The Specialist Committee on Environmental Modeling

Final Report and
Recommendations to the 22nd ITTC

1 GENERAL

1.1 Membership and Meetings

The Specialist Committee appointed by the 21st ITTC consisted of the following members:

Prof. Dr.-Ing. Günther F. Clauss (Chairman)
Technical University Berlin, Germany
Mr. Paul Crossland (Secretary)
Defence Evaluation Research Agency, UK
Prof. Dr.-Ing. Carlos Guedes Soares
Universidade Tecnica de Lisboa, Portugal
Dr. Seok-Won Hong
Korea Research Institute of Ships and Ocean Engineering, Korea
Dr. Roumen Kishev
Bulgarian Ship Hydrodynamics Centre
Bulgaria
Prof. Dr. Yusaku Kyozuka
Kyushu University, Japan
Dr.-Ing. Carl Trygve Stansberg
MARINTEK, Norway

In addition, the committee received specific contributions from the following appointed corresponding members to cover special experiences in the field of environmental modelling:
Dr. David L. Kriebel
United States Naval Academy, USA
Prof. Julian Wolfram
Heriot-Watt University, UK

Four Committee meetings were held as follows:
March 1997.
Technical University Berlin, Germany
February 1998
Korea Research Institute of Ships and Ocean Engineering
September 1998
Delft University of Technology,
The Netherlands
January 1999
Defence Evaluation Research Agency, Haslar, UK

1.2 Recommendations of the 21st ITTC

The recommendations for the future work of the Specialist Committee made by the 21st ITTC were as follows:

1. Survey the work done by the IAHR and others and recommend techniques for modelling the environment, including simultaneous generation of waves, currents and wind.
2. Evaluate physical and numerical modelling of realistic wave time histories.
3. Assess the quality of modelling of full scale conditions and the uncertainty in results due to differences from ideal conditions.

Following the above recommendations of the 21st ITTC the Specialist Committee undertook the tasks summarized below.

1.3 Contents of the 22nd ITTC Report

2. INTRODUCTION

The Specialist Committee on Environmental Modelling was newly created by the 22th ITTC Conference as a result of restructuring. It replaces Seakeeping and Offshore Engineering Committees in their activities in analyzing and modelling environmental conditions from the viewpoint of ship hydrodynamics.

Defining the environment is the basic input for all issues concerning the assessment of the realistic behaviour and safety of ships and offshore platforms. Specifying environmental data in addition to methods of data collection and processing have been assessed by some international research organizations such as IAHR, ISSC and other oceanographic centres. The approaches have generally reflected the specific profile of their work, which is not suitable for the needs of hydrodynamic problems. Hence, a new ITTC Specialist Committee on Environmental Modelling was formed to coordinate, generalize and amend, where necessary the achievements to date and to submit its findings in a form suitable for use as an ITTC procedure.

Techniques for wave generation and analysis have been the subject of much interest for the ITTC and is reflected in previous reports of the former Seakeeping and Ocean Engineering Committees. It can be concluded that the ITTC is almost in a position to have generalised standard procedures for routine regular and 2D irregular wave modelling, and so one main effort in this report is directed to assessing 3D wave and transient wave generation techniques as well as modelling the joint environmental actions of waves, current and wind. However, some comments on techniques and procedures which are considered essential in 2D wave modelling are also included.

3. SURVEY AND RECOMMENDATION OF TECHNIQUES

3.1. Wave Modelling in Tanks and Basins

3.1.1. Needs and Applications. In order to ensure that a new design of ship meets its desired operational performance, methods of assessing that design must be established.

Seakeeping model tests can consist of three types of experimental tests

- Regular waves (low and high amplitude)
- Random waves (Uni- and multi-directional)
- Transient waves (low amplitude)

To derive the following combination of effects

- linear motions and loads
- non linear motion and loads and related phenomena
- Capsize

Testing in low amplitude regular waves is usually undertaken to generate benchmark test data for validating the basic numerical models, especially models that are based on linear theories. Testing in high amplitude regular waves is usually performed to investigate the effects of non linearities in the motion responses (non linearities at high motion amplitudes) to compare with non linear numerical simulations.

In some cases regular waves can not be used to test certain non-linear and to obtain sufficiently well defined transfer functions means performing many regular wave tests. Investigations into non-linear phenomena such as deck wetness and slamming and linear phenomena can benefit from random wave testing in different ways. Regular wave linear transfer functions can be derived directly from random wave tests. The seakeeping performance of two or more ships can be compared by testing all designs in the same random wave train, which could be a representation of a real sea state and measuring the responses of interest .

Transient wave testing is seen as a way of minimising the run duration needed to fully define the linear responses transfer functions. Only one short experiment need be performed to obtain transfer functions over the relevant frequency range.

Model testing in offshore engineering includes testing various types of marine structures. Recently much work has been concentrated on floating structures, including very deep water systems as well as very shallow. Tests in regular and irregular unidirectional (2D) waves are most common with more emphasis on irregular waves recently. This can be seen in relation to the use of model tests for verification studies in harsh weather conditions, where possible nonlinearities and non-Gaussian extremes may be essential. Tests using multidirectional (3D) and a combination of sea and swell waves are increasing. It is a more realistic method of determining loads and responses which can be different to those measured in unidirectional waves. The construction of new facilities together with the constantly improved knowledge from field data means that the capability to test in 3D waves is possible.

Types of wave induced loads and responses to be measured or derived include linear and nonlinear vessel forces and motions, structural loads, wave diffraction, air-gap and run-up, mooring line forces, and slamming. Regular and transient wave tests are primarily used to estimate linear transfer functions and mean drift (to validate theory); other effects, including nonlinearities, may be studied. Irregular wave testing, including 2D and 3D, is also used to check linear effects, and gives a lot of additional information on nonlinearities, statistical properties and extremes. This is especially the case in testing complete platform systems with a large number of data channels and complex nonlinear interactions

3.1.2. Specification from Full Scale Much work has been done recently leading to a better understanding of the directional spectrum of waves. The availability of waverider buoy measurements and remote sensed data has also increased the knowledge about the directional nature of the seas. The development of radar measurements has provided data that allow an understanding of the wave spectrum in the capillary wave regime, and has motivated work to model the spectra of those types of waves.

The increasing trend to test in 3D waves requires that the model basins are able to reproduce the type of directional spectra that are considered representative of full scale conditions.

Scalar Spectra The main models of scalar spectra that have become widely accepted in design and model test are the Pierson-Moskowitz and the JONSWAP spectra. The latter represents developing wind sea states, while the first is applicable to fully developed seas. The JONSWAP spectrum reduces to the

Pierson-Moskowitz when one of the spectral parameters (the peak enhancement factor) is equal to unity. Those spectra represent only some of the situations that occur, in which there is only one wind sea system present. Guedes Soares, (1991) has provided evidence that, both in the Atlantic Ocean and offshore areas of Europe, about 20% of the sea states are composed of two or more wave systems, leading to scalar spectra with two peaks. It is therefore obvious that these conditions need to be considered in design and in model tests.

A 6-parameter model of two-peaked spectra has been proposed by Ochi and Hubble, (1976), obtained by superposing two Pierson-Moskowitz spectra.

Guedes Soares, (1984) has proposed a 4 parameter model that is based in superposing two JONSWAP type of spectra which can be reduced to the single peaked JONSWAP model. Typical values of the spectral parameters are found in Guedes Soares and Nolasco (1992). Henriques and Guedes Soares (1998) improved the models adopting the peak period of each of the spectral components which leads to a better fit to the measured spectra. Based on offshore data from Norway Torsethaugen, (1994) has proposed an additional two-peaked model, which in its latest version uses only two input parameters.

