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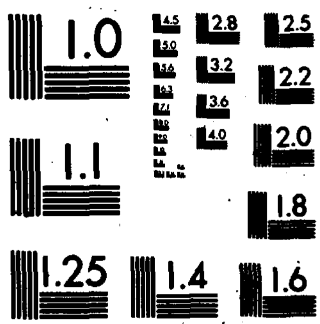

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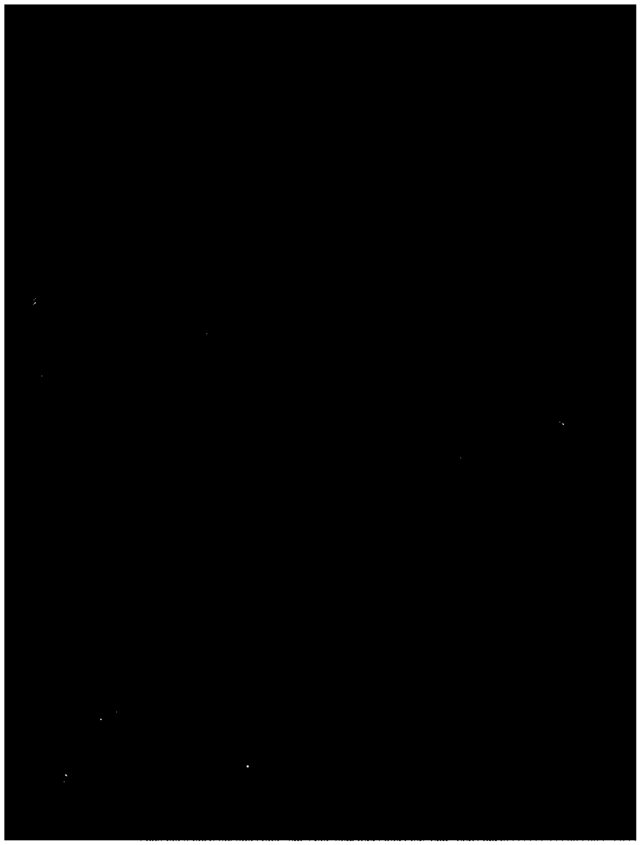

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APPLICATION OF SHORT-CRESTED WAVE THEORY IN THE DESIGN OF THREE DIMENSIONAL COASTAL HYDRODYNAMIC MODELS

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INTRODUCTION

In spring 1973 a series of field experiments was initiated to investigate the three dimensional structure of a coastal hydrodynamic system. Specific emphasis was placed on those components of the system which were driven primarily by incident wind-waves. These field investigations supported the concept that short-crested wave theory is applicable to modeling of incident wind-wave transformations from offshore to the outer surf zone. Application of short-crested wave theory to the design of coastal hydrodynamic models was also considered appropriate because of the theories inherent three dimensional structure. Concurrent with this work two field experiments were conducted in 1974 and 1976 to measure longshore current velocity structure. These experiments were designed to measure vertical and horizontal distribution of current velocity and to monitor temporal variations in current velocity at a point. In fall 1978 a series of experimental laboratory investigations was initiated to make precise measurements, at close spatial intervals, of wave height decay after breaking. These experiments were carried out to determine a wave height decay expression based upon the assumption that an appropriate physical conceptualization of wave energy dissipation after breaking must consider turbulence dominant to bottom friction. This report presents a detailed summary of these investigations and their results.

During the project period of this contract five professional papers, five Technical Reports, and eight papers for presentation at national meetings have been prepared. A complete listing of these reports and papers is appended to this report.

SHORT-CRESTED WAVES AT A COAST

The common occurrence of short-crested waves in open ocean and over the continental shelf suggests that these waves must have significant influence on coastal wave distribution. A preliminary evaluation of coastal aerial photographs and satellite imagery from regions of the Atlantic and Pacific coasts of North America indicate that short-crested wave fields are common in offshore areas and that they usually persist to the outer surf zone. McClenan and Harris (1975) in a study on the use of aerial photography for determining wave characteristics concluded that two to five directionally distinct wave trains were present in most offshore regions. Photographs at Cape Hatterus, North Carolina, Cape Canaveral, Florida, Point Reyes, California, and various locations along Lake Michigan also show that short-crested waves are commonly present at the outer surf zone.

