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REPORT FROM THE NATO ARW ON WATER WAVE KINEMATICS, MAY 1989 by Alf Tørum¹ and Ove T. Gudmestad²

ABSTRACT

A report is given on the NATO Advanced Research Workshop on "Water Wave Kinematics" held in Molde, Norway, 22 -25 May 1989. The reports from the five working groups set up during the workshop are included in full.

1. INTRODUCTION

Water wave kinematics is a central field of study in ocean and coastal engineering. The wave forces on structures as well as sand erosion on coastlines and in the ocean are to a large extent governed by the local distribution of velocities and accelerations of the water particles.

Our knowledge of waves has generally been derived from measurements of the water surface elevations. The reason for this is that the surface elevations have been primary interest and fairly cheap and reliable of instruments have been developed for such measurements. The water wave kinematics has been derived from the surface elevation information by various theories. However, the different theories for the calculation of water particle velocities and acceleration have turned out to give significant differences in the calculated responses of structures. In recent years new measurement tech-niques have made it possible to make accurate velocity measurements. Hence, the writers deemed it to be useful to bring together a group of experts working actively as

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researchers in the field of water wave kinematics. These experts included theoreticians as well as experimentalists on wave kinematics. It was also deemed useful to include experts on the response of structures to have their views on what information is needed on water wave kinematics.

The objectives of the workshop were:

- to summarize research related to wave kinematics (state-of-the-art)
- to define approaches for design of safe and cost efficient offshore and coastal structures
- to exchange ideas and methodologies and to serve as a forum for idea generation
- to define further research needs and the most efficient methods to solve those needs.

A grant from NATO International Scientific Exchange Programme made it possible to hold a NATO Advanced Research Workshop in Molde, Norway, 22 - 25 May 1989. Additional funding was obtained from Statoil, Norway, the Royal Norwegian Council for Scientific and Industrial Research, Norway (NTNF) and from the Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology, (SINTEF), Norway.

The workshop was organized as a series of lectures, including invited lectures, with discussions. Five working groups were also set up on five different subjects: Deep water waves, shallow water waves, breaking and freak waves, measurements and forces. The discussions and conclusions of the working groups were summarized in reports.

The scientific committee for the workshop had the following members:

Professor A. Tørum Norwegian Hydrotechnical Laboratory/ Norwegian Institute of Technology, Norway. Director of the Workshop.

Dr.Scient. O.T.Gudmestad Statoil, Norway Director of the Workshop

Professor R.G. Dean University of Florida, USA

Professor D.H. Peregrine University of Bristol, United Kingdom

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Dr. S. Sand Danish Maritime Institute, Denmark

60 persons from 13 different countries attended the workshop.

The proceedings from the workshop have been published by Kluwer Academic Publishers, The Netherlands. The title of the proceeding is "Water Wave Kinematics" with A. Tørum and O.T. Gudmestad as editors. 35 papers and 13 written short contributions are included in the proceedings. The proceedings also contain the reports of the working groups.

It is not possible within the framework of the paper to ICCE'90 to give proper justification to all the papers and discussions. However, it is felt that the summary reports from the working groups give state-ofthe-art reports as well as recommendations for further research. They are therefore included in this paper.

2. REPORT FROM THE WORKING GROUP ON DEEP WATER WAVE KINEMATICS

2.1. INTRODUCTION AND SUMMARY

There are presently many wave kinematics procedures that are used by the offshore engineer to calculate design kinematics. These procedures include the highly nonlinear, two-dimensional breaking wave methods, the linear, random three-dimensional methods and others. In many cases the application determines the procedure to be used, e.g. for steel piled jacket (SPJ) static design the Stokes type procedures have traditionally been used. In other instances, the choice of the procedure depends on regulartory agency requirements, familiarity, avail-able experimental verification, and also simplicity. The argument can be made that all these procedures have served the offshore industry well since there have been no major offshore platform failures that are directly attributed to wave kinematics inaccuracies. This success, however, may be due to general conservative approaches used in platform design, and to compensating factors. All procedures represent approximations to the real offshore kinematics problem, and as design procedures become more sophisticated, aiming to improve safety while reducing platform costs, there is a two-fold need (1) for additional verification and improvement of the various available procedures and (2) for development of procedures that solve satisfactorily the general problem of three-dimensional irregular waves with currents. The additional verification and establishment of ranges of applicability of present procedures is of utmost importance since some of the procedures, e.g. stretching methods for irregular waves, give significantly different kinematics in the wave crest region.

