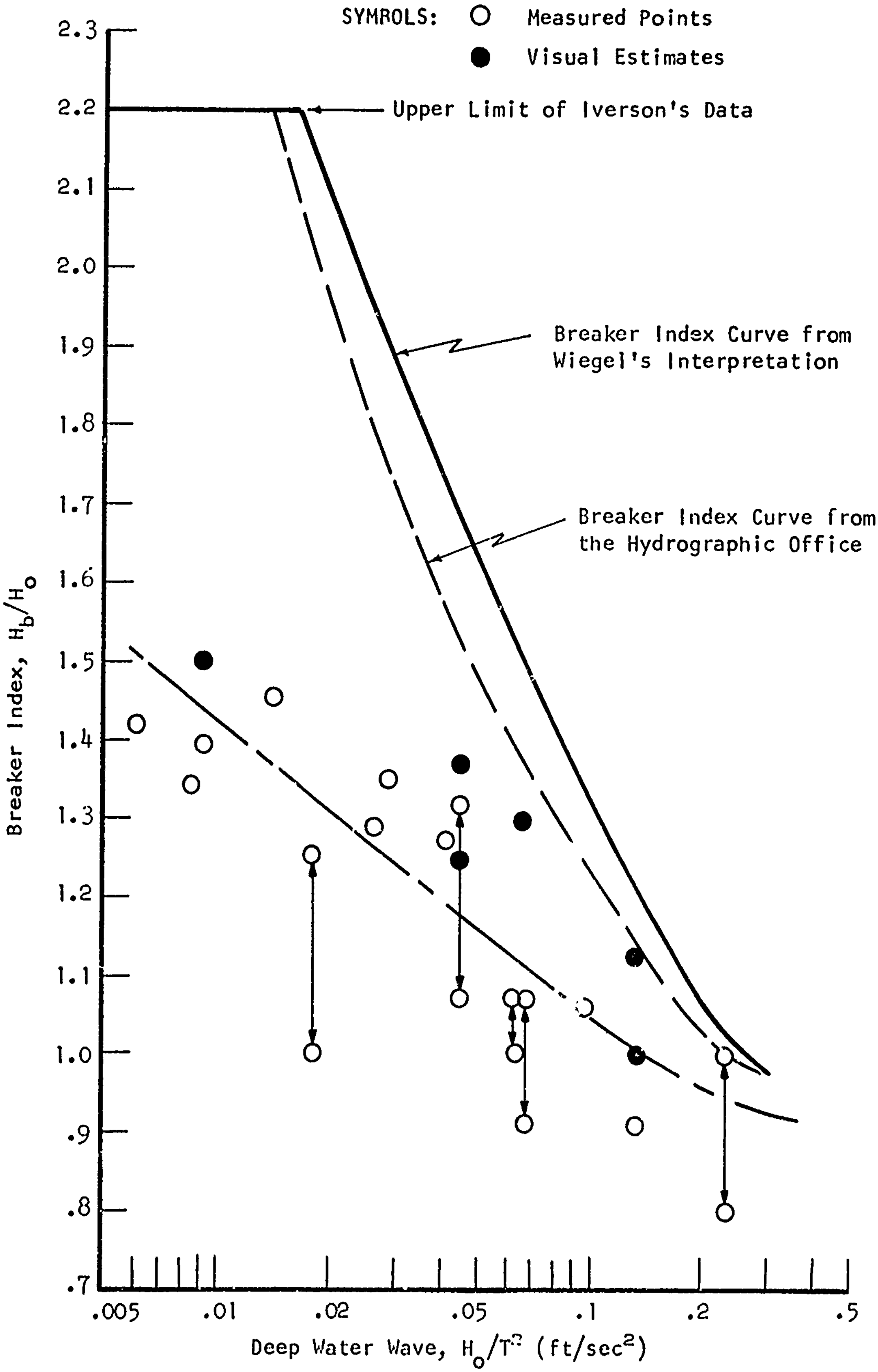


FIGURE 36. OBSERVED BREAKER INDEX DATA ON 1/20 BEACH

A mean line was put through the data points (Figure 36) and this mean line was used in conjunction with the revised wavemaker calibration (Figure 35) to "predict" breaker heights for wavemaker strokes of 8.2 and 5.6 inches. The results appear as the dotted lines in Figure 32. Since these mean lines are fairly reasonable representations of the observed data, the method was used to extrapolate a rough "calibration" curve for the Davidson Laboratory beach (Figure 37). The ranges of breaker type are shown as well as a rough surf zone scale (made by assuming $d_b/H_b = 1.1$).

D. Summary: 1:20 Beach Regular Surf

While the types and proportions of periodic breakers produced compare reasonably well with other data, the maximum breaker height capability is low, relative to the predictions made earlier. The reason is the much lower breaker index than that reported by others (see Figure 36).

Since the breakers produced were reasonably proportioned, the low breaker index should not have any practical bearing on results of tests of vehicles in surf. Thus, if the maximum breaker capability will allow test specifications to be met, the beach configuration of Figure 29 should be adequate.