This common occurrence of short-crested waves at a coast stimulated initial interest in research on short-crested wave theory applied to coastal hydrodynamic modeling and in conducting field experiments to verify modeling results. In fall 1974 a three by three grid of wave staffs was placed in the surf zone to measure wave height variability along-the-crest of transforming, breaking waves. Results from these short-crested wave transformation experiments showed crest-wise variability in wave height to be present at the outer surf zone. Statistical analysis of these along-the-crest wave height variations indicated significant differences in their probability distributions. The spatial scale of this along-the-crest variability was of the order of normal incident wave length. A discussion of these results was published in the Proceedings 15th International Conference on Coastal Engineering (Wood, 1976).

Four mechanisms have been evaluated as possible causations of non-uniformity along-the-crest of waves incident at the outer surf zone. These mechanisms are: significant long-shore variation in bottom geometry; interaction of long-crested swell arriving from two distinct directions; interaction of edge waves with the incident wave field; and arrival of a "short-crested" wave field generated by local storm winds. Of these four mechanisms surf zone bottom geometry was shown to have little influence on short-crested wave structure (Wood, 1976).

Interaction of long-crested swell arriving from two or more distinct directions is clearly an important mechanism in the generation of non-uniform wave crests and has been discussed by Longuet-Higgins (1956), McCleanan and Harris (1975) and Dalrymple (1975). Qualitatively, it would be expected that waves of the same wave number, approaching from different directions, would be refracted so that their crests are more nearly parallel to each other and to the coast. For small differences in wave angle of approach ($\delta\theta \sim 10^{\circ}$-$20^{\circ}$) the deviation of wave components is greatly reduced and the resulting incident wave field tends to become long-crested. For large differences in wave angle of approach ($\delta\theta \sim 60^{o}$-90^{o}) the deviation of wave components is far less effected and the wave field remains short-crested. If wave angle of approach (θ) is held constant, but a spectrum of wave numbers is considered the expectation is that individual wave numbers will be differentially refracted. This will increase the angular deviation of individual components and produce a short-crested wave field. A broad wave number spectrum will produce an extremely short-crested wave field.

Edge wave interaction with the incident wave field is possible. Fluctuations in longshore velocity with a periodicity close to that of a zero mode edge wave have been observed under field conditions (Wood and Meadows, 1975; Meadows, 1976). However, the wave length of longshore wave height fluctuations, from this experiment, are equivalent to the incident wave length of breaking waves. Periodicity of these fluctuations is much shorter than those calculated from edge wave theory. Likewise the observed magnitude of wave height fluctuations is in excess of that calculated from edge wave theory.

An incident wave field arriving with a "short-crested" structure which is independent of the other three mechanisms, is theoretically possible but, within the limitations of existing experimental observations difficult to substantiate. Turbulence in a wind field can result in the generation of a short-crested wave field (Jefferies, 1924). Likewise McClenan and Harris (1975) analyzed 40,000 aerial photographs of waves in shallow-water and concluded that the dominant pattern is one of short-crested waves and randomness. Notably missing between these studies are concurrent observations of wind and wave field structure in shallow-water. The crest-wise wave length correspondence to incident breaking wave length and the large fluctuations in wave height along-the-crest do, however, strongly support short-crested wave structure. Clearly, the question left unanswered is whether energy is being transmitted along the crests of these waves. In order to address this question affectively it is necessary to understand internal dynamics in the upper half of transforming and breaking shallow-water waves.

Since experimental evidence supported the contention that short-crested waves were an anticipated form of incident waves at a coast, a theoretical evaluation of three-dimensional surf zone motions was initiated. Two distinct causes of longshore variation in surf zone motions were initially investigated: variations in longshore bottom geometry and longshore incident wave height variability. In a paper "Dependency of Surf Zone Motions on Longshore Bottom and Wave Variability" Wood (1976) presented a first attempt at a linearized solution to the three-dimensional equations of motion using variable non-dimensional bottom and wave height parameters. That paper presented the following results.

Let ε and B be two small parameters characterizing normal and longshore bottom slope respectively. The ratio of these two parameters has two value ranges which are of interest:

$B/\varepsilon \simeq 1$ and $B/\varepsilon \to 0$. If $\varepsilon \to 0$ momentum transport parallel to shore dominates shoreward normal transport. However, when $B/\varepsilon \to 0$ with $B \ll \varepsilon$ and longshore currents are still observed, then longshore wave variability must be considered as an important driving mechanism.