2.1.1. Statement of the problem

The general problem of wave kinematics and currents in deep water is quite complex, and needless to say it has not been solved. The physical model assumed for this disucssion is deterministic (stochastic aspects of wave kinematics are not considered) and includes:

- regular or irregular finite height, non breaking waves
- wave conditions with or without energy spreading
- wave conditions with or without current.

In the case of waves only or waves with uniform current, the fluid is assumed irrotational and incompressible. For the case of nonuniform current with waves, the appropriate vorticity is assumed to be included. It is belived that any accurate solution to the analytical relationships describing this stated problem will give sufficiently accurate kinematics. Of course this will need to be substantiated with data.

2.1.2. Status

A satisfactory method for calculating kinematics in the general irregular wave with energy spreading cases that satisfies to high degree of accuracy Laplace's equation and boundary conditions is not presently available. For practical application, however, there are many analytical and empirical procedures that can be used depending on application. These procedures are backed up by varying degrees of experimental and/or analytical verification.

The extension of the two-dimensional wave procedures to three-dimensional waves is not straightforward neither from the analytical or technical nor from the wave input description side. Available solutions (empirical or low order analytical) are approximate, and, no extensive comparisons with data have been carried out.

The presence of storm tide or other non-uniform currents adds to the difficulty of the general wave only problem. Analytical solutions for regular waves (Stokes) with arbitrary current profiles are available. Also, empirical solutions are available for the general case, but those solutions can benefit from additional data.

2.1.3. Recommendations

Further measurements in the laboratory followed by carefully defined field tests are required. Test programs should be based on the need of the offshore industry. The industry should define the acceptable levels of accuracy in the kinematics, which would normally depend on application.

It is also required to develop analytical or numerical methods which solve the more general problem of kinematics for currents plus irregular, three-dimensional waves. In order to achieve this goal there is need for international cooperation and data sharing. Definition of standard bench-mark wave and current cases would also expedite verification of the procedures.

2.2. KINEMATICS MODELS

There are four major classes of wave kinematics problems that are discussed below which represent different levels of difficulty in the search for solutions. These are: two dimensional waves with and without current, three-dimensional waves with and without current.

2.2.1. Two dimensional waves

There is no kinematics procedure or theory presently available for the general case which satisfies the governing equations and the boundary conditions. The relatively new boundary integral methods hold promise but at present have computational and free boundary limitations.

Simple procedures (e.g. Wheeler stretching, delta stretching, Gudmestad method etc) which represent extrapolations of linear theory to finite height irregular waves have been successfully compared to available data according to published results. Since these procedures are basically empirical, their use far outside the range of wave parameters for which they have been verified should be done with caution. Additional kinematics data (laboratory and field) are needed in the wave crest to further verify and define the range of applicability of these methods. Theoretical efforts to assess the methods are also worthwhile.

There exist analytically robust procedures (Stokes methods, boundary integral methods, etc) to treat regular or or limited groups of waves with high accuracy although further testing against available data is necessary for these procedures, also. Verified methods for using these procedures with irregular waves are yet to be established.

Numerical procedures (e.g. stream function, EXVP method, etc) that treat irregular single or multiple waves can also be used. These procedures fit with high accuracy one or both boundary conditions. The applicability of these procedures is limited by the assumptions they are based on (rigid shape or changing shape waves) and the required length of the wave trace that can be treated.

Linear theory could be used for low wave steepness or for elevations beyond one wave height below the deepest wave trough. Higher order theories (2nd order) are available and are applicable for low steepness. These theories, however, require additional comparisons with data, also.

2.2.2. Three dimensional waves

There is no general theory presently available apart from general linear wave theory and there is no procedure under development which is computationally efficient for the nonlinear case. Some of the available two-dimensional empirical procedures (stretching methods) may in principle be extended to the threedimensional wave case. Test data will be needed to verify the accuracy of such extensions.

The linear wave theory could be used for the low wave steepnesses. Higher order numerical procedures (e.g. Forristalls KBCF-method) could be used if made computer efficient. Here also there is a need for data verification.

2.2.3. Current with waves

There is no analytical procedure available for the general case. There are, however, empirical procedures which are used by the offshore industry; these procedures have not been validated with data. For two-dimensional, steady regular waves and collinear current of arbitrary profile new theories exist and insight can be gained with these theories as to how waves interact with currents. Measurements are needed in the wave zone in particular to test the goodness of these various procedures.