To simulate 10-ft breakers at 1/12 scale would require ten inch model breakers. From Figure 37, the maximum present capacity is six-inch breakers, but at periods which are on the low side relative to full scale observations (compare Figure 37 and Figure 21). It appears that a significant increase in maximum wave height capability will be needed for significant tests of amphibious vehicles in surf.

From the experiments on the 1:10 beach, it is natural to guess that more sealing and stiffening would improve the breaker index of the 1:20 beach. Unfortunately, this may be a hard job, and possibly not result in the desired increment in breaker height.

Another point of view would be to accept the installation of Figure 29 and just make bigger incident waves. This might be done by replacing or adding volume to the plunger of the Tank 3 wavemaker. For the periods

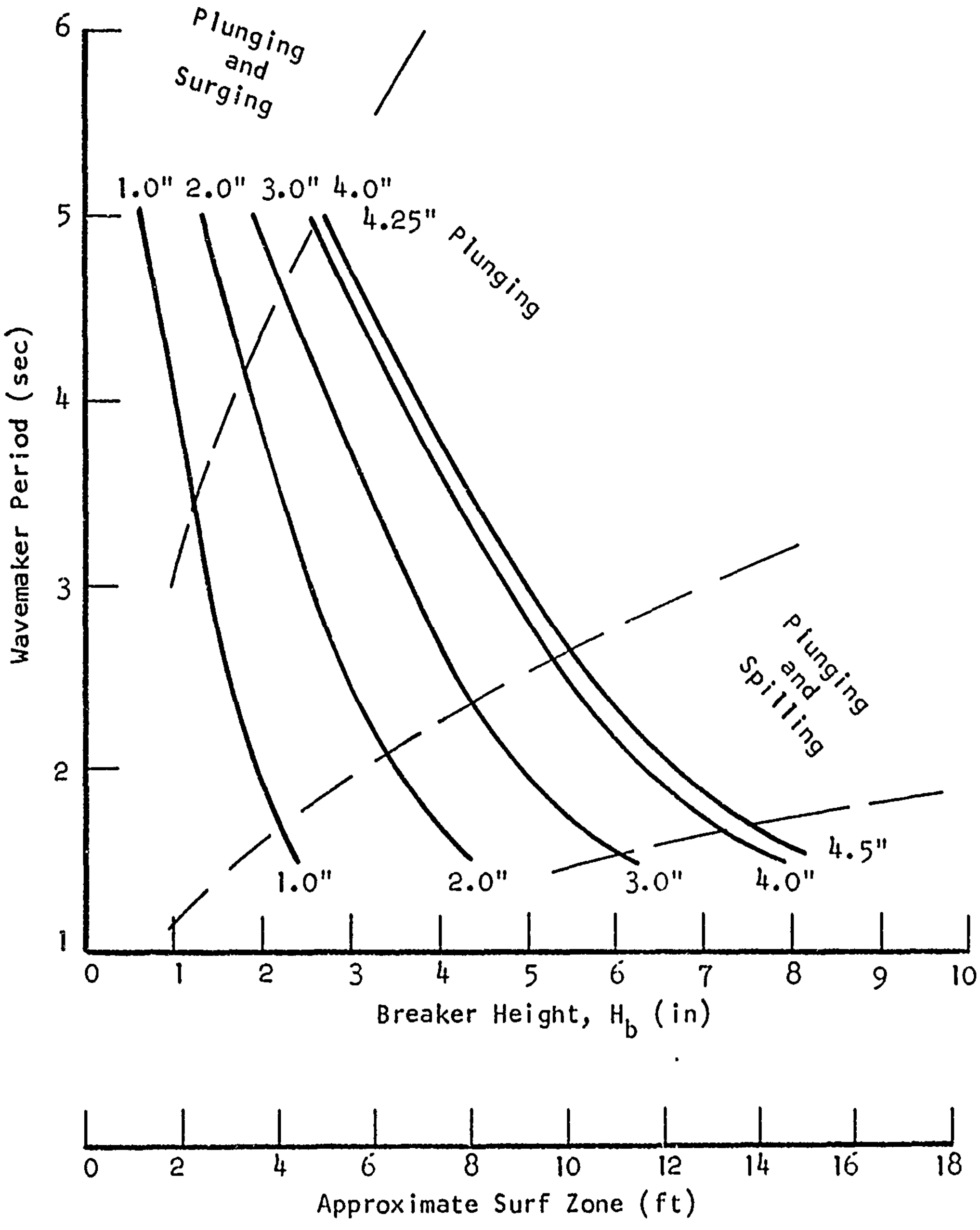


FIGURE 37. APPROXIMATE CALIBRATION CURVE FOR TANK 3 WAVEMAKER ON 1/20 BEACH, PERIODIC SURF. PRECISION OF BREAKER HEIGHT ESTIMATE ABOUT ±15%.

of interest (two seconds and upward), this wavemaker may well have enough power to displace two or three times as much water as at present. It appears that the most promising approach to increasing the breaker height capability is to replace or add to present plunger so as to displace more water (make bigger incident waves).