A linearized solution to the three dimensional equations of motion was obtained under the assumptions of $B/\varepsilon \to 0$ and $\partial/\partial y \neq 0$. The resulting hyperbolic equation could be transformed to a wave equation with coordinates oblique to the surf zone. The solution of this equation was complex but, the form of the equation suggested three possible physical interpretations: first a solution may exist with a velocity potential which is dependent upon a cos mx cos ny form, where m and n are onshore and longshore wave number respectively; second along-crest variations in wave height may serve as a momentum transfer mechanism in the surf zone; third an interaction of longshore stresses with crest normal stresses may provide a longshore forcing function in three-dimensional space. These results were far from complete, yet even in their preliminary form they opened up an area of theoretical endeavour which needed further development.

An evaluation of momentum balance related to non-uniform wave height distributions along the crest of breaking waves was subsequently completed, producing two interesting results.

First it showed that the principal radiation stress parallel to the wave crest is underestimated. This underestimation occurs from the physical neglect of the ρV^2 term in the gradient of the dynamic pressure. Second the various long-shore gradients in the momentum balance expressions which had been ignored by previous investigators, appear to contribute to the momentum balance in a non-negligible way. These two results are additions to the original recognition by Battjes (1972) of the overestimation in the principal radiation stress normal to the wave crest under non-uniform conditions.

Short-crested wave refraction modeling was initiated utilizing narrow-band spectra of wave angles and wave numbers. Initial formulation followed the basic line of reasoning put forth by Longuet-Higgins (1956, 1957). However, Longuet-Higgins (1956) did not attempt to extend his formulation of the wave refraction problem, into shallow water ($d/\lambda < 0.05$). Furthermore, he noted that the linear treatment utilized in his 1956 work was totally unacceptable near and within the surf zone.

Initial tests of this linear short-crested wave refraction model yielded results which agree physically with those results suggested by Longuet-Higgins (1956). Specifically, the mean crest-length of short-crested waves refracting in shallow water may either increase or decrease. Likewise, the ratio of crest length to wave length, in general, tends to increase as waves pass over a gradually shoaling, plane, shallow water bathymetry.

This model is limited by the conventional constraints of small-amplitude wave theory. This dispersive type of refraction, which is dependent upon wave number and depth, is not appropriate to shallow-water regions adjacent to and within the surf zone. Therefore, an amplitude dependent dispersive type wave refraction approach was introduced into the model.

This new modeling approach utilized a modified form of solitary wave theory in and near the surf zone. The introduction of solitary wave theory, to the model, would have little effect on wave refraction as long as a uniform long-crested wave field was used as input. However, for incident waves with non-uniform crests, a pronounced differential refraction occurs as a direct function of wave height. An incident short-crested wave field refracts much more rapidly than a long-crested wave field because of the height dependency of the celerity field. The amount of refraction is governed by the ratio of successive differences in along-the-crest wave height to crest-wise wave length. As this ratio increases, the wave angle spectrum broadens. For a set of initial conditions, where a continuous straight non-uniform wave crest is imposed at the outer limits of a gradually shoaling plane bottom, differential refraction will create a surface wave pattern characterized by angular discontinuities. This pattern is strikingly similar to patterns observed in aerial photographs of short-crested waves in shallow water.

This work on short-crested waves has broadened our understanding of three-dimensional surf zone dynamics. It has contributed to physical conceptualization of longshore forcing which can be as important as any of the other proposed forcing mechanisms. Modeling of three-dimensional surf zone motions utilizing short-crested wave theory has not been as successful as was originally anticipated because of complexities in solving the necessary mathematical expressions. Qualitative results have been encouraging, but quantitative solutions have not been achieved.

Recently, some effort has been directed towards understanding transformations of wind generated short-crested sea surfaces as they move from deep to shallow-water. Wood (1980) showed that the characteristic along-the-crest wave length at a coast for a transformed short-crested sea surface is equivalent to the deep water wave length of that system. This result is interesting because the calculated longshore periodicity of these short-crested transformed sea surfaces is close to that of observed long period variations in longshore currents (Wood and Meadows, 1975; Meadows, 1976; Meadows, 1978; Meadows and Wood, in press).