Different studies (e.g, Toba, 1996) highlighted the inadequacies of the high frequency tail of the JONSWAP model, which is proportional to the –5 power of frequency. Yu and Liu, (1994) have observed spectra with a tail of –4.1 in Bohai Sea in China. Prevosto et al., (1996) have provided experimental evidence that this dependence is closer to –4 for deep-water wave spectra. There was some variability in the results but Rodriguez and Guedes Soares (1998a) have shown that a significant uncertainty can be expected in the estimation of the high frequency tail based on relatively short time series.

In the high frequency range the wave spectra have a different slope depending on the frequency range because different physical mechanisms dominate the physics of the process. Rodriguez et al., (1998b) have provided additional evidence of the existence of different power laws. The very high frequency range provides the transition to capillary waves, which have started to be studied as a result of radar data.

Another scalar model that has the –4 frequency dependency is due to Banner, (1990), which has been used by Apel, (1994) to generalise it so as to cover also the secondary gravity-capillary region and to include a spreading function.

Elfouhaily et al., (1997) have proposed a unified model of directional spectra of wind generated seas, which covers the range from the long waves to the capillary wave regime. The model in both regimes has a similar description with a generalised wave age parameter, which accounts for the air-sea interaction.

The preferred spectral models are applicable for deep water situations, which have been the ones most commonly adopted for obtaining design information. However, the shape of the shallow water spectrum is different and in many applications it may be important to consider this situation.

For shallow water, the model that received relatively wide acceptance is the TMA spectrum (Bouws et al, 1985). It is based on the Pierson-Moskowitz spectrum and has a tail with a –5 frequency dependence. Another spectrum has been proposed by Donelan and Pierson, (1987), based on the JONSWAP model modified in the high frequency tail to have a –4 slope. Tucker (1994) has proposed an improvement of the dispersion relation to use in association with this formulation.

Goda (1998) pointed out that the wave attenuation of the TMA spectrum corresponds to the random wave breaker index curves of the wave steepness of 0.04 and 0.08.

The shape of the spectrum will vary as the water depth changes and different approaches can be used to predict the change in its shape accounting for saturation, shoaling and refraction, as shown for example by Lando et al., (1992) and Guedes Soares and Caires, (1995) for single peaked spectra. Mase et al., (1997) presented an approach applicable to double-peaked spectra.

Young, (1998) dealt with the prediction of waves in waters of finite depth, while Wang and Li, (1998) discussed the problems of wave simulation in shallow water basins.

Directional spreading function. The general formulation of the directional spectrum is a product of a frequency dependent scalar spectrum and a spreading function that is a function of frequency and direction.

The cosine type of parametric function proposed by Longuet-Higgins, (1963) is probably the most used one. Mitsuyasu et al., (1975) proposed a different expression, including a generalised wave age parameter, which was confirmed and improved by Hasselmann et al., (1980). However Donelan et al., (1985) concluded that an hyperbolic secant function would fit the data better; an approach adopted later by Banner, (1990). Apel, (1994) proposed a Gaussian expression for the spreading function, which matched the Donelan-Banner function within experimental errors. Caudal and Hauser, (1996) proposed two extrapolations to the high wave number region of the formulations of Donelan-Banner and of Apel. The correction factor varies strongly with wave number but only slightly with wind speed. It also models the spectral region in the short gravity range where the sea spectrum shows a weak dependence on direction. It represents an increase in the anisotropy of the spreading function at higher wave numbers

Radar and in situ measurements have suggested distinct directionality for short gravity-capillary waves. However, the shape of the spreading function continues being a controversial issue and there is no satisfactory standard form that correctly unifies the long-wave and the short-wave regime (Elfouhaily et al., (1997)). Other studies of this type were made by Krogstad et al., (1997).

3.1.3 Generation techniques. *Wavemakers.* Descriptions of wavemakers for unidirectional waves have been given in previous ITTC, and in Ploeg & Funke (1980). A survey of multidirectional wave facilities is given by Mansard et al. (1997).

Regular wave generation. The minimum distance from the wavemaker to the model should be at least 2 wavelengths, to avoid near-zone effects. At more than 20 – 30 wavelengths wave instabilities and attenuation may occur, see Section 3.1.5. The duration of regular wave trains depends on the application. In linear studies it is often sufficient to use the first stable 10 – 20 waves after the front waves. An early time window reduces effects from beach reflections, reflection from the model and standing waves. In mooring tests, however, low frequency motion transients may require longer wave trains.

Unwanted free overharmonic components, most pronounced in shallow and finite water depth, can be reduced by introducing a second-order correction signal to the wavemaker (Schäffer 1996). See Section 3.1.5.

Irregular 2D wave generation.. Waves are generated from a specified spectrum (see Section 3.1.2 for types and formulations). Frequency domain synthesization methods are mostly used, with the phase at each frequency chosen randomly and independently of the others. Spectral amplitudes are chosen from the given spectrum either by the deterministic amplitude or the random amplitude approach. Both methods are in frequent use. While the former is a convenient and engineering friendly method, it can be argued that the latter method generates purely random realisations of the given spectrum, see e.g. Tucker et. al. (1984), Stansberg (1989). Different realisations of a given spectrum are chosen through random seed numbers. The inverse Fast Fourier Transform (FFT) provides an efficient signal generation. High numbers of frequencies gives a high frequency resolution and a proper statistical representation. In offshore testing for example, for a 3 hour full scale sea state, a single FFT requires more than 10000 frequencies if the sampling rate is 10 times the highest input wave frequency. Alternatively, long records are obtained by running several independent realisations after each other.

For nonlinear response statistics, long irregular wave durations are preferred. Simulation of 3 hours sea states (full scale) is common in offshore engineering, assuring satisfactory short-term wave statistics although it may be short with respect to slow-drift responses. Previous ITTC reports have shown the requirements for ship model testing. In seakeeping tests, the accumulated duration of short model test sequences in encounter waves is normally shorter.

Wave group formation in linear sea states are random events which can be statistically predicted as a natural result of the spectral shape (Mansard and Sand 1994), and is normally not generated explicitly. In sections 3.1.5 and 4.2 further details on wave grouping are given.

Wave generation techniques accounting for second-order effects created at the wavemaker are proposed by several authors, such as Schäffer (1996). These effects, discussed in Section 3.1.5., become significant especially in finite and shallow waters.

3D wave generation.. Miles et. al. (1997) and Mansard (1998) give detailed overviews on this topic. A comprehensive bibliography is given in Mansard et. al. (1995). 3D wave synthesization may be classified into single-summation and double-summation (Miles and Funke, 1989). Most literature is on single-summation which generates waves with a spectrum systematically constant in space. It can be argued, however, that true random 3D wave fields should be modelled with natural statistical variations generated by double summation methods, related to the random spectral amplitude approach in 2D spectra. The number of frequencies and directions should be high such that individual harmonics cannot be resolved from the measured waves. A case study with 16384 frequencies and 100 directions per frequency has been demonstrated in Stansberg (1998b). Statistical variations in directional spectrum estimates, obtained in single-summation as well as in double-summation fields, are interpreted as natural results of finite time series records

For multiple segmented wavemakers, synthesized control signals are combined with directional transfer functions to generate waves. Without further modifications the wavemaker then operates in the „snake“ mode. Outer parts of the resulting wave fields are disturbed by diffraction effects, reducing the optimal working area in the wave basin. Various techniques to increase this area exist, such as Dalrymple’s (1989) method, taking into account diffraction and sidewall reflection as integrated parts of the generation. Thus the „snake“ motion of the outer wavemaker elements is modified to take care of end effects.