IV. BEACH SLOPED AT 1:20, IRREGULAR SURF

A. Program and Test Methods

The primary purpose of this part of the test was to see what happens when irregular waves are run at the beach and, if possible, to obtain a calibration curve. Due to time and budget limitations, the irregular wave tests had to be done in a final rush, and the test program turned out to be a series of guesses at interesting combinations of wavemaker stroke and period settings for the irregular wave program which happened to be set up at the time.

The instrumentation used was the same as that for periodic waves with the addition of a manual events marker on the oscillograph. Thus, two wave probes were available in the surf zone. These probes were positioned in the outer part of the surf zone. Probe 3 was located approximately eight feet from shore, Probe 2 approximately 12 feet. Records were taken continuously from the start of the wavemaker for 100^{+} steps of the programmer. From the time of first wave arrival on runs after the first, the manual event marker was used each time a breaker appeared at a distance from shore greater than six feet.

Included in the first motion picture session were three rolls of film at 64 frames/sec of three portions of the same nominal irregular wave. The view was a quartering shot of the grid indicated in Figure 29 and mentioned previously. A picture of the surf obtained is shown in Figure 38.

The wavemaker parameters and the observed extent of the surf zone are summarized in the top part of Table 1 for the four good runs obtained.

B. Results and Analysis

1. Incident Waves

A "crest to trough" analysis of the incident waves at 250 ft from shore was carried out and the results are summarized in Table 1. As luck would have it, the guesses about combinations of power and crank radius