2.3. RECOMMENDATIONS

The recommendations below address both short term and long term needs. The wave kinematics problem remains still a challenging problem for the theorists and experimentalist, and will require good imagination to bring about new and improved solutions that can be put to use in offshore design.

2.3.1. Data

It is recommended that the industry clearly define the required accuracy of new data needed for the different applications. Laboratory measurements on kinematics for the following wave cases are needed:

- 2D regular waves and groups of waves for a larger range of parameters to verify analytical and numerical procedures;
- 2D irregular waves to verify and extend the test data base;
- 2D current with regular and irregular waves;
- 3D irregular waves in order to extend methods and procedures presently used for 2D waves;
- 3D irregular waves with current.

The laboratory tests should also aim towards definition of <u>field tests</u> which subsequently should be carried out.

2.3.2. Analysis methods

Research should concentrate on the following main tasks:

- Develop fully consistent 2D theory for irregular waves;
- Develop empirical procedures for current with waves;
- Develop fully consistent 2D theory for current with regular and with irregular waves;
- Extend empirical procedures from 2D to 3D,
- Develop higher order analytical and numerical procedures for 3D irregular waves with and without current;
- Clarify further the mean flow in the kinematics in waves.

2.4. COOPERATION

In order to successfully develop the analytical tools needed and to fully benefit from future testing in the laboratory and in the field, international cooperation is required. It is recommended that standard test cases be defined through the cooperation of the offshore industry and research institutions in order to verify procedures. For advancing the kinematics procedures, it is essential that there be data sharing. Also, the offshore industry must continue to provide data for long term research projects at the institutions and the research institutions must continue to carry out basic research to solve engineering needs.

3. REPORT FROM THE WORKING GROUP ON SHALLOW WATER WAVE KINEMATICS

INTRODUCTION

The Working Group on Shallow Water Wave Kinematics (WGSWK) defined "shallow water" as extending from the conventional deepwater limit, h/Lo = 0.5, to the shoreline. A decision was made to focus on the needs for the next two or so decades with criteria of methodology and data required by the designer and a generally improved understanding of the phenomena related to shallow water wave kinematics. Although of importance, wave hind-casting was not considered as within the Group's scope. Finally, in order to provide focus to our recommendations, only six problem areas have been selected for emphasis.

STATUS

The shallow water region is characterized as one of substantial nonlinearity, and directionality with the possiblity of strong currents and large tidal fluctuations. At present, substantial variability in methodology ranging from ad hoc to sophistication is employed in the prediction of shallow water wave kinematics. The range of methodology encompasses regular vs irregular waves, deterministic vs stochastic representation and various methods of combining waves and currents. Although each of them can play useful roles, a better understanding is needed of the strength and relatively applicability and differences to be expected. Regulatory agencies prefer straight forward procedures suitable for codification. A need exists to develop and introduce procedures that have greater realism and physics and can be readily applied by industry.

The workshop addressed a number of problems relative to shallow water kinematics. It was concluded that for the case of regular waves without currents, existing wave theories are adequate. However, more emphasis needs to be directed to the problems of regular waves with a current which varies over depth. Of particular concern is the appropriateness of methods for predicting near surface kinematics. Due, in part, to the high nonlinearity of the surf zone and the significance of sediment transport in this area, more effort here is needed. Other areas of research need are described in the following sections of this Working Group Report.

LONG-TERM CLIMATE DESCRIPTION

- A Long-term climate description of a region is an important engineering activity which requires research in order to improve its reliability. In the absence of long-term widespread measurements, emphasis is thrown onto the use of recently developed shallow water codes such as -3 GWAM. The hindcasting is performed for adjacent deep water and wave energy is then radiated in towards the shallow water region. Inherent difficulties with this systematic approach centre around the influence of current-interaction, shoaling, and large variations of still water level with time. Areas of immediate research concern include the following:
 - Algorithms to optimize long-term information whilst reducing the bulk of wind and pressure fields processed. (Such as sequential bootstrapping techniques and other sub-sampling procedures).
 - Improving storage techniques for time-step and spatial interpolation.
 - Statistical methods for addressing questions of simultaneity of water depth, current wave fields.
- B. Although many platforms are equipped to record seastate data, this is still done on a systematically intermittant basis (e.g. 20 minutes for each 3 hours). This appears to be satisfactory for most spectral and statistical requirements, but cannot be expected to record the more extreme events which may occur whilst the instruments are on stand-by. Without resorting to continuous recording, and hence involving storage and servicing problems, it would be highly desirable to develop methods of recording the extre events in as much detail as possible.