LONGSHORE CURRENTS

In two nearly simultaneous studies Dette, 1974 and Wood and Meadows, 1975 observed that velocity fluctuations in longshore currents on the order of 150% of mean velocity occurred on time intervals from three to eighty seconds. Since that time extensive analysis has been carried out in order to resolve spatial and temporal structure in longshore currents. The following discussion is designed to summarize this analysis. Detailed discussion is omitted when it exists in other published forms.

Three distinct longshore current velocity components have been isolated, which contribute to the total observed longshore current velocity

$$V = \bar{V} + V'_W + V'_L$$

where $\bar{V}$ is the steady component, V'_W is a fluctuating component with a periodicity of the incident breakers, and V'_L is a long-period fluctuating component. The mean longshore component $\bar{V}$, has been found to be dominated by the combined fluctuating components. The high frequency unsteady component corresponds to the incident wave horizontal particle velocity resolved alongshore. Resolution of the long-period component is not as simple.

Long-period variations in longshore current velocity have been observed by numerous investigators (Inman and Quinn, 1951; Sonu, 1972; Huntley and Bowen, 1974; Suhayda, 1974; Wood and

Meadows, 1975; and Meadows, 1977) and have been shown to be an important component of nearshore dynamics (Bowen and Inman, 1971; Waddell, 1973; Suhayda, 1974; Meadows, 1977). However, with all of these studies the mechanism responsible for and general form of long-period waves in the surf zone has not been well established.

Analysis of phase relations between sequential 1000 second time series records of the free surface show that both standing and progressive long-period waves are present in the surf zone at the same time. Previous studies have related surf zone circulation to one or the other of these two modes, but have not recognized their coexistence. Physically, it is quite reasonable to expect both wave modes whenever long-period progressive waves pass through the surf zone and reflect from shore. Comparison of observed and calculated long-wave phase velocity for progressive waves in the surf zone indicated they were non-dispersive. Amplitudes of long-period progressive waves decreased shoreward, in response to energy loss and redistribution. Standing waves occurred, both singularly and in groups, at irregular time intervals between sequences of progressive waves. This pattern is most likely created by non-linear interactions of the progressive wave groups. Standing wave amplitudes appear to reach a maximum within the range of breaking waves and approach nodes at the shoreline and offshore. This positioning of nodes and antinodes is in agreement with that of Suhayda (1974), but the irregular periodicity is not.

Actually, this lack of similarity in the time domain is easily explained by the difference in incident wave conditions. Suhayda's observations were made under conditions of regular swell arriving at the coastline while ours were made when wind-waves dominated the incident wave field. Thus, from a mechanistic standpoint both sets of results seem to be in complete agreement.

The long-period component, from decomposition of synchronus 1000 second longshore current velocity time series, ranges from 45 to 48 seconds. This periodicity greatly exceeds that of the incident progressive long wave (15 to 18 seconds) and cannot be reasonably compared with that of the standing wave. It is qualitatively interesting to note that irregular periodicities in the long-period component of longshore current velocity have been observed during earlier analyses of this data (Meadows, 1977). Likewise these long-period variations have been postulated to be related to non-linear wave interactions which result in irregular standing wave patterns. The correlation between standing wave period non-linearities and non-linearities in the long-period component of longshore current velocity strongly supports a driving mechanism which arises from complex surf beats. A recent paper "Long-Period Surf Zone Motions" (Meadows and Wood, in press in JGR Green) discusses these relationships in detail.

Existing methods for the prediction of longshore current velocity distribution across the surf zone utilize, either a monochromatic, incident wave field and a horizontal mixing coefficient (Bowen, 1969; Thornton, 1969; Longuet-Higgins, 1970 a and b) or a probabilistic, incident wave field and differential breaking (Collins, 1972) to approximate velocity distributions. There is no expectation of longshore current flow, outside the break point, when a monochromatic wave assumption is used for prediction. Therefore, Bowen (1969), Thornton (1969) and Longuet-Higgins (1970 a and b) introduced various forms of mixing coefficients in order to obtain better matches between observed and predicted longshore current distributions. Collins (1972) assumed that a probabilistic incident wave field was much more representative of observed field conditions and then utilized this assumption to develop a method for predicting longshore current distributions across the surf zone. Differential wave breaking, which results from an ensemble of incident wave heights, creates a well mixed outer region of the surf zone, without having to apply a mixing coefficient. Collins (1972) argued, quite reasonably from physical principles, that differential wave breaking provided the mixing mechanism for the outer surf zone.