Sidewall reflections are also applied in Funke and Miles (1987), Gilbert and Huntington (1991) and Hirayama (1997). Some methods use phase locking with symmetric directional spectra normal to the wavemaker only.

Advanced simultaneous generation and absorption by multielement wavemakers is described in Naito (1998). This promising approach can possibly be used in the development of future multidirectional wave basins of arbitrary shapes.

Transient wave modelling. The transient wave technique based on linear wave theory has been proposed by Davis and Zarnick (1964) and was further developed by Takezawa and Takekawa (1976) and Takezawa and Hirayama (1976). Clauss and Bergmann (1986) recommended a special type of transient waves, i.e. Gaussian wave packets, which have the advantage that their propagation behaviour can be predicted analytically. With increasing efficiency and capacity of computers the restriction to a Gaussian distribution of wave amplitudes has been abandoned, and the entire process is performed numerically (Clauss and Kühnlein, 1995). The shape and width of the wave spectrum can be selected individually for providing sufficient energy in the relevant frequency range. As a result the wave train is predictable at any instant and at any stationary or moving location. In addition, the wave orbital motions as well as the pressure distribution and the vector fields of velocity and acceleration can be calculated. The point of wave/ structure interaction can be selected arbitrary, cause and effect are clearly related.

Advanced techniques of modelling transient wave groups incorporate the nonlinearities of the free surface. The interpretation of wave spectra is then more complicated because of free-wave and bound-wave components. The latter do not satisfy the dispersion equation. Clauss and Steinhagen (1999) use a FEM based time-stepping procedure, which is validated by laboratory data. Nonlinear wave-wave interactions among the free-wave components are investigated by Zhang et al. (1998) using the Directional Hybrid Wave Model that is capable of decomposing the wave field into a set of directional free-wave components. Clément and Gil (1997) performed numerical simulations of counterpropagating monochromatic wave trains with a mixed Euler-Lagrange BEM method.

Single transient wave groups may be used to model extreme waves. The NewWave model is essentially a linear, broad banded theory and uses a given sea spectrum to compute the most probable extreme wave by superposition of all wave components (Tromans et al., 1991, Jonathan et al., 1994, Rozario et al, 1993). In order to calculate the wave kinematics above mean water level “Delta stretching“ is applied. Nonlinearities are considered by simply correcting the amplitudes of the sea spectrum. The Quickwave and Designer Wave models are developed for the preliminary design of compliant towers (Morrison and Leonard, 1995). The *RealWave*-concept which is based on linear theory solves a set of coupled non-linear semi-empirical equations to include nonlinear effects by an iterative procedure (Clauss and Kühnlein, 1997a,b, Clauss, 1998). Hirayama et al. (1995) present a technique of generating directional spectrum wave groups in a towing tank. One application are point concentrated transient water waves.

The transient wave technique proves to be very efficient as a standard tool for evaluating RAO’s of stationary offshore structures or towed/self propelled ships. Nonlinear transient wave groups – both numerically and experimentally – may also be used to simulate extreme waves in irregular seas or deterministic wave/structure interactions. According to Clauss (1998) the technique is unsuitable for long term mooring or drift motion investigations.

3.1.4. Methods of analysis and documentation of laboratory waves. Wave elevation calibration is normally done prior, in the absence of a model. A set of acceptance criteria on the parameters is normally established for the calibration process. For reference use, waves are also measured with the model installed. Repeatability of waves is crucial and should be documented.

The number of pre-calibration measuring points will vary according to the requirements of the test. However, locations should be well documented, including at least some probes in the neighbourhood of the model position. It is essential to measure at the points of interest, as waves may vary over the basin area. In seakeeping tests probes over a larger area may therefore be a requirement. Measurements close to the wavemaker, in addition to input control signals, are convenient for internal control purposes. Active wave absorption requires probes on or close to the wavemaker. For laboratory 3D waves, either an array of probes, or a combination of a probe and a 2D particle velocity meter, is normally used. Typical array dimensions are slightly smaller than the dominating wavelengths, and the array typically include from 3 to about 8 probes.

Regular wave analysis. Documentation could include time traces, Fourier analysis including up to 3 - 5 harmonics, and zero-crossing statistics of individual wave It is helpful to record the full signals from calm water to completed wave train to check mean levels at start, although final analysis may include 10-20 stable cycles only. Zero level definition is important for individual crest height analysis.

The Fourier analysis can be done by FFT, provided that high frequency resolution is obtained. Average crest-to-trough wave heights, crest heights and wave periods, as well as their variability in time, are obtained.

An alternative methods of regular wave analysis may be using linear regression techniques to obtain the amplitude and phase of the time traces.

Irregular 2D wave analysis. Standard calibration is based on a selected time window with stationary conditions, for example 2 - 5 minutes after wavemaker start-up, depending on the facility. It is helpful to record the complete wave train from calm water, to check mean water levels. Mean water level definition is important for crest height statistics.

In the following, a summary on laboratory analysis procedures is given. A detailed list of wave parameters is given in IAHR (1987).

Standard analysis of irregular elevation records histories may include:

simple statistics
spectral analysis
zero-crossing wave analysis
wave group analysis.

Simple statistics includes positive and negative extremes, mean values and standard deviations. Additional parameters are the skewness and kurtosis indicating non-Gaussian and nonlinear properties based on 3rd and 4th order statistical moments, as in Vinje and Haver (1994).

Spectrum plots should include a comparison to the target spectrum. Main spectral parameters are the significant wave height H_s, estimated as $H_{m0}=4\sqrt{m_0}$, the zero-crossing period T_z estimated as T_2, the average period T_1, and the peak wave period T_p.

Zero-crossing or mean-crossing analysis is defined as up-crossing or down-crossing, see IAHR (1987). The choice should be documented. Main parameters from the analysis are the significant wave height Hs (estimated as $H_{1/3}$), the maximum wave height H_{max}, the significant crest height $A_{1/3}$ and the maximum crest height A_{max}, as well as the mean zero-crossing period T_z.. In linear waves, $H_{1/3}$ is ≈ 0.96-0.98 of H_{m0}, and $A_{1/3}$ is $0.50H_{m0}$.

Short-term distributions of wave heights and crest heights, compared to corresponding Rayleigh estimates, indicate deviations from a Gaussian process. Weibull-fitting or Weibull-tail-fitting procedures give improved extreme estimates. Due to nonlinear effects, extreme crests in deep water should be expected to be higher than Rayleigh estimates. Second-order prediction models are discussed in Stansberg (1998c). See also Section 4.1.2.

Analysis methods for wave groups are descibed in section 4.2

Comparisons to linear or nonlinear numerical reconstructions of measured time histories can be helpful in the documentation of experiments, see e.g. Stansberg (1995b). It can be a check on the experiment, and it can clarify physical effects in the wave trains. This is a field of potential future development.

3D wave analysis. A review on the laboratory use and application of 3D waves is given in Mansard (1998). Many papers were presented on this topic at an IAHR Seminar, see Mansard (1997).

Benoit et.al. (1997) present a review on various analysis methods. Most methods use cross-spectra estimated between elevation probe signals, or between elevation and particle velocity signals. The difference between analysis methods has mainly to do with how cross-spectra are combined. Types of analysis methods in use can roughly be grouped as:

Fourier Series Decomposition (FSD)
Parametric Methods (PM)
Maximum Entropy Methods (MEM)
Maximum Likely Methods (MLM)
Bayesian Methods (BM)
Deterministic Decomposition (DD)

Within each group there are several types of versions and modifications. Various applications have been compared against each other in a comparative numerical study, Hawkes et. al (1997), carried out by an IAHR Working Group, Briggs (1997). It was seen that for simple monomodal directional spectra, most methods work fine regardless of the spreading. For the resolution of secondary peaks in the spectrum, however, there are differences. Parametric methods assuming secondary peaks identify them more easily than other methods. The size of the array also determines the resolution, discussed in Stansberg (1998b).