WAVE TRANSFORMATION & DETERMINISTIC MODELS

A In the analysis of nearshore wave phenomena, the starting point will most often be information (e.g., the directional wave spectrum) of the wave field in deep water. Therefore, one needs wave transformation models that can transfer this information into the shallow water area of interest and to provide input for surf zone models. The different model employed are chosen according to the scale and distance from the shore of the area under consideration:

- Outer area: Depth-Current refraction models (linar) Ray theory, finite difference Mesh size 100 m - 1 km Size of area modelled 25 km² - 1000 km²
- Intermediate area: Models based on mild slope equation (linear, extended to include dissipation and boundary absorbtion) the parabolic approximation (linear or weakly nonlinear and dissipative). Mesh size: 5 m - 20 m. Size of area modelled: 1 km² - 25 km².
- Harbour areas: Models based on "Boussinesq equation". (Weakly nonlinear). Helmholz equation or 30 linear potensial solutions Mesh size: 5 m - 20 m. Size of area modelled: < 5 km².

Research needs:

- Spectral model including refraction, diffraction, frequency shifts due to wave breaking.
- Generation of long waves by short waves, and their transformation.
- B As the water depth becomes small and/or the waves become high, the analytical wave models seize to be valid: The prediction of maximum waves of constant form (with or without current) require the use of stream-function-like theories. In some cases these data can also be fitted to extreme wave data to account for the asymmetry found in nature. Asymmetry statistics or realistic methods of generalizing wave asymmetry should be developed. The wave models for prediction of kinematics under waves should be evaluation with high quality data.

2D models based on potential flow can now solve fully nonlinear problems from deep to shallow water. Up to now they are however limited:

- to the first breaking wave
- lack of a radiation boundary for arbitrary waves
- cannot model friction and flow separation

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Research should be directed toward:

- introducing variety
- investigating post-breaking extensions of such models
- developing a free boundary (i.e. weakly reflective boundary conditions)
- 3D potential flow models

WAVE-CURRENT INTERACTION

Waves interact with current in a number of important, and often nonlinear ways within the upper frictionless part of the water column and through their combined friction at the bed. These strongly influence the wave propagation characteristics, the current distribution, the resulting sediment transport, and forces on structures. The State of the Art and the Research Needs on various modes of interaction are as follows:

A Refraction

At the moment, refraction of linear waves by horizontally sheared, vertical uniform currents can be calculated. It is however, necessary to extend these methods to nonlinear waves.

B Kinematics

Methods for the computation of regular nonlinear waves on codirectional vertically sheared currents have recently appeared. They should be extended to noncodirectional cases, and to random waves. Also, they should be combined with above mentioned item to predict refraction and kinematics due to horizontally and vertically sheared currents.

C Mass transport

Theories exist to calculate the mass transport of water near the bed for a laminar wave boundary layer in the absence of currents. These should be extended, first to the turbulent wave boundary layer, then to the case where an external (e.g. tidal) current is imposed.

D Bottom friction

Several theories extist to calculate mean and peak bed shear stresses due to sinusoidal waves superimposed on a current. These prediction methods need to be simplified (without offering much of their accuracy) to be applicable in wave phase averaged numerical wave and current models. Also, extensions should be made toward irregular (frequency and direction) waves, breaking waves and to distinguish the wave propagation direction.

All the above topics require advances through theoretical and numerical methods, and laboratory and field measurements.

The topics require to be combined together to provide fully interactive 2D numerical models of wave and current fields, leading possibly (on the long term) to 3D models.

NONLINEAR DIRECTIONAL WAVE THEORY

A constant reoccurring problem in ocean engineering consists of finding the best choice for a given application between random, linear, directional wave theory and nonlinear unidirectional deterministic wave theory. Each approach seems to be optimal for some class of problems, but there are other types of problems for which neither is quite right. A nonlinear, directional, wave theory is sorely needed to bridge between the two extremes. In recent years, several new approaches to the problem have emerged. This, coupled with the increasing power of available computers, makes now an appropriate item to undertake the solution of this reoccurrent problem, both for deep and shallow water.

One potential direction of attack is to combine waves from several directions while forcing satisfaction of the wave equation and free surface conditions. A second direction consists of an iterative procedure which starts with a linear, directional sea surface and, in a stepwise fashion, proceeds to modify the surface toward a better satisfaction of free surface conditions while maintaining the proper directional spectrum and any conditioning constraints.