Comparisons have been made between observed, single maximum, horizontal longshore current profiles and profiles predicted from the semi-theoretical work of Longuet-Higgins (1970) and Collins (1972). Additional comparisons with predicted profiles of Bowen (1969), Thornton (1969) and James (1974) have also been carried out. An extensive discussion of this work is presented in Meadows (1978).

An extensive evaluation has been made of Longuet-Higgins (1970) formulation for the prediction of longshore horizontal current velocity profiles. A matching of predicted profiles, generated from Longuet-Higgins semi-theoretical formulation, with observed profiles from this study has been carried out by manipulating the range of constants applied to his formulation. These manipulations involved the amplitude to depth ratio (α), the deep water to shallow water transformation coefficient (B), the friction coefficient (C), the dimensionless scaling coefficient (N) and the horizontal eddy viscosity (μ). Comparisons between predicted and observed profiles for the range of observed parameters were not good. The magnitude of the predicted velocities was too small and the shape of the predicted profile was not similar to the observed. Specifically, the predicted outer "mixed" region of the current profile truncated too abruptly. Variation of the friction coefficient allowed the predicted and observed profiles to be matched at the point of maximum velocity, but the shape distortions became greater. The physical significance of this type of "matching" is not at all clear or necessarily reasonable. In fact it may well be an exercise in futility if the problem lies in the basic formulation of Longuet-Higgins (1970).

Comparisons between Collins (1972) longshore current velocity predictions and direct field observations show that the shapes of predicted velocity distributions are much broader than actually observed. This result is somewhat anticipated because Wood (1974) has shown that the Rayleigh distribution assumed by Collins (1972) is not representative of the observed incident wave field in the surf zone. Specifically, the tail of the distribution, composed of high incident waves, is compressed so that a truncated Gaussian distribution results.

A truncated Gaussian distribution was substituted for the Rayleigh distribution assumed by Collins (1972) and a new set of predicted longshore current distributions were generated. These predicted distributions had shapes which compared favorably with observed distributions. However, the magnitude of these predicted distributions was greater than observed.

One of the primary reasons for this lack of agreement is the unrealistic neglect of turbulent dissipation of energy, due to breaking. This neglect is surprising since most investigators readily acknowledge its importance. What seems to have been assumed in derivations of existing longshore velocity formulations is that any effects of turbulent decay are linear from the break-point shoreward. While this assumption provides tractable algebra it is not supported by field observations (Horikawa and Kuo, 1966; Wood, 1972; Suhayda and Pettigrew, 1977).

A semi-theoretical formulation for calculating longshore current velocity across the surf zone has been derived using turbulent decay of breaking wave energy to balance incident wave energy flux. Basic assumptions to this formulation are that the: wave field is two-dimensional, individual waves behave as a second order solitary wave, bottom is essentially horizontal in the range of decay, and wave height decay due to breaking is an exponential function of distance from break point. The resulting formulation for mean velocity ($\bar{V}$) at any point x in the surf zone is

$$\bar{V} = 1.22\ e^{-0.02x} \sin \theta$$

where θ is the wave angle of incidence at x. Initial comparisons between velocities calculated using this formulation and observed longshore current velocities showed considerably better agreement than was achieved using existing formulations. Maximum error in the calculated velocities occurs in the immediate region around the break-point. Much of this error can be explained by the use of single-valued means for the input parameters. Computations and comparisons currently being carried out utilize distributional properties of the input parameters and should yield better agreement with the new formulation. A paper "Horizontal Distribution of Longshore Current Velocity" (Wood and Meadows, in preparation) describes this work in detail.

Vertical distribution of longshore current velocity has always been assumed to be uniform from the bottom to the free surface. This assumption has been applied to all existing theoretical and empirical formulations for predicting longshore current velocity. Consequently, surface longshore current velocity distribution has been used to approximate the velocity distribution at any level throughout the vertical, exclusive of the near bottom boundary layer.