Frigaard et. al. (1997) present an updated list of parameters in 3D wave modelling and analysis, including a discussion on 3D wave reflection and related parameters.

3.1.5 Problems to handle. *Reflection and absorption.* Beach and tank wall interference and its correction has been discussed in previous ITTC Seakeeping Committee reports.

A profound analysis of the impact of tank wall interference on the investigation of wave-current interaction effects on large-volume structures is published by Zhao et al. (1988). A comprehensive theory for predicting the effect of side-wall interference upon the hydrodynamic forces on a ship advancing in waves generated in a long tank is presented by Kashiwagi and Ohkusu (1990). For checking the side-wall interference diagrams may be used presented by Kashiwagi and Ohkusu (1989). Jamieson and Mansard (1987) describe an efficient upright wave absorber, constructed of multiple rows of perforated metal sheets which progressively decrease in porosity towards the rear of the absorber. A similar wave absorber is used to reduce the impact of side-wall interference significantly (Clauss and Kühnlein, 1993, Clauss and Kühnlein, 1995). Since the orientation of the sheets is parallel to the direction of the incident waves, only perpendicular waves caused by diffraction and radiation are absorbed (Clauss et al., 1998). Another design of a wave absorber for ship tanks and seakeeping model test basins is discussed by Fryer and Mitchell (1991).

Some research institutes use the wavemaker to absorb the energy of regular and irregular waves in a tank. Chia et al. (1994) report on an absorbing wave maker system that is capable of absorbing reflected waves while generating the target incident wave train. Naito (1995) treated the generation and absorption in general. Christensen et al. (1994) present an absorbing wave maker operated by means of online signals from digital FIR-filters. The reflected wave train is seperated from the sum of incident and reflected wave trains and the necessary additional motion of the wave paddle to absorb the reflected wave train is determined. A comparison of wave gauge and velocity meter based active absorption systems is presented by Hald and Frigaard (1997). The systems are based on digital FIR-filters. Schäffer and Klopman (1997) describe another wave maker control system using digital recursive filters for online seperation of incident and reflected waves. The surface elevation measured close to the wave board is used as the hydrodynamic feedback. Hence the evanescent wave modes must be accounted for in the filter design.

Hirayama et al. (1995) use the side-wall reflections in combination with a snake type wave maker to generate directional spectrum waves.

Wave instabilities in time and space. Instabilities can arise from reflections, diffraction, nonlinear modulations of the base frequency component, low-frequency variations, and variations in the high-frequency harmonics. They increase with increasing distance from the wavemaker, with increasing wave steepness, and with decreasing water depth. For regular wave trains, nonlinear instabilites were reported and analysed by Benjamin and Feir (1967), and later by several authors. Experiments by Stansberg (1993a) show such instabilities after about 20-30 wave lengths of propagation. Frequency downshift, wave breaking, 3D effects and dissipation may also develop further downstream. 3D nonlinear instabilities are observed and discussed by Su (1982) and by Trulsen et.al. (1999). Unstable and breaking waves in the front of the wave train can be avoided or reduced by a smooth time-domain ramp in the wavemaker input signal over the first wave cycles.

In irregular waves, similar instabilities are observed as nonlinear groups at 10 – 20 wave lengths or more from the wavemaker, Stansberg (1998a). Extremes may become significantly higher than predicted by the Rayleigh distribution, sometimes with wave breaking. Although probably explained by wave physics, and not by tank-related effects, the statistics of occurrence in the ocean is not yet quite clear. The effects are clearly reduced in multidirectional waves, Stansberg (1995a). With further propagation, spectral changes as well as wave breaking, dissipation and 3D wave formation is observed.

Wavemaking filling only a part of the basin width leads to diffraction-generated spatial variations in outer parts of the wave field, with the optimal test area near the central axis of wave propagation. In cases with multiflap wavemaker, sophisticated methods can be used to reduce the problem (Dalrymple, 1989).

Encounter waves. The encounter wave problem arises in seakeeping tests. Pre-calibration is often done at a fixed point in space, but the vessel response is excited by the encounter frequency. An encounter wave signal following the vessel can be obtained by a wave gauge mounted on the towing carriage. For freely running vessels in a model basin this may be difficult. An alternative procedure has been proposed in Aanesland and Stansberg (1995): The undisturbed local encounter wave signal is estimated from a fixed-reference calibrated signal, through linear dispersion combined with the continously updated global vessel position. Promising results have been obtained for frequency domain analysis in 2D waves.

Second-order corrections. Physical waves are normally weakly nonlinear with increased crests and reduced troughs, especially in finite water depths, but also seen for steep waves in deep water. However, nonlinear „free“ waves from the wavemaker can cause problems. For large random waves on deep water, the „free“ overharmonics normally represents a small problem, since their average amplitudes are small, and the phasing is random compared to the „bound“ waves of large waves at the same place at the same time. In more shallow waters, the problem is increasing. To avoid this, a second-order correction signal can be added in the control signal, Schäffer (1996). This is also used to suppress „free“ long waves, see below.

Difference-frequency wave components, „set-down“, is a similar second-order effect in real waves, propagating as bound waves with the wave groups. With linear wave generation, and due to reflections, they are accompanied by unwanted „free“ long waves which can be reduced by second-order correction in the control signal. In deep water, these are seen as very small, normally negligible, low-frequency oscillations.In more shallow water, the set-down wave energy, including „free“ components, can be more pronounced.

3.2. Current Generation

3.2.1. Needs and Applications.

In offshore engineering, model testing in conditions including current is becoming increasingly important. A basic effect is the additional offset of moored floating platforms and ships, especially in deep water where current forces on mooring lines and risers can become considerable. This also introduces addional damping of the slow-drift floater motion, as well coupling from surge to other motions through the mooring. The current-induced separated flow effects on risers can be significant. Similarly, lock-in effects on spar buoys can occur. The current also affects the heading control of FPSO’s etc. In addition, wave-current interaction effects can be important, see Section 3.4.

3.2.2 Specification from full scale

Full scale measurement of ocean current is commonly done by ADCP(Acoustic Doppler Current Profilers). It enables us to measure the vertical velocity profiles of ocean currents, although the maximum range of the measurement is limited to within several hundred meters. It is used as a moored ADCP to measure the deep ocean currents, for example, Johns et al. (1998), and it can also be used as a shipboard ADCP, see Cokelet et al. (1996).

Geostrophic current can now be measured by radar altimeters on satellites, such as GEOSAT and ERS-1. Challenor et al. (1996) presented a new method for combining altimetry data with hydrography in order to produce absolute surface currents from altimetry.

Coastal Surface currents in the horizontal plane can be measured using a pair high frequency radars, which utilize the back scattering of radio waves by the ocean surface.

In general, little has been published in the literature on full-scale current profiles and directional variations in deep water. Some data can now be found on the internet, for example (www.jodc.jhd.go.jp). Kyozuka (1998) showed some examples of such data, one obtained by a shipboard ADCP to measure the surface current in deep ocean off the Hawaiian Islands and the other obtained by moored velocity meters in Tokyo bay. The WOCE (World Ocean Circulation Experiment) Project is routinely measuring ocean currents at several points. The data of such full scale ocean currents are stored and available to everyone, which may help in understanding the real ocean.

3.2.3. Physical Modelling

In model testing, current is often modelled by simplified methods such as mechanical winches or by towing of the model. The consequences of such simplifications should be evaluated. A real current generation in a model basin is more complex. In some cases it is done by propellers between the wavemaker and the test location, see for example Johnson et. al. (1994). The current is generated primarily over a limited area, and the stability and homogenity of the resulting wave and current field over a larger area is a subject of concern.