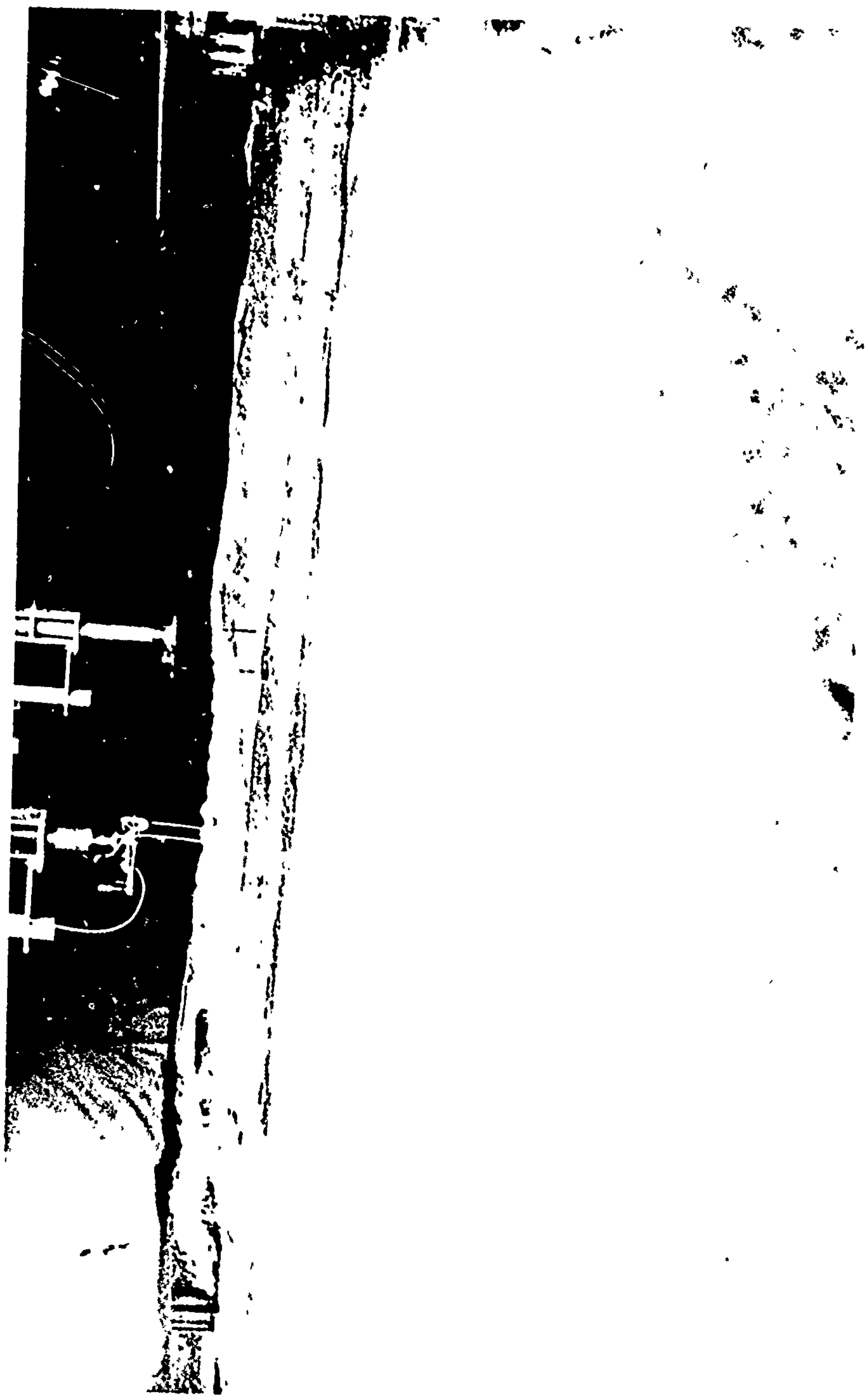


FIGURE 38. SURF OBTAINED FROM IRREGULAR WAVES ON 1/20 SLOPED BEACH

Table

Summary of Results: Irregular Surf

(Irregular Wave Program X)

Run	22	23	24	26
Stroke (in)	5.60	5.60	8.20	7.00
Powerstat	740	620	500	620
Time for 100 Waves (sec)	152.5	225.0	350.7	227.0
Estimated Extent Surf Zone (ft)	11.5	11.5	10.8	13.3
Motion Pictures for Analysis	No	No	Yes	No
Incident Wave:				
Average Height (in)	4.4	3.1	3.7	3.8
Significant Height (in)	6.6	5.0	6.0	5.8
No. Waves in Two Wavemaker Cycles	48	61	69	53
$\tilde{T}$ (sec)	1.60	1.85	2.56	2.20
Surf Estimates:				
Total No. Waves (Two Wavemaker Cycles)	52	67	96	64
Number Marked Breakers	?	25	42	30
Significant Breaker Height (in)	4.8	4.7	4.7	5.1
Range of Height:				
1/3 Highest Breakers (in)	4-6	3.5-6	3-6.5	4-7.5
$\tilde{T}$, (sec)	1.46	1.68	1.85	1.77
Average Period of 1/3 Highest Breakers (sec)	4.7	5.1	4.5	5.7
Range of "Periods" 1/3 Highest Breakers (sec)	1-16	1-18	1-24	1-14

setting were compensating. No large variation in significant height was achieved and thus no hope of a proper calibration.

Since it happened that the wavemaker program used repeats every 25 steps, the waves were nearly periodic in 1/4 the control time. The distributions of crests and apparent periods of all wave traces for two successive wavemaker cycles (25 steps), were compared for Run 24. Differences were within precision of measurement and it was concluded that the records should not be sampled as quasi-random processes. All analyses were carried out over two wavemaker cycles (or 1/2 the control time). Incident wave records were visibly nearly periodic in 1/4 control time for all runs. Records in the surf zone were at least qualitatively periodic.