There probably are other alternatives also available. The development of such a general random directional wave theory would be of great value in future ocean engineering investigations.

SPLASH ZONE KINEMATICS

The wave kinematics at or near the free water surface are very critical in determining overturning moment and other load parameters in an offshore structure. It is difficult to make field measurements of wave kinematics in this zone since the measuring devices are alternately submerged and in the air. The abrupt shock to the instrument at the moment of passing through the air-water interface typically induces transients in the

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measurements which are difficult to interpret. Measurements of forces in the splash zone experience similar shock problems. Non intrusive measurement scheme for both kinematics and forces need to be developed and studied.

From an analytical perspective relative to random, linear directional wave theory, the prediction of kinematics and forces for locations above mean water level are perplexing and create paradoxes within linear wave theory. Linear theory assumes infinitesimal amplitudes and so kinematics above mean water level are contradictory. If the theory is used without modification above mean water level, the velocities are overestimated in a part of the force regime critical to most structural computations. Various "stretching" schemes have been proposed and used, but these are quite "ad hoc" in nature and theoretically unsatisfactory. It would be much more desireable to have some scheme which closely satisfies the free surface boundary conditions.

Some experiments have been carried out to investigate splash zone kinematics and forces under laboratory conditions. Use of these results demands a knowledge of scale effects which for these processes are poorly understood. In field conditions also there is likely to be a thin wind-induced surface current which may locally enhance particle velocities and forces.

In summary there is a research need for (a) improved instrumentation for measuring forces and kinematics in the wave splash zone, and (b) more theoretically sound ways to modify random linear directional wave theory for loading points in the splash loading zone. (c) improved understanding of scale effects and (d) of the importance of wind-induced surface currents.

SURF ZONE HYDRODYNAMICS SEDIMENT TRANSPORT

To further our understanding of the processes that shape our coastline, it is essential that we understand the hydrodynamics of the surf zone. Of particular interest are the distribution over depth of wave induced longshore and onshore-offshore currents and the momentum fluxes which drive them. Advances in this area will enable more refined studies of sediment transport modes and rates.

As has been stressed by Dr. N. Barltrop during this workshop it is important to determine the appropriate wave theory to use for a particular study. Waves in the surf zone are non-linear. The hydrodynamics of the surf zone is further complicated by the geometry of the bottom. Therefore it is suggested that shallow water wave theories (for constant and variable depth) be evaluated for applicability over various geometries (starting with planar and simple curved geometries and eventually extending to geometries which include bars). In parallel with the theoretical studies numerical approaches (such as the Stream Function Wave Theory or the Numerical Wave Tank) should be considered. Infragravity waves can also cause substantial velocity fluctuations and water surface displacements in the surf zone.

The turbulence associated with wave breaking causes the wave height to decay which is directly related to the momentum fluxes. Thus studies to determine the variation of eddy viscosity over depth and across the surf zone are essential. Another process to be further studied is the reforming of waves as they propagate over the troughs between bars.

Further research is also required in including the effects of the bottom boundary layer on the wave induced currents. In the area of sediment transport studies are required to model sediment transport across the surf zone and over depth. Shallow water symmetrical and asymmetrical waves and their interactions with currents should be considered as driving mechanisms.

Sediment transport driven by random waves is also an area requiring research efforts.

Better models to quantify longshore and crosshore sediment transport rates for suspended and bedload load transport are required. The threshold of motion and sediment pick-up rates are topics still requiring better understanding. One area of particular interest is the determination of the extent over depth of the breaking induced mixing and its effects on sediment transport. In this respect breaker types should be considered in analysis. Equilibrium beach profiles also need further research. To obtain a broader understanding of the mechanisms shaping coastal regions the sediment transport outside the surf zone requires attention. The study of the transport in this zone including tidal and storm surge currents is of importance. Surf zone and non-surf zone models of transport need to be connected in attempts to obtain a global model.

The verification of the results of the investigations suggested through laboratory and especially field testing is of utmost importance.

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4. REPORT FROM THE WORKING GROUP ON BREAKING AND FREAK WAVES

DEEP-WATER BREAKING

Presentations at the workshop have included discussion of waves breaking in deep-water but details are only given in the context of wave tank simulations. Conventional measurements at sea do not distinguish broken from unbroken waves.

We wish to emphasize that the physics of breaking waves can differ between wave tanks and waves at sea. In particular, the most frequent and important occurrences of deep-water breaking are in wind-driven waves. The character of wind-driven waves varies with their age, but at any time breaking is intermittent and shortcrested. This makes it difficult to quantify and measure breaking events.