Measurements of vertical longshore velocity distribution at four points across the surf zone were made during the fall, 1976 field experiment. A similar set of measurements had been made during the 1974 field experiment, at three locations within the surf zone. These earlier measurements were closely spaced near the breaker zone. Analysis of both sets of data shows that the vertical distribution of longshore current velocity is relatively uniform with depth. However, there is a consistent reduction of velocity in the lower third of the vertical profile. This velocity reduction occurs in the same depth range at which Wood (1970) measured extremely reduced horizontal particle velocities in transforming breaking waves.

A series of overlapping 30 second time averages of the longshore velocity at each level in the vertical profile shows that the profile is unsteady. However, the long-period variations (30 to 90 seconds) in the mean velocity profile are in phase throughout the column. Thus, the shape of the vertical profile remains constant, but the absolute magnitude of the velocity at each level fluctuates in a periodic manner.

Future work should be pursued to establish a method for predicting the vertical velocity distribution of longshore current. Clearly, the existing assumption of steady, vertically uniform currents is oversimplified and may lead to erroneous conclusions when it is applied to calculation of bed shear stress and resulting sediment transport. An adequate solution to this problem can only be obtained through detailed laboratory measurements.

Our work has provided the first detailed observations on horizontal and vertical structure in longshore currents and has raised interesting questions on temporal variations in current velocity. Although a number of papers and reports have been prepared on this work there is still a great deal more analysis which can be done on this data field. It is anticipated that at least two more papers will be prepared from these results within the next 18 months.

LABORATORY EXPERIMENTS ON BREAKING WAVES

Three separate laboratory experiments have been conducted on breaking wave height decay over a horizontal bottom. The primary purpose of these laboratory experiments was to verify the scale lengths which are predicted from application of isotropic turbulent kinetic energy dissipation theory to second order solitary wave theory. Specifically, an attempt was made to establish the interrelationship between internal "vortex" dimensions and the rate of wave height decay with respect to horizontal distance from breaking.

Conceptualization of these experiments is based upon the recognition that energy is released into the surf zone in a turbulent state under most breaking wave conditions. This physical state is, however, a difficult one to model appropriately without developing a proper set of mathematical relationships between the energy transport mechanism (waves and associated particle motions) and the energy dissipation mechanisms (internal turbulence). Field measurements tend to sample surface wave characteristics and in a limited number of cases, internal flow fields. Through the application of linear wave theory, semi-theoretical tuning of wave height decay prediction equations has been accomplished. Extension of these theories to interpretation of internal flow fields is not acceptable because none of them have been formulated within the context of turbulent flow. Use of mean values from field measurements of surf zone flows to verify these physically unrealistic internal flows create two additional problems. First, it perpetuates a conceptualization of surf zone dynamics which is quite incorrect. Second, it minimizes the wealth of information recorded by field sensors.

Development of a more appropriate theoretical approach is proceeding along the following lines: first it is assumed that isotropic or axisymmetric turbulent flow can, to a first approximation, be applied to conditions of wave breaking; second it is assumed that second order solitary wave theory provides a reasonable description of wave form and behavior up to breaking; third waves are considered at normal incidence (a restriction which can be relaxed later) and in only two dimensions; fourth only dissipation of kinetic energy due to turbulence is considered (energy transfer from mean motion through turbulent shear stresses and work done by viscous shear stresses are initially being neglected). A comment on this last simplifying assumption; for the initial case, $\partial \bar{U}j/\partial x_i$ in the energy transfer term is assumed to have a constant negative value, thus kinetic energy of turbulence decreases in a regular manner across the surf zone. In the future it would be of interest to consider this term and then allow it to become positive within the surf zone in order to evaluate its contribution to reforming of breaking waves.

Three separate laboratory experiments have been conducted on breaking wave height decay in shallow water. A total of twenty-nine complete wave series (each consisting of eight individual wave decay sequences) were measured during these experiments. Wave heights at breaking ranged from 10cm to 26cm and water depths were held constant at 16cm, 20cm and 24cm in each of the three experiments respectively. This range of conditions produced a full spectrum of wave types, from unbroken solitary to fully turbulent plunging breakers.