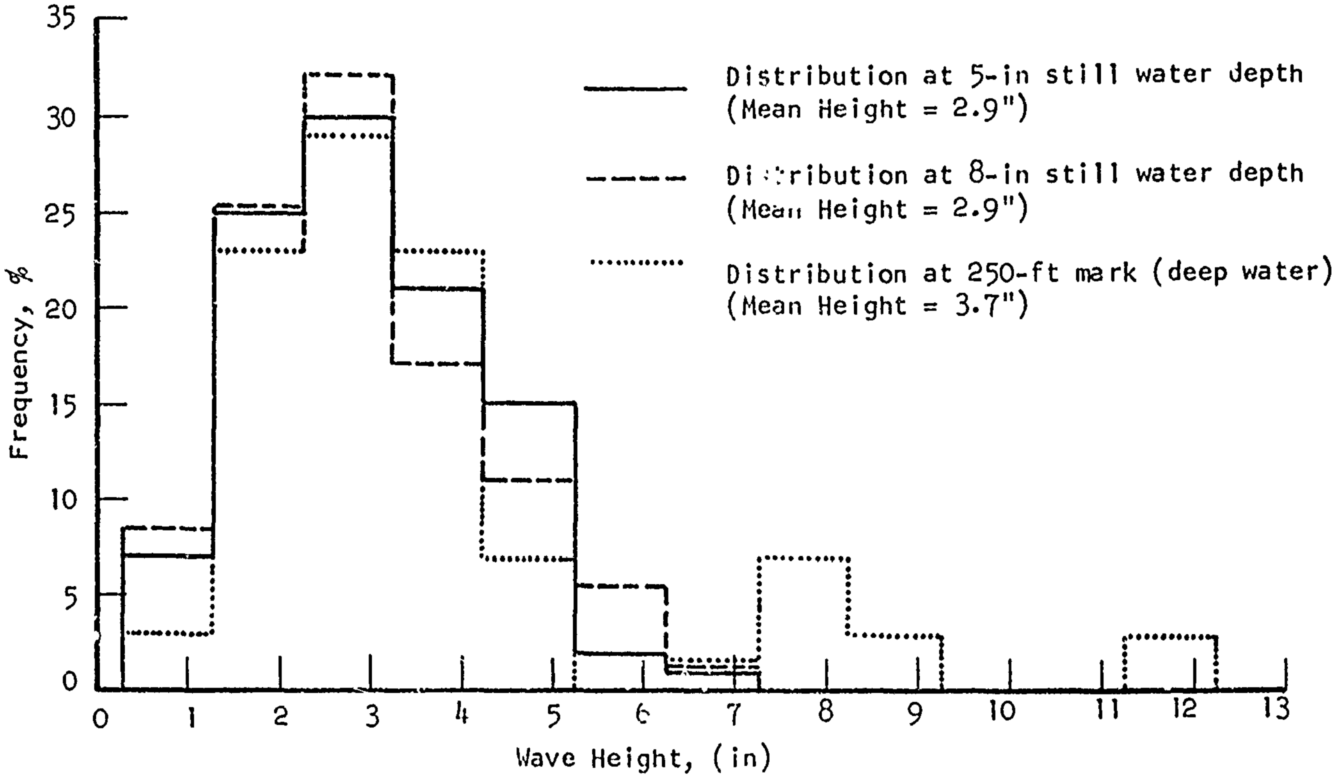
2. Records in the Surf Zone

The total number of waves (zero crossing convention) in two wavemaker cycles for each probe was found to be more than in the incident wave. A crest to trough analysis of all waves was done for Run 24 and the distributions are compared with the corresponding data from the incident wave in Figure 39.

The beach or the propagation process down the tank, apparently tends to shorten apparent periods and reduce the maximum wave height. (The distributions of incident wave for the other runs also have the same unusually high proportion of extreme heights. It is suspected that none of the records of incident wave obtained would pass tests for normality or for Rayleigh distribution of maxima.)

3. "Breaker Heights" and Apparent Periods

The records at two selected points in the surf zone do not necessarily contain the proper information for an assessment of "breaker height." It is doubted that there is an undisputed technical version of just what breaker height and apparent period really is when measured in the field. For present purposes, it must be assumed that a test breaker specification should correspond to the eyeball observation data. Though not specifically observed in the tests, the impression was that there are, on the average, about the same number of breakers of <u>all</u> sizes as the number of



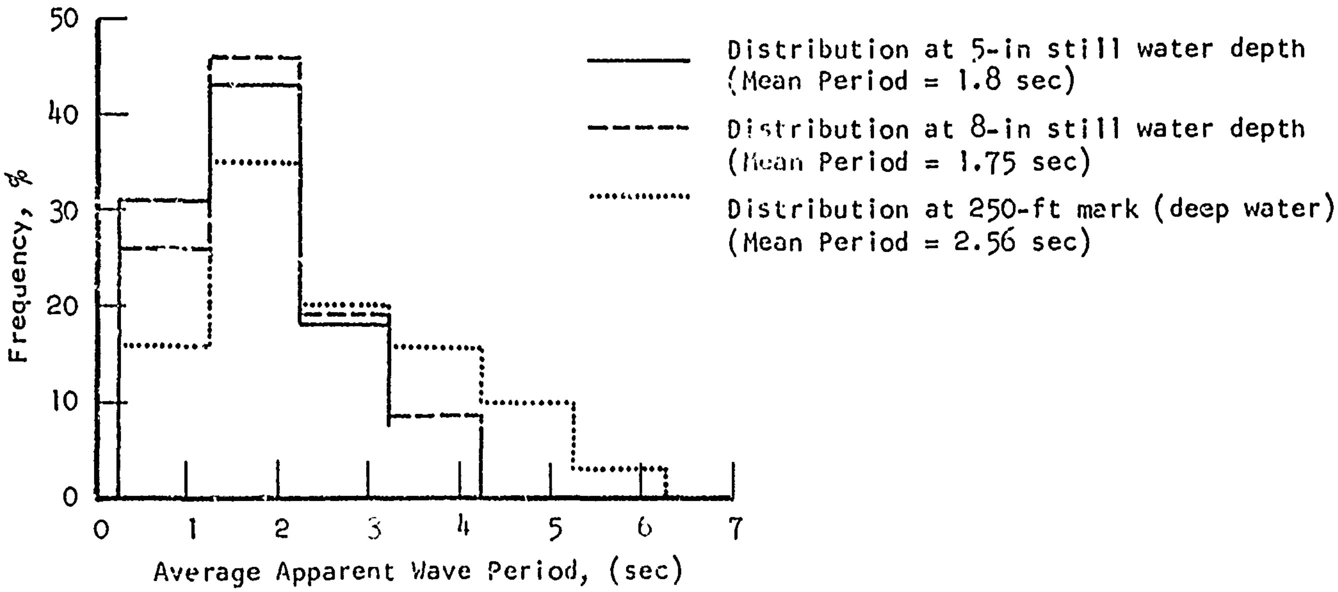


FIGURE 39. DISTRIBUTION OF MODEL WAVE HEIGHTS AND APPARENT PERIODS FOR ALL WAVES (BREAKING OR NOT) OCCURRING DURING RUN NO. 24

identifiable wave crests entering the breaker zone. Approximately the same impression was gained from Byrnes' films. Those who observe surf in the field ordinarily are making an estimate of significant breaker height, and it will thus be assumed that "breaker height" is the average of the N/3 highest breakers observed anywhere in the surf zone: where "N" is the total number of identifiable wave crests entering the zone. Observers are told to report the average apparent period from the elapsed time for ten waves. It is possible that some of the wide scatter of observed average periods shown in Part One, is attributable to some observers counting every bump (breaker or not), and other observers counting elapsed time for ten breakers of the size which figures in their estimate of height. Accordingly, two measures of "period" were adopted:

$\overline{\tilde{T}}$ = average apparent period of all waves entering the surf zone (corresponds to $\tilde{T}$ for stationary probe)

$\overline{\tilde{\tilde{T}}}$ = average period of N/3 highest breakers

It is clear from the foregoing that the instrumentation in the present tests was inadequate to the production of the required numbers. (There should have been 12 wave probes on one-foot spacing out to about 14 feet from shore.) However, it was observed that few, if any, of the breakers occurring between shore and six feet out, were larger than the smallest breaker more than six feet from shore. Where there was a marker channel working, Table I shows that a breaker was observed beyond six feet from shore for between 1/3 and 1/2 of the identifiable waves entering. It was thus assumed that the set of waves indicated by the marker channel contained the N/3 highest breakers.

The waves to which the events marker referred were not hard to identify on the oscillograph traces.

The interpretation of the two wave traces was as follows:

Position of Wave Breaking Assumed	Interpretation
Between shore and 6 feet	No marker—none of these waves would be counted or measured
Between 6 feet and 8 feet	Marker: wave at 8 feet higher of the two and forms a slight underestimate of H_b
Between 8 feet and 12 feet	Marker: either wave may approximate H_b: take higher of the two
Outboard of 12 feet	Marker: wave at 12 feet forms an underestimate of H_b—possibly gross

The analysis rule for this interpretation is relatively simple:

- o Count all waves over time = 1/2 control time and divide the result (N) by 3.
- o Relate individual waves on the two surf traces and measure the higher of the two.
- o Find the N/3 highest of the measurements and the time intervals between. These form the data for producing $\bar{H}_b$ and $\bar{\bar{T}}_b$.

The above procedure was first followed for Run 24 with results shown in Table 1. To check for plausibility, the breaker heights were estimated from two rolls of motion pictures corresponding to Run 24. In the motion pictures, nothing could be seen of the area between shore and about 5 feet out, and two rolls of film correspond roughly to two wavemaker cycles. A total of 57 breakers were observed from the film. Since 32 had been averaged from the tapes, the highest 32 of these 57 were used to form alternate estimates for Run 24. The results are summarized in Table II. The significant breaker height and periods correspond within about 10%.

Table II

Comparison of Surf Statistics

Estimated from Tapes and Movies

	Tapes	Movies
Run	24	5 & 6
Number "Observed" Breakers	42	57
Average of 32 Highest Breakers (in)	4.7	5.2
Range of 32 Highest Breakers (in)	3-6.5	4-8
Average "Period" 32 Highest Breakers (sec)	4.5	4

Considering the expected deficiencies of the tape method and the precision of estimates from the film (not very good) this degree of correspondence was taken as acceptable.

Results for the remaining three runs were obtained from the tapes in a similar fashion (Table I). Figure 40 shows how little variation in significant breaker height was achieved. In this figure the boxes indicate the range of breaker height for both $\tilde{\tilde{T}}$ and $\tilde{\tilde{T}}_B$.

In Figure 41 the distributions of breaker heights and apparent periods for Run 24 are compared with Byrnes' data (from Part I). Referring to this figure, Byrnes probably counted <u>all</u> breakers; not just the largest, and this would account for the smaller variability of the present data. The apparent period correspondence would not be bad except for the period of four times the average which was observed in Run 24. Something like this happened in all the other runs also. To <u>model</u> scale, at least once in every wavemaker program cycle there was a period of 15 to 24 seconds during which the waves were very low and in which none of the N/3 highest breakers occurred. If this period had been deleted from the data, $\tilde{\tilde{T}}_B$ would have been about three seconds in all cases, an average which, according to Figure 40, would indicate quite realistic simulation for 5-inch plunging breakers. (The general observation during the test was that most of the breakers were plunging—the largest a spill-plunge combination.)