Statistics of breaking would be invaluable. Some statistics of white caps have been collected and are clearly related to breaking events. Efforts to quantify the relation would be welcome and should be contrasted with statistics of breaking based on spectral distributions which only present the exceeding of a mathematical criteria. Such criteria need to be established from the physics of wind-wave interaction. An initial approach based on measurements following the mariner's type of observation is recommended, e.g. the percentage of braking waves as a function of wind speed, the size and duration of white caps, depth of air entrainment etc. We consider relations between sea state and Beaufort number could be confirmed and compared withh modern wind casting methods.

Short-crestedness implies a need to account for three-dimensional breaking in multi-directional seas, but first the behaviour of ideal regular waves needs clarification both experimentally and theoretically.

The important effects of wind, with its pressure distribution driving the waves and the vorticity that wind drift induces in the surface layer have yet to be quantified, although, their qualitative importance has been demonstrated. This research is urgently needed since wave breaking is intimately linked with wave generation, and this linkage produces the most severe states that ships and offshore structures encounter.

We propose that measurements of breaking wind-waves be first conducted in wind-wave flumes, where it should be possible to measure all significant parameters, though some development of instrumentation may be needed, especially to recognise wave breaking. In particular local properties worth measuring include elevation, velocity, vorticity, turbulent intensity, in both air and water as well as air or water entrainment. General properties to be examined include the type of breaking, three-dimensional structure and the role of breaking in frequency downshifting.

Theoretical studies need to be encouraged into quantifying the effects of surface drift and of threedimensionality. Current numerical models can describe two-dimensional irrotational waves as they break. Addition of a layer of vorticity at the surface is feasible. Three-dimensional irrotational programs are likely to be developed but combination with vorticity seems unlikely in that case.

SHALLOW-WATER BREAKING

Breaking induced by bottom topography is a wellstudied area because of its importance in all aspects of coastal engineering. For the purposes of this working group we ignore its implications for and interactions with surf-zone processes, other than the basic hydrodynamics. The presentations in the workshop reflect current research frontiers. That is investigation of the complex but deterministic flow field that occurs after breaking is represented by Tallent's detailed description of the eddies and splashes for a wave on a beach, the numerical modelling of wave behaviour before any splash occurs is described by Grilli and by Peregrine. These are all two-dimensional studies. For shallow-water breaking this limitation is not serious since such breaking is usually longcrested.

A number of substantial field experiments in the last decade are giving a good appreciation of surf-zone kinematics. However, for many practical purposes results from regular wave trains are used, often with extremely simplified models of the surf zone.

At the research level, many detailed aspects need study as mentioned below but the only major gaps in our knowledge concern the flow once breaking starts, until, on gentle slopes, the wave has become a turbulent bore; and the flow when breaking stops as when a broken wave enters deeper water. Further study is required because of the importance of the breaking phase in processes such as sediment transport, the generation of nearshore circulation which influences dispersion of pollution etc, the determination of set-up and run-up with relevance to flooding, and the severe conditions that breaking provides for structures such as breakwaters and sea walls.

Research is needed in the experimental area to clarify the strong effects of wind which at the present time are mainly recorded in books on surfing. Onshore winds lead to a dominance of spilling breakers, whereas offshore winds encourage plunging breakers. Several aspects of breaking need to be quantified, although we can recognise spilling and plunging breakers, intermediate cases are not readily described. That is, we still lack good definition for the relative size and strength of breakers.

The present initial studies on breaker structure need to be developed and extended since for many applications this is the most significant phase of wave development. There are still distinct experimental difficulties, and instruments or measuring techniques need to be developed, e.g. to measure air-water ratios.

Experiments and characterization of irregular waves as they break are required, especially on steeper slopes where backwash has a significant influence on breaker character.

Field observations have provided substantial data banks which can be usefully studied with further analysis and interpretation. We note however that conventional measuements can be of much greater value if simultaneous film or video records are made since it is not always easy to recognise wave breaking from other records.

Theoretical study is hampered by the difficulties of describing the breaking process, though there is a good chance of progress if the simple turbulence modelling of Svendsen and Madsen (1984) is developed. Verification of the potential flow models up to breaking by comparison with a wider range of experiments is desirable, and these models can be improved in a number of ways, e.g. inclusion of vorticity layers may mimic wind drift, or a sheared backwash flow.