In other solutions to this problem, the whole water volume is circulated in the basin system, see e.g. Huse & Tørum (1981), Yang et. al (1998). Also in these cases, some turbulence and rotational flow must be expected, since a perfectly laminar flow is very difficult to obtain. This is especially the case in deep water. Results in Huse (1992) indicate that current fluctuations observed in a model basin can be similar to fluctuations in the ocean, but more field data are needed to clarify this further. For a better understanding of these phenomena, complex computational fluid dynamics (CFD) studies may be necessary, as in Yang et. al. (1998).

Physical modelling of deep-water currents can be difficult to obtain in practice, due to limiting depths in existing facitilites. Various methods are then suggested, such as equivalent mechanical forces on truncated risers, or hybrid testing methods combining truncated model tests with full-depth computer simulations. It is expected that hybrid methods is a field of future development.

3.3. Wind Modelling

3.3.1 Needs and Applications

Wind is a major environmental factor affecting the safe design and operation of ships and floating structures. Here is a summary of some of the most important aspects of the physical simulation of winds in experimental facilities. Wind modelling in towing tanks and model basins has been briefly addressed in the 20th ITTC and in the 21st ITTC.

3.3.2 Links to Full Scale

Statistical descriptions of the wind climate for site specific areas of the world oceans or coastlines are becoming increasingly available and numerous data sources may be located. One good starting place for locating wind data is the Internet site of the Japanese Oceanographic Data Center (www.jodc.jhd.go.jp/inf/nodclist.html) which gives contact information for national data centres in 52 countries. An excellent summary of satellite-based wind data is in the 12th ISSC (1994) Committee Report on Environmental Conditions, while a review of wind hindcast is contained in the 13th ISSC (1997) Committee Report on the Environment.

3.3.3 Wind Characteristics

Several basic characteristics of ocean surface winds are of interest when winds or wind loads are simulated in the towing tank or model basin. Among these are the variation of wind speed with elevation, the temporal variation of mean and gust winds, the spectral characteristics of winds, and the statistical or probabilistic properties of winds.

Wind speeds may exhibit strong variations with elevation within the atmospheric boundary layer; and, over ocean wind speeds are assumed to vary with elevation according to one of the standard turbulent boundary layer models. In the lower elevations, within about 100m of the water surface, wind speeds are generally assumed to follow a power law formulation or a logarithmic boundary layer model, both of which are reviewed in the 21st ITTC.

The magnitude of wind speeds measured is typically specified in terms of: (1) a mean wind speed and (2) a measure of the turbulent fluctuations. Mean wind speeds are based on averaging winds over some specific time period. Typical values are the 1-minute average, 10-minute average, or the 1-hour average, with the 1-hour average being most widely used. Wind gusts are then quantified as either a “gust wind speed”, defined as the absolute magnitude of short-duration peak wind speeds, or as a root-mean-square turbulent intensity about the mean wind speed.

New relationships between wind gust speeds and the mean 1-hour wind speeds are given by the American Society of Civil Engineers (1995). These are defined by gust factors, G_t, which relate wind speeds for any duration, V_t, to the 1-hour (3600 second) average wind speed, V_{3600},. These new results include the work by Krayer and Marshall (1992) on hurricane winds and give higher gust factors for hurricanes than for non-hurricanes. For example, for the 1-second gust speed, non-hurricane winds have speeds 1.57 times the one hour wind, while the hurricane gusts a re1.73 times the one hour wind.

An alternative method of representing turbulent wind fluctuations is to define the “relative turbulence intensity" as the ratio of the standard deviation of the wind speed divided by the mean speed. Specific guidelines for the relative turbulence intensity are given by Ochi and Shin (1988), and Forristall (1988).

Under normal wind conditions, winds are usually assumed uni-directional. Van den Boom and Kuipers (1994) analyzed wind data from three North Sea platforms and found that variations in wind direction occur mainly on time scales outside of the range of response periods of floating platforms, so that winds could be assumed uni-directional. Ochi (1993) also notes that within a 10 minute data sample, nearly all of the wind energy is concentrated within $\pm 5^o$ of the mean direction.

A more severe type of wind directional change is a "wind gust front" characterized by a rapid change in both the mean wind speed and direction, often associated with a sudden change in meteorological conditions. Seelig and Headland (1998) present an example of a gust front and related problems with the dynamic motions of moored ships associated with the passage of typhoon Omar in Guam. Dahle et al. (1990) identify a similar phenomenon, the "fall wind" which includes strong gusts out of a different direction than the sustained wind and which may lead to capsizing of small vessels.

Fluctuating wind speeds may be represented in the frequency domain by turbulent wind spectra. Several wind spectra have been proposed in the literature and these latterky reviewed Feikema and Wichers (1991). In general, most turbulent wind spectra agree reasonable well in the high frequency range but differ significantly in the low frequency range.

An assessment of wind spectra is given by Van den Boom and Kuipers (1994) based on wind measurements made at three fixed platforms in the North Sea. They found that the Ochi and Shin (1988) spectrum provided the best agreement with their data over the full range of frequencies. This spectral shape was based on curve-fitting through the average measured over-water wind spectra from seven different geographical locations. For wind speeds of 40, 60, and 80 knots (about 20, 30, and 40 m/s), the Ochi and Shin spectrum gives peak wind periods of approximately 50, 30, and 25 seconds, so that the peak of the wind spectrum is near the natural period of many types of floating platforms.

Relatively little information appears to exist on the probabilities of wind speeds obtained from short-term measurements, e.g. up to 1 hour in duration. Feikema and Wichers (1991) present some data showing that short-term wind speeds follow the Gaussian probability density function. Dahle et al. (1990) also state that wind gust speeds follow the Gaussian probability reasonably well, although they also present an example in which the maximum gust speeds was 4.6 Φ_V greater than the mean wind speed which is higher than would be predicted by the Gaussian probabilty distribution.

Long-term probabilities of wind speed are generally based on several years of observations of some averaged wind speed, such as the daily maximum 1-hour average wind speed. These are then extrapolated to some extreme wind event with a specified return period of 50 or 100 years based on fitting some extreme-value probability distribution to the observed (or hindcast) wind speeds.

A reverse Weibull distribution, bounded on the lower end but with an infinite upper tail has been found to provide the best fit to hurricane wind speeds by Simiu et al. (1996). Blendermann (1998) analyzed long-term wind records at 126 sites world wide and found the reverse Weibull distribution provided the best description of long-term probabilities.

3.3.4 Physical Simulation of Winds

Winds and wind loads are generally simulated in one of two ways: (1) in wind tunnels with a stationary model or (2) in towing tanks where both winds and waves may be simulated simultaneously on a movable or partially restrained model.

A comprehensive review of wind tunnel testing as applied to marine vehicles is given by Barlow et al. (1999). Wind tunnel tests are generally performed with a fixed floor simulating a stationary water surface but with relatively high wind speeds in order to attain near-prototype Reynolds Numbers.

Recent examples of wind tunnel studies on the above-water hull and superstructure include those of Blendermann (1993, 1995), who give longitudinal and lateral wind load coefficients for various ship types, and McTaggart and Savage (1994), who discuss wind tunnel tests on a heeled (damaged) frigate model.

Various techniques are employed in wind tunnels to achieve wind characteristics which model the ocean environment as realistically as possible. SNAME (1988) contains a broad overview of modelling techniques to simulate the vertical variation of winds and the gust properties. One technique used to simulate wind effects on ocean structures in wind tunnels replaces the flat floor by a “frozen” or fixed wave form. This type of testing was reviewed in the 19th ITTC.