One of the most striking results from these experiments was the identification of two step like transitions in wave height decay of fully turbulent plunging breakers. At breaking a plunging breaker was observed to undergo a rapid loss of wave height (30 to 40 percent of maximum wave height) over a very short distance. It then traveled with relatively constant height, while still visibly turbulent, for considerable distance until it underwent a "jump" like transition to a solitary wave. The first of these transitions was dependent on initial breaking height, but the second was independent of initial height. The first of these transitions is similar to that observed in earlier field experiments on wave transformations (Wood, 1970, 1972). The second of these transitions would not be anticipated in the field because of rebuilding and secondary breaking. However, it is a significant result because it strongly supports the argument that the dynamics of a plunging breaking wave are "well behaved".

Analysis is completed on wave height decay data for breaking waves on a horizontal bottom. A full range of breaker types (spilling to plunging) are represented in these data. Breaker types are determined from both free surface time history profiles and photographic records of the wave, which eliminates the ambiguities inherent in using only free surface profiles. Figure 1 shows a set of wave height decay results for "G" settings of 18 (gently spilling) to 30 (fully plunging). These data show increasing non-linear decay with respect to "G" in the region immediately following breaking. Physically this means that as wave energy density at breaking increases, the intensity of post breaking dissipation increases. This physical behavior of decaying waves after breaking is not explained by existing frictionally dominated decay expressions. In fact the most commonly used relation for post breaking wave height decay $\alpha = H/2d$ is inconsistent with these data. These laboratory results are, however, in agreement with field results from earlier work under this contract (Wood, 1970, 1972). Most importantly these results provide a quantitative framework for development of appropriate nearshore energy (momentum) models. For example much of the difficulty in the longshore current model of Longuet-Higgins (1970) results from his use of the aforementioned linear decay criterion.

These wave height decay results were used to evaluate a numerical model of wave energy dissipation in a turbulent flow field. The primary objectives of this evaluation were