Mathematical models of a simpler kind, such as those using the finite-amplitude shallow-water equations could provide insight into the interaction between the dominant waves and longer period waves (infra-gravity waves) whose origin may be in the surf-zone region and which have a dominant influence on run-up on gentle beaches. FREAK WAVES

The workshop presentations of Kjeldsen and Sand give a good indication of the "state of the art" in this area. The following definition of freak waves has been proposed by Kjeldsen

 $H_{max}/H_s > 2.0$

since this will in most cases (number of waves n = 1000-2000) represent a clear exceedance of the most probable maximum wave according to the Rayleigh distribution (c.f. Sand et al.). On the basis of observations in the Gulf of Mexico, the North Sea, the Irish Sea, off the coast of Norway, etc. it is believed that the phenomenon appears in both deep and shallow water, and is dependent on locality.

It is proposed that the following causes be further investigated:

Wave phenomenon causing freak waves:

- wave focusing
- waves arising from different directions
- super-position of waves of different scales

Amongst the physical causes are:

- topographical refraction, diffraction and reflection on different scales
- wave-current refraction
- colliding low pressure systems (e.g. collisions between polar lows and ordinary low pressures)
- combination of swell and wind seas
- response of the wave field to a turning wind field such as a hurricane

In many cases freak waves appear as a result of combinations of the phenomena mentioned above (see Kjeldsen).

Recommendations for future research are listed under the following headings:

- Full scale freak wave measurement program (selection of instrumentation, site platforms, etc)
- Extended analysis of existing data.
- Correlation of meteorological information and freak wave occurrence.
- Further description of freak wave categories as non-breaking, spilling or plunging breakers.

- Kinematic theory of 3-D freak waves (especially above MWL).
- Ultimate and accidental limit state design guidelines and possible forecasting for ships and the oil industry.

(See also recommendations given by ISSC on ship subject in August, 1988).

5. REPORT FROM THE WORKING GROUP ON MEASUREMENT OF WAVE KINEMATICS

5.1. INTRODUCTION

It was the position of this group that the other working groups in this workshop would provide the needs and justification for additional wave kinematics measurements. Consequently, our recommendations will focus more on the means of implementing measurements and making suggestions for improving the state-of-the-art. Given the very different natures of field and laboratory measurements requirements, this group felt it best to consider the requirements independently. It is important to note that our recommendation philosophy will not be limited to currently available methods and techniques but to also include technology and techniques that show promise for future wave kinematic measuments.

5.2. STATUS

5.2.1. Field

The quantity of field measurements available is inadequate and the quality, with respect to wave kinematicss, is, in general, low. Furthermore, available measurements are often severly limited in usefulness due to the measurement locations, structural influence and lack of one or more velocity components. Instrument reliability is very uncertain as instruments are often improperly calibrated and maintenance and recalibration are infrequent or non-existing. Not infrequently, valuable information in severe storms is lost due to equipment failure.

5.2.2. Laboratory

In contrast to field measurements, the quantity and variety of laboratory measuements available is signifiant, but are still lacking in the important near-surface and bottom zones. The possibility of excellent quality in measurements is high given: the opportunity for assured reliable instrument operation through frequent testing and calibration; the disturbance to the flow, by the measuring instrument or its support structure, can be made negligible or completely eliminated altogether; and that three-component measurements are attainable. Despite this, laboratory measurements must be viewed cautiously due to the possibility of improper modelling and uncontrollable tank effects.

5.3. USE OF MEASUREMENTS

5.3.1. Field

In general measurements are made for a specific purpose. Field measurements are though focusing on topics not covering the wave kinematics. Instead oceanographic knowledge is sought in order to define statistical parameters, for example:

- wave height
- tidal and ocean currents
- wind speed

However, time series of more severe events are in general available.

5.3.2. Laboratory

Laboratory experiments are, in general, conducted to verify the validity of theories and extensions to theories. Therefore laboratory measurements are, for the present, limited to unidirectional problems and most often to shallow or very shallow water cases since theoretical efforts are extensive here.

Laboratory measurements, therefore, do not cover the complex situation as found in nature that we attempt to learn more about.

5.4. MEASURING TECHNIQUES

5.4.1. Field

The most frequently used velocimeters are of the electromagnetic flow meter type. A few acoustic meters are also now available, their applicability to wave kinematics is uncertain. For current measurements, mechanical propeller meters are commonly applied for short term measuring programs. They are all kept at fixed positions by mounting directly to fixed structures or suspended from buoyant bodies. In general, none of the above mentioned meter types are suitable for measurements in the splash zone.