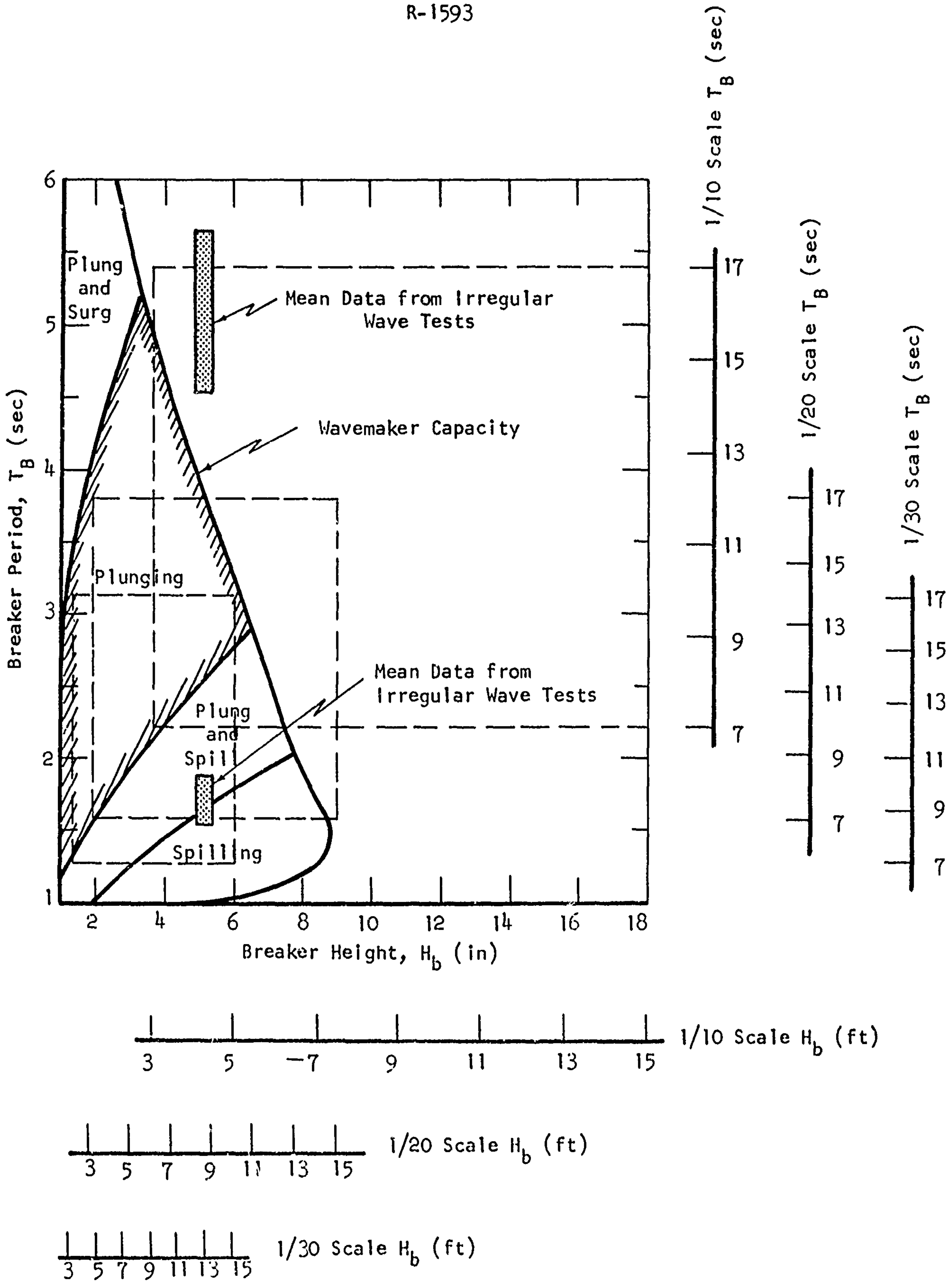


FIGURE 40. RESULTS OF IRREGULAR MODEL SURF TESTS PLOTTED ON DATA FROM FIGURE 21.