Numerous model test facilities now simulate over-water winds, or wind load effects, in towing tanks. Two general techniques are used. In one method, fans are used to generate a simulated wind field with resulting wind loads on a vessel. Examples of this method are given by Murray and Fudge (1989), Feikema and Wichers (1991), and Mercier et al. (1997) who address methods used to simulate the turbulent wind spectrum over a wave basin through computer controlled fan systems. All of the above papers suggest the use of Froude scaling laws to scale wind speeds. This assumes that wind loads on most above-water structures are relatively independent of Reynolds number due to the sharp-edge geometries used on most structural elements.

An alternative to relying on Froude-scaled wind speeds in the laboratory is to mechanically apply a force equivalent to the expected wind load at the wind centre of pressure. An example of this procedure is given by Brown and Liu (1998).

3.4.Combined Wave, Current and Wind Generation

3.4.1 Needs and Applications.

Model testing in offshore engineering verification studies often includes combined environmental conditions. The move towards response based design has led to the need to model the extremes of the combined effects of wind, wave and current and their interaction Smith and Burkinshaw (1996). When considering FPSOs it is important to consider not just the magnitudes in combination but also their relative directions as the most extreme responses may occur when the wave , wind and current are not collinear.

It is important to understand the effect that a current has on the superposed wave spectrum. Current is an important loading for some offshore structures and it is becoming increasingly more widespread the use of model tests with current and combination of wave and current. This type of situation can also affect ships, in particular in the entrance of harbours and at river mouths, where currents can be large. This situation has been studied by Wolf, (1997) and O'Connor et al., (1997a). Currents can also significantly increase wave drift forces.

3.4.2. Wave-Current Interaction Effects

Physical effects of steady uniform currents on waves have been well established in the linear theory. Refraction by slowly varying current and depth is explained by the geometrical optics approximation, see Mei (1989) for an example.

Nakagawa et al., (1996) examined the characteristics of distortion of the estimated spectra by current effects through numerical simulations and analysis of experimental data. Their studies show that the directional spread of estimated spectra becomes narrower than that of the actual wave field and the spectral peak is overestimated in the case of adverse currents. They proposed modifications of wave numbers and transfer functions as a solution.

In model test basins, inhomogenities in the current field may introduce unwanted refraction effects on the waves.

In finite and shallow water conditions, the problem becomes more complicated, due to the bottom geometry and coastal lines. Some numerical third-generation wave models, such as WAM models (WAMDI group, 1988) have developed to include effects of the depth- and current-induced refraction. Booij et al.(1996) presented the “SWAN” wave model which is a fully discrete spectral model based on the action balance equation implicitly taking into account the interaction between waves and currents through radiation stresses.

Benoit et al.(1996) have developed a similar third-generation model called “TOMAWAC” which uses a finite-elements technique for solving the wave action equation in spherical or Cartesian co-ordinates for infinite or finite water depth.

Chen et al.(1998) studied Boussinesq-type equations for the combined motion of waves and currents in shallow water areas. The ambient current is assumed to be uniform over depth and to have a magnitude as large as the shallow water wave celerity, allowing for the consideration of wave blocking of fairly long waves. The temporal variation of the current is ignored, while the spatial variation is assumed to take place on a larger scale than the wave-length scale.

Suh et al., (1994) developed an equation for the equilibrium range spectrum of waves propagating on an opposing current in finite water depth.

The laboratory measurement of currents in presence of waves is another problem to be investigated in the future. Thus practical procedures should be worked out for the calibration of waves and currents in combined conditions.

4. EVALUATION OF REALISTIC WAVE TIME HISTORIES MODELLING

The following is a discussion on irregular wave time series characteristics, given that the sea states (spectra) are already defined. An evaluation of realistic input spectra is given in Section 3.1.2. A general, more comprehensive review on wave modelling has been given at the 13th ISSC (1997).

4.1. Non-Gaussian Properties

4.1.1. Full Scale Data. Recent publications on field measurements document significant non-Gaussian effects in steep and extreme waves on deep water. Compared to earlier data, new data are expected to be more accurate on extremes since more measurements are now done with wave staffs, radars or lasers, while buoy data may miss details on sharp crests, Allender et. al. (1989). Second-order amplifications of crest heights, increasing extreme crests by up to 15 – 20% relative to linear theory but not affecting wave heights, are confirmed by several authors. This includes statistical skewness observations in Marthinsen and Winterstein (1992) and in Vinje and Haver (1994), wave profile observations in Jonathan et.al. (1994), and crest height observations in Jonathan and Taylor (1997), Forristall (1998) and Warren et. al. (1998). It can be concluded that the engineering relevance of a second-order deep-water random wave description and modelling has been established.

Wolfram et al (1994) examined 23558 waves from three severe storms recorded at the North Alwyn platform in the northern North Sea and found there was no significant correlation between individual waveheights and individual wave steepness. However when just those waves over 15m were considered (153 waves) then a significant positive correlation was found. In addition the Fourier analysis of these storm wave time series show that wave components do not have uniformly distributed random phase. The non-uniformity in the phase distribution may be attributable to bound waves and is of interest because linear wave generation techniques using the sum of sinsoidal components or filtered white noise assume uniformly distributed random phases.

Nonlinear behaviour of waves in shallow waters is frequently addressed in coastal engineering, Edge (1997), Edge and Helmsley (1998). See also Section 4.5.

4.1.2. Theoretical and numerical models. Second-order irregular wave theory was originally formulated by Longuet–Higgins (1963) and extended by Sharma and Dean (1981). Later formulations and discussions are done by several authors, such as Srokosz and Longuet-Higgins (1986), Marthinsen and Winterstein (1992), and Vinje and Haver (1994). A numerical model in the bi-frequency domain, including all second-order interactions in irregular waves of any spectral shape, was proposed by Stansberg (1993b). Duggal et. al. (1995) and Forristall (1998) describe other procedures on the same problem, the latter also including 3D waves. The large statistical variability of nonlinear random extremes is studied numerically by Stansberg (1998c). Narrow-band approximations are described by Tayfun (1980) and by Kriebel and Dawson (1991,1993). Probability distributions are proposed in the latter references and in Nerzic and Prevosto (1997). In conclusion, the second-order modelling seems to be well established, in deep as well as in finite waters, and it agrees reasonably well with experiments in not too shallow water.

Higher-order effects leading to modulational instabilities and large extremes in wave groups have been numerically modelled by e.g. Lo and Mei (1985), Wang et. al. (1993) and Yasuda and Mori (1994). Nonlinear wave dispersion plays a central role, as demonstrated in Stansberg (1998a). It is suggested that this may explain certain „unexpected“ (or „freak“) extreme random wave heights, sometimes observed in laboratories and in full scale. Third-order irregular wave modelling has also been described by Pierson (1993) and by Nestegard and Stokka (1995).

Nonlinear extreme wave simulations by advanced, fully nonlinear numerical models (numerical wave tanks) is a field of rapid growth. Some development still remains, it seems, before it becomes a standard engineering tool.

4.1.3. Laboratory wave trains. Evaluation of irregular deep-water wave records from a model wave basin was carried out by Stansberg (1993b), later extended to wave dispersion and kinematics studies in Stansberg (1995b) and Stansberg and Gudmestad (1996), respectively. It was concluded that a second-order numerical model describes much of the non-Gaussian effects observed, with higher crests and shallower troughs than in the Rayleigh model, and also the measured kinematics. Some underprediction of the most extreme waves, and of their phase velocities, is seen. In unidirectional waves propagating more than 10 –20 wavelengths, particularly high extremes reported in Stansberg (1998a) are interpreted as higher-order nonlinear instabilities.

Kriebel and Dawson (1993) found that extreme wave crest probabilities predicted by a narrow-band second-order probability model agree quite well with those measured in the laboratory and with limited measurements from the ocean. Studies by Ye and Zhang (1994) and by Duggal et. al. (1995) also confirm that second-order models work well against laboratory measurements.

4.2. Wave grouping

Wave grouping such as runs of consecutive high waves is commonly known to have a significant influence on the responses of fixed and floating structures in irregular waves. Its formation in linear sea states are random events resulting as a natural result of the spectral shape. Methods of characterising wave groupings can be divided into the following

1. Spectral shape parameters
2. Run lengths
3. Correlation coefficients
4. Wave envelope profile functions

Medina and Hudspeth (1990) and Mansard and Sand (1994) provide useful (if sometimes contradictory) reviews of the various techniques. Linear waves are normally considered, in which case the different methods are all closely related. In addition, nonlinear effects may influence and enhance the effects.

4.2.1. Spectral shape. It is generally accepted that spectral width is related to the amount of wave grouping. narrow banded sea states tend to show a higher amount of wave grouping. As indicated by Mansard and Sand (1994), most statistical information regarding wave groups in Gaussian waves, including such as run lengths, correlation and energy envelope statistics, is contained in the spectrum shape itself. Non-Gaussian effects due to wave–wave nonlinearities may modify this.

Several measures of spectral peakedness or width have been presented in the literature, among which are the peakedness by Goda (1970) and the correlation function κ by Battjes and Van Vledder (1984).

4.2.2. Run lengths. Kimura (1980) developed a formulation which accounted for the dependence of successive wave heights on each other, based on Markov chain assumptions. As commented in Mansard and Sand (1994), the essential correlation properties in a linear wave train can be found in parameters extracted directly from the spectral shape, such as the correlation function proposed by Battjes and Van Vledder (1984).

Battjes and Van Vledder (1984) looked to verify Kimura's theory for wave group statistics by comparing the wave group length from North Sea records. They concluded that the main features of wave group phenomena can be explained using a Gaussian model, and that the grouping can be described in terms of the correlation function κ directly derived from the spectral shape (see above). Furthermore, Burcharth (1980) compared the occurrence of wave grouping in field storm conditions with waves generated in the laboratory. Within the limitation of the small amount of data used, the paper concluded that wave group statistics were satisfactorily reproduced by certain types of wave maker generators.

4.2.3. Correlation coefficients. Medina and Hudspeth (1990) provides a detailed review of the formulations of the various correlation coefficients between successive wave heights and wave periods. They also related these correlation coefficients to the autocorrelation functions of the envelope or wave height function. Recently, Rodriguez et. al. (1998b) have investigated the correlations and run lengths in numerically simulated double-peaked spectra. A reasonably good agreement with Kimura's (1980) model is seen

4.2.4. Wave envelope profile functions. The Smoothed Instantaneous Wave Energy (SIWEH) function, introduced by Funke and Mansard (1980), is computed by squaring the wave surface elevation and applying a low pass filter (based on the spectrum peak period). A Groupiness Factor (GF) is derived. The logic behind this approach is that it may provide a method of predicting the structural response of a floating structure which responds only to low frequency drift excitation. Funke and Mansard (1980) also presented a methodology for synthesising wave time histories with known, artificial wave groups, realising that spectra alone may not be sufficient for some applications. Such wave records will then generally be non-Gaussian.

The Hilbert transform technique, see e.g. Medina and Hudspeth (1988), introduces a wave envelope which involves no low pass filtering. Mansard and Sand (1994) recognised that using the Hilbert transform was better than using SIWEH because it involves no low pass filtering.

In Gaussian waves the Groupiness Factor GF_H from the Hilbert transform procedure is equal to 1. Thus the GF from SIWEH, which is always lower than 1, is is a measure of the most low-frequency portion of the group spectrum. GF_H is related to the 4th order statistical parameter kurtosis. If higher than 1, it indicates a non-Gaussian wave, see below.

The measured group spectrum and GF_H show large statistical sampling fluctuations. Systematic increase from the linear-wave prediction indicates, however, higher-order wave-wave non-linearities, unless artificially made by manipulation. This is related to high kurtosis values and increased extreme wave heights, and are observed in narrow-band unidirectional laboratory waves propagating 10 – 20 wave lengths or more, Stansberg (1998a).

Yuxin and Manhai (1996) shows how to generate numerical and physical wave time histories with a specific group height factor from the Hilbert transformation of the wave profile.

Yasuda et al (1986) developed an alternative approach using envelope function to aid in analysing wave drift forces. The authors compared two wave group measures (groupiness factor and the average run length) with the inverse of the wave number times the water depth. There appears to be little correlation between any of these methods to quantify essentially the same thing.

Dawson et al. (1996) have extended the second-order probability model to include the probability of a succession of consecutive high wave crests based on the Markov theory. This was verified using both laboratory data as well as field data from hurricane Andrew..

4.3. Extreme and Breaking Waves

The physical or numerical modelling of ship motions in severe seas should consider the possible encounter with individual extreme waves. Critical stability conditions may occur due to the ship encounter with a single large wave, or due to the ship encounter with a group of two or more high waves. Important parameters of these extreme waves may then include the individual wave height, wave steepness, crest or trough amplitudes, and whether the wave is breaking.

Extreme Wave Characteristic. Several recent studies have considered the characteristics of individual extreme waves, either theoretically and experimentally. For example, Jonathan et al. (1994) present some evidence that the time series in the vicinity of the extreme wave, matches the autocorrelation function of the wave record. Similar results have been reported by Tromans et al. (1991) and Jonathan and Taylor (1997). Johannessen and Swan (1997) describe extreme 2D water waves in an unsteady or irregular sea state.

Taylor et al. (1995) and Harland et al. (1996, 1998) discuss the use of constrained simulation to produce a time series of irregular waves in which an extreme design is embedded in a group of irregular waves. They apply the method to the simulation of the maximum force on a fixed platform, but the procedure could also be applied in seakeeping studies. Wave profiles associated with extreme loading in random waves were also investigated by Drake (1997).

In the extreme, large individual waves may be termed “freak” waves owing to their very low probability of occurrence. Freak waves are typically defined as individual waves which exceed twice the significant wave height, a wave height which would occur only once in about 3,000 waves according to the most probable maximum wave height from Rayleigh statstics.

Sand et al. (1990) and Kjeldsen (1990) applied this criterion for freak waves, $H_{max} > 2.0\ H_{s,}$ to the analysis of waves measured in the North Sea. They found instances of freak wave occurrence in which the wave height was in the range of 2 to 2.6 times the significant height. Wave crest amplitudes were then found to be in the range of 1 to 1.5 times the significant wave height.

Skourup et al. (1996) present an analysis of 400 freak waves, identified as individual waves whose height exceeded 2.0 H_s or whose crest amplitude exceed $1.1H_{s,}$ based on wave measurements in the North Sea over a period of 12 years. Scatter plots are presented showing correlations of various wave parameters for these freak waves; it is found that the wave crest amplitudes for freak waves are, on average, nearly 70 percent of the wave height. In addition, most freak waves were found to be at or near the theoretical limiting steepness for breaking waves.

Yasuda, Mori, and Nakayama (1998) suggest an even more stringent requirement that freak waves exceed 2.5 H_{max}. Clauss (1998) confirmed the possibility of such waves by generating an extreme wave with H_{max} = 3.2m in a spectrum with H_s = 1.25m and T_P = 8s. The ratio of crest amplitude/wave height for this wave was 0.65, and the 2.1m crest height surpasses the sum of component wave amplitudes by 30%. Theoretical explanations of such events clearly require higher-order theoretical models.

Breaking Waves. Extreme wave heights and extreme crest amplitudes are eventually limited by wave breaking. Wave breaking characteristics are also of direct importance to ship capsizing as discussed by Dahle and Myrhaug (1996).

Two general approaches have been taken in the simulation of breaking waves. In the first approach, individual geometic, kinematic, or dynamic properties of breaking waves have been considered. In the second approach, the statistical occurrence of breaking waves in a random sea has been considered.

Easson (1997) reviews the application of regular wave breaking criteria based on limiting steepness and crest asymmetries. As in other studies, e.g. Kjeldsen (1990), it was concluded that the individual wave steepness was not sufficient to identify breaking waves. The ratio of crest amplitude to wave height seemed more promising with limiting values near 0.65, although other studies, e.g. Kjeldsen (1990), have found breaking waves with even higher asymmetries. Similar results were found by Kway et al. (1998) based on laboratory tests with deep water wave packets. She et al. (1997) discuss many details of the geometrical characteristics and kinematics of breaking waves for three-dimensional waves.

For irregular waves, Kriebel and Dawson (1994) show that the continual breaking of a wave, as the wave evolves in a moving wave group, may partly explain why no simple geometrical parameter can uniquely define breaking events. Dawson et al. (1993) and Kriebel and Dawson (1993) then coupled a second-order model for nonlinear wave crest probabilities with a breaking criterion based on the average or mean steepness of breaking waves to predict the overall probability of breaking. This work, and a study by Massel (1998), shows wave breaking in random seas occurs, on average, at lower values of steepness than is observed in tests with regular or transient waves.

Nepf et al. (1998) gives a complete review of breaking criteria formulated for application to random waves, and then compares breaking characteristics in two- and three- dimensional waves as observed in multi-directional wave tank tests. They found that the onset of breaking in three dimensional seas can be enhanced or suppressed compared to two-dimensional seas, for waves that converge or diverge respectively. Similar work by Johannessen and Swan (1997) showed the importance of the directional spreading on the breaking process.

4.4 Joint probabilities of individual waves

A series of papers by Myrhaug and co-authors address the joint probabilities of various wave parameters with possible application to ship capsizing associated with ship rolling in successive waves. These include papers by Myrhaug and Rue (1993), who consider the joint probability of wave height and wave steepness in deep water, Myrhaug (1994), who considers the probability of wave crest front steepness for successive waves, and Myrhaug and Kvalsvold (1995), who consider the joint distribution of wave height and period.

This highlights the difficulty of fitting simple joint probability models to such (see Myrhaug and Kvalsvold 1992). Myrhaug and Kvalsvold transformed the theoretical distributions of Longuet-Higgins 1983 and Cavanie et al 1976 for joint probability of individual waveheight and wave period, obtained from linear theory, into corresponding distributions for wave height and steepness; and then compared these with wave data collected in 22 gales at three sites off the Norwegian coast. They find the theoretical distributions provide a relatively poor fit to the data. Olagnon and Krogstad 1998 have examined wave steepness in the context of 16 702 wave data from the Frigg platform in the North Sea. They have transformed the time series in the region of each crest into a corresponding spatial expression using Fourier transforms and the wavenumbers for each component frequency obtained from the linear dispersion relationship. They show that the individual wave profiles so obtained in the spatial domain are very different to the corresponding profiles in the time domain; and obtain an empirical relationship between space and time domain steepness. They find that the theoretical distributions of Longuet-Higgins and Cavanie et al over estimate the average steepness of waves. The also establish an empirical relationship between sea state steepness and the mean steepness for individual waves and show (also empirically and quite convincingly) that the expect seastate steepness increases as the logarithm of Hs.

Myrhaug and his co-workers have consider wave front and wave back steepness as well as the steepness of successive waves (Myhaug 1994 and Myhaug and Rue 1993). These studies (and that of Olagnon and Krogstad among others) show that there can be very significant horizontal and vertical assymmetry in individual waves.

There are three well known theoretical models based on linear theory for joint probabilities of individual waveheights and periods; notably those of Longuet-Higgins, Cavanie et al and Lingren and Rychlik 1982. The last of these was been found by Srokosz and Challenor 1987 to provide the best fit to empirical data but it is complex to use as it cannot be written in an explicit form and currently the Longuet-Higgins is probably the mostly widely-used theoretical joint distribution. Various empirical and semi-empirical distributions have been developed to fit particular sets of data.

Feld and Wolfram 1996 found the Plackett distribution (see Athanassoulis et al 1994) a particularly flexible model when considering storm wave data from the northern North Sea as the marginals for waveheight and wave period can be chosen arbitrarily and independently before combining to form the joint probability distribution. They found the Plackett distribution to produce better fits to the data than the Longuet-Higgins distribution and they also found the distribution of periods to be bi-modal. Rodriguez and Guedes Soares 1997 point to other cases of bi-modality in data sets from mixed sea states and Sobey 1992 has found using simulation that such bi-modality is endemic to the JONSWAP distribution..

Bitner-Gregersen et al 1998 compare maximum likelihood and conditional modelling approaches to joint probability modelling in the context of Hs, Tz, average wind speed and directional data from the DB1 buoy of the south west corner of the U.K. It is concluded that the conditional modelling approach is more flexible but that there is no theoretical way of defining the best joint density. This is a fair reflection of the current position as there is little common consent either about the best distributions to use for the joint probability modelling of full-scale data, or the best fitting procedures, or about the best way to assess goodness-of-fit and confidence intervals.

4.5. Shallow water effects

It has been known that waves in finite water depth are generally considered to be a nonlinear, non-Gaussian random process.
Ochi (1998) presented a formula for evaluating the probability functions of peaks, troughs and peak-to-trough excursions of coastal waves. The probability functions were compared with wave data sets ARSLOE, and good agreement between them was obtained.

5. UNCERTAINTIES IN FULL SCALE TO MODEL SCALE

The different sources of uncertainty from full scale measurement of the environment through to analysing waves in the laboratory are shown in Figure 1. This chapter considers the uncertainties related to full scale measurements, their analysis and predictions from them. The generation of waves in the tank, their propagation, their measurement and analysis are discussed in Chapter 3. However the associated uncertainties are not addressed and these are topics we recommend are considered by the next ITTC Environmental Modelling Committee.

Generation in Tank. Problems of wave generation in model tanks are related mostly to, control signal synthesis, mechanical restrictions and wave propagation (decay over tank length and reflection). Wavemakers possess relatively narrow frequency band transfer functions, often nonlinear.

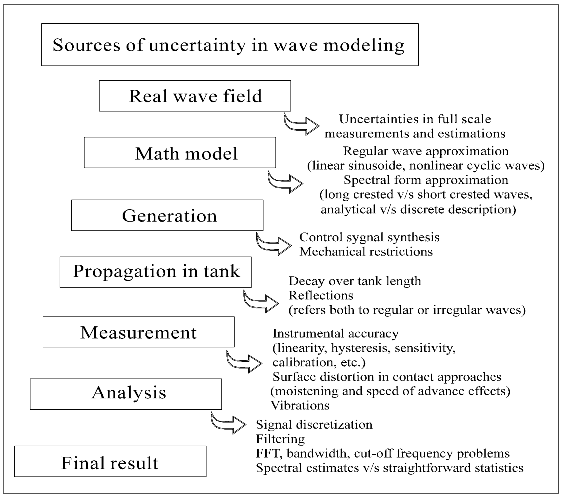

Figure 1. Sources of uncertainty in wave analysis

Consequently, there might exist very low or high frequencies of still significant spectral components, which the unit is not able to reproduce, and nonlinearity as