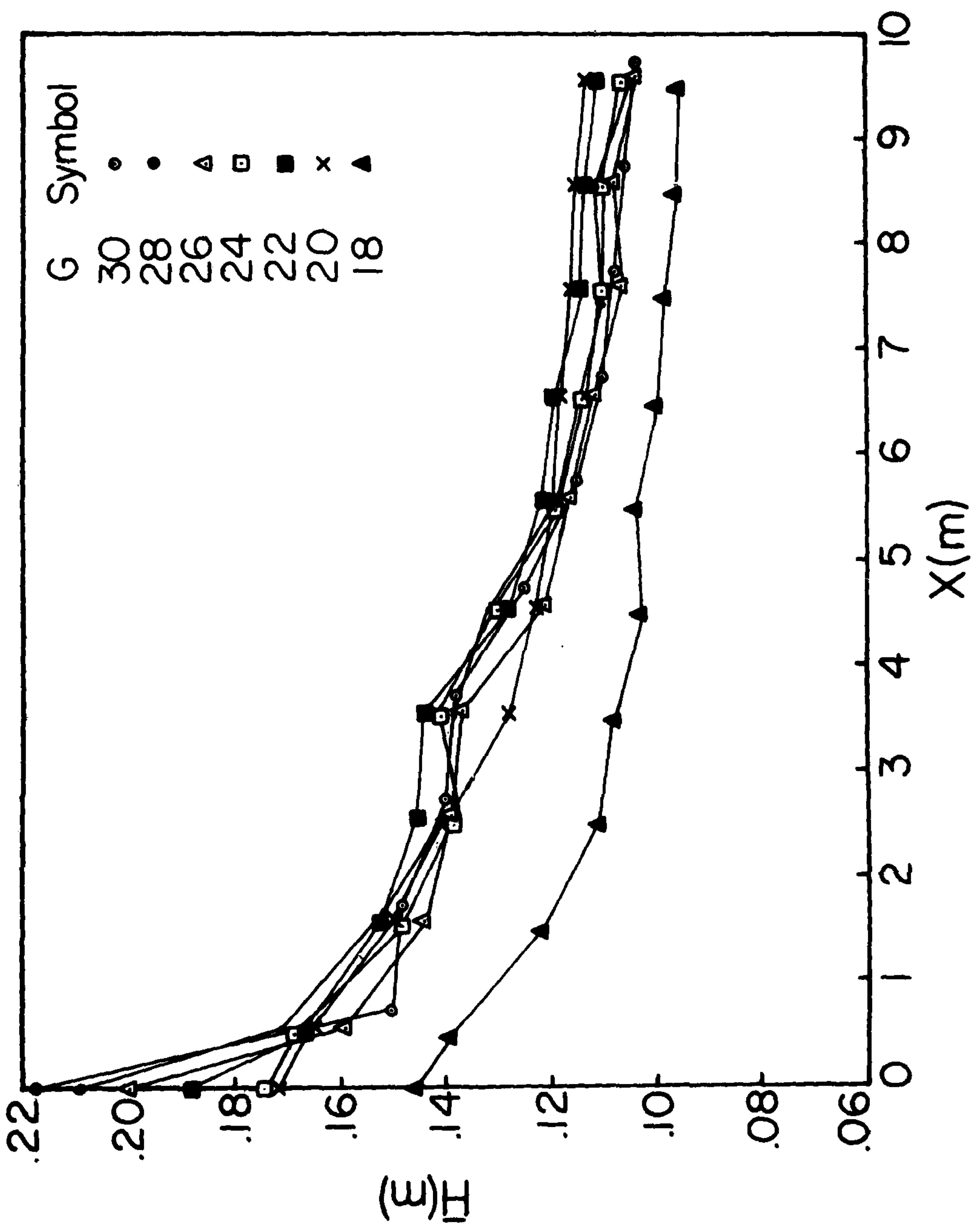

Figure 1. Wave height decay with distance from break point.

to determine whether the turbulent decay coefficient (β) was a constant and to calculate its magnitude. β is the only model parameter which is not assumed to be directly dependent on initial wave characteristics. Therefore, the initial conditions for each experimental data set were used as input to the model and β was varied until a "best" fit was achieved between the model decay curve and the observed data.

Results of this evaluation show that β is not a constant, as suggested by Horikawa and Kuo (1966). β varies directly as a function of wave height and has a range of 0.2 to 1.5. This range of values for β is similar to that obtained in earlier Lake Michigan field studies conducted under this contract (Wood, 1970, 1972). These results contradict the original conclusion of Horikawa and Kuo (1966) that β is a constant value between 4 and 5 for laboratory scale decay and near 1 for field scale decay. Clearly, laboratory results from this study support field results of Wood (1970, 1972) and Ijima (1958). The reason for Horikawa and Kuo's (1966) high β value from laboratory data is not obvious because their scale lengths were comparable to those used in this set of experiments.

Most important in this set of results is the agreement between field and laboratory values for turbulent decay coefficients. It is equally important that the variation of β was systematic and dependent upon the same parameters in both field and laboratory experiments.

A paper "Breaking Wave Decay in the Surf Zone" (Price, 1979) presents a detailed discussion of these results. A second paper "Wave Height Decay Due to Breaking" (Wood, 1981) discusses the implications for turbulent decay models in the surf zone.

This laboratory work has been considerably more revealing than originally anticipated. The agreement achieved between laboratory and field scales for β resolves a long standing problem in the turbulence dynamics of wave height decay.

Recently hot film anemometer measurements of horizontal particle velocities have been made simultaneously with collimated light motion pictures of transforming breaking waves. Resolution of internal motions in breaking waves and their associated flow fields, from motion picture records, is being greatly enhanced through the use of a computer interactive film analyzer "Galetea". It is premature to comment on these results except to point out that measurements of free surface deformation and internal particle accelerations are being made on a scale previously unattainable from laboratory data.

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APPENDIX A

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In spring 1973 a series of field experiments was initiated to investigate the three dimensional structure of a coastal hydrodynamic system. These field investigations supported the concept that short-crested wave theory is applicable to modeling of incident wind-wave transformations from offshore to the outer surf zone. Application of short-crested wave theory to the design of coastal hydrodynamic models was also considered

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) appropriate because of the theories inherent three dimensional structure. Concurrent with this work two field experiments were conducted in 1974 and 1976 to measure vertical and horizontal distribution of longshore current velocity and to monitor temporal variations in current velocity at a point. In fall 1978 a series of experimental laboratory investigations was initiated to make precise measurements, at close spatial intervals, of wave height decay after breaking. These experiments were carried out to determine a wave height decay expression based upon the assumption that an appropriate physical conceptualization of wave energy dissipation after breaking must consider turbulence dominant to bottom friction. This report presents a detailed summary of these investigations and their results.