5.4.2. Laboratory

Commonly used types of velocimeters are electromagnetic, acoustic, and micropropeller meters. Optical techniques such as Laser Doppler Velocimetry have become increasingly used providing measurements without disturbing the flow.

5.5. RECOMMENDATIONS

5.5.1. Field

- a. Equipment operation should be kept at a level securing high fidelity, i.e. sufficient calibration and verification are needed.
- b. Equipment should be made durable.
- c. Measurements are to be taken at sufficient distance from structural influence. All three velocity components are needed.
- d. Equipment for near surface measurements needs development.
- e. Three-component LDV should be developed.

5.5.2. Laboratory

Techniques in general should be improved to allow for a more free choice in setting up an experiment. Whole-field measurements may prove excellent for verification after improvement of the recording and processing techniques. Maintenance and reliability should be given the utmost attention.

6. REPORT FROM THE WORKING GROUP ON FORCES

The discussions of this working group were an example of the dialogue and international co-operation that is personally rewarding for all participants and leads to valuable consolidation of the state-of-the-art and also points to future research needs.

This has been a workshop on water wave kinematics. Forcing on ocean and coastal structures is fundamentally related to kinematics - the two subjects should not be considered independently. However, the discussions of this working group were focussed on the issue of how knowledge of kinematics can lead to predictions of forcing. The discussions began with consideration of Morison's equation, and expanded to include other topics such as freak waves, laboratory standards, and the need for an accessible complete information data base of field and laboratory data.

We have seen that the determination of force coefficients for an irregular wave case cannot be expected to follow from any regular flow situation. The case of coexisting waves and current should also be considered separately. It has been suggested that the use of random process theory to determine the variance and statistics of extreme Morison equation forcing in irregular waves leads to very encouraging results.

It is generally recognized that kinematics in the near field are more significant than those in the far field. Further study of wave effects on force coefficients is recommended.

More data is needed on force coefficients in situations typical of the real ocean environment. Continued research into force coefficients appropriate for: multidirectional seas, coexisting waves and currents, clusters of cylinders, and relative velocity situations, is recommended. The emphasis of this research should remain on understanding the physics of the forcing process, particularly the importance of kinematics in the near field.

Having called for more research and more data, the working group considers it important to recommend that the data be available to researchers around the world, and that it be reported in a sufficiently complete manner so that results from various sources may be compared. Probabilistic format and methods should be more systematically used in the processing and presentation of experimental results in order to:

- a) make them objectively comparable, and
- b) provide the information needed for reliability design methods.

A common data base for force coefficient values, together with the ability to inter-compare the results from various sources, would encourage more rigorous application of the Morison equation.

The accident at the Ekofisk field in 1984 in which a control room wall ws damaged by a wave crest at least 22 m above mean water level has been mentioned by both Kjeldsen and Sand et al. This event provides graphic evidence that "freak" waves are a definite hazard to ocean structures. There is a need to learn more about the processes through which these waves are formed, their kinematics, and their probability of occurrence. Efforts to understand the influence of crossing seas, topography, and co-existing current, on the frequency and formation of these extreme waves should continue. More good field data is needed to extend our understanding of "freak" waves. It has been suggested that the wave rider buoy is not capable of making these measurements.

A related topic is the forcing caused by breaking waves which may not necessarily be "freaks". Breaking and very steep asymmetric waves can exert significantly larger forces on ocean structures than steady symmetric waves of similar hight and period. Such unsteady waves exist in real seas, and they should be considered by the designers of ocean structures. It is recommended that research into the probability of occurrence of wave breaking in a variety of realistic multidirectional seas should continue. It is also recommended that study of the forcing due to unsteady and breaking waves should continue.

A gap still exists between regulations - and therefore, engineering practice - and state-of-the-art research. There is a need for continual upgrading of design specifications to reflect advances made by the research community.

There was some discussion of the need for quality assessment of wave basin tests. Information of reflection characteristics, wave generator capabilities, and the vertical distribution of kinematics measured in the basin at various distances from the wave generator, should be documented and made available by basin operators.

More research on long waves and their influence on the slow drift motions of floating structures is recommended.

In summary, we would like to encourage the participants of the other working groups to continue to advance on many of the kinematics-related issues discussed at this workshop. This will help those of us in the forcing working group to solve some of our own problems. Expressed in a different way, learning more about hydrodynamic forcing on coastal and ocean structures is intimately linked to greater understanding of wave kinematics.

7. ACKNOWLEDGEMENT

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