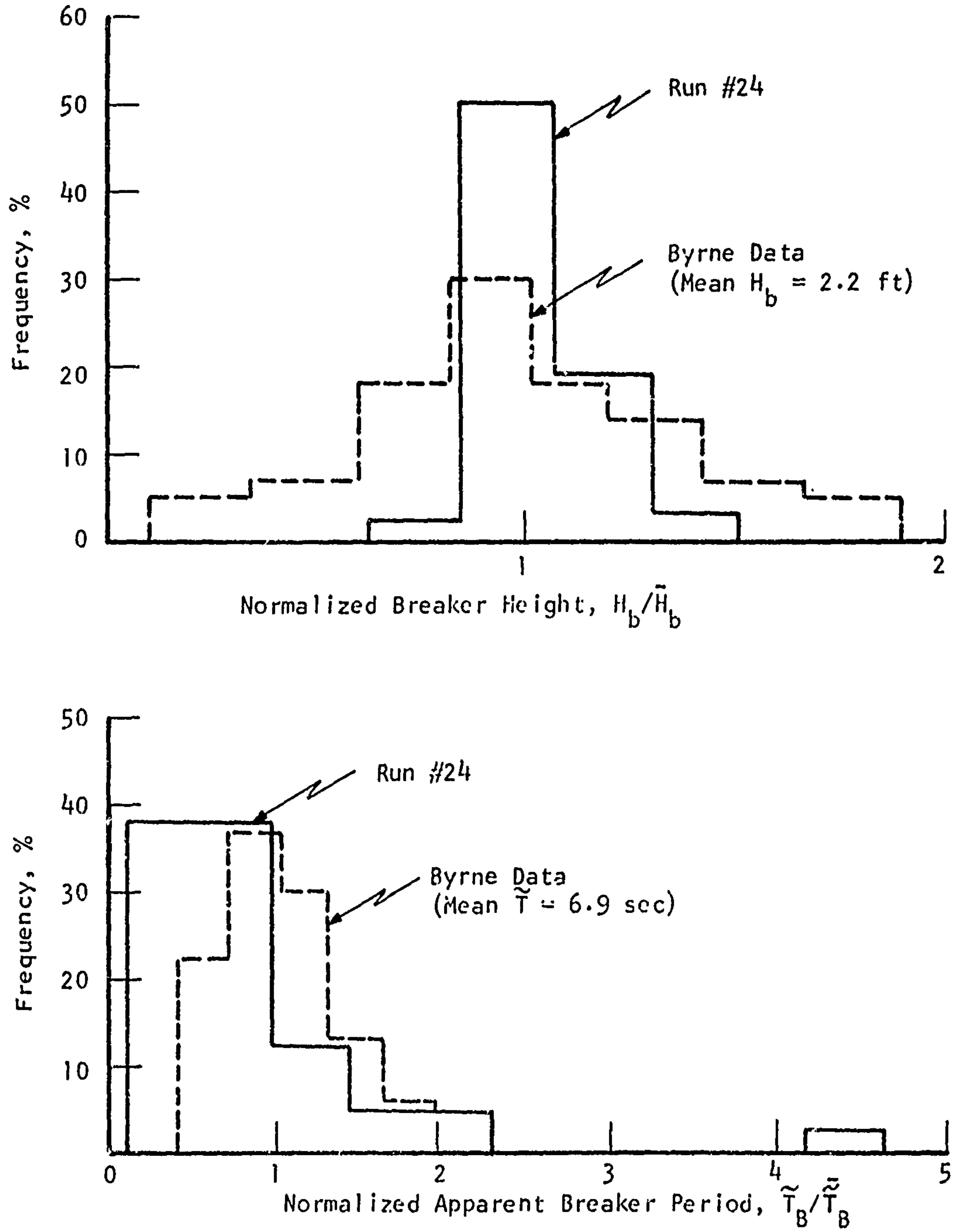


FIGURE 41. COMPARISON OF BREAKER DATA FROM RUN #24 WITH DATA FROM BYRNE

C. Summary: Irregular Surf

The wavemaker parameters used were near maximum. Though no calibration was obtained, it appears that the installation was under capacity relative to a 10-inch irregular breaker requirement for self-propelled amphibious vehicle tests. Table I shows that significant breaker height is roughly 20% lower than the significant height of the incident wave. If this follows, an incident significant height of eight inches is needed and this is the largest obtainable in the D.L. Tank 3 facility.

Of the waves actually run, the last (Run 26) was the most interesting. It appears that the waves as generated in that run, would be a plausible simulation. However, it should be noted that even average high surf conditions are as likely to arise from swell as from fully developed sea conditions. The aim in the development of the irregular wave programs has been to produce a spectrum having bandwidth appropriate to a fully developed sea. Swell spectra are much narrower. Accordingly, it is suggested that a "swell program" could be developed which would probably produce surf which is just as plausible as that reported upon in the literature, and, in addition, may not have the very long low section observed.

The unsatisfactory path, which had to be followed to estimate irregular breaker heights from oscillograph tapes, suggests that if much of this sort of thing is required, a multiple wave probe setup should be developed which will allow individual waves to be more or less traced along throughout the surf zone.

V. SUMMARY AND CONCLUSIONS TO PART TWO

Not surprisingly, the bulk of the time spent in these first experiments was in installation and modifications to the beach. Relatively little time could be devoted to measurements and photography. Nevertheless, a reasonably large amount of good photography was conducted and at least a minimum of measured data was obtained.

With respect to the initial objectives:

1. A 1:20 slope beach installation which may be acceptable for contemplated work was built, and the problems involved exposed. Installation and tear out time for similar installations is estimated at less than 32 tank hours. This figure would appear to provide for relatively economical tests.

2. A calibration was developed for periodic surf on a 1:20 beach with existing wave generation equipment. Reasonable qualitative agreement was observed between present results with the model and full scale surf data of others. The testing of military amphibious vehicle models may require breaker heights beyond the capacity of presently installed wave generation equipment. It is suggested, however, that the required increase in capacity is economically feasible.

3. The measurements made of irregular surf were too few for generalization. However, no observation indicated that major problems exist in this area.

4. The practicality of beach slewing as a method of producing waves which break at an angle to the beach, was indicated indirectly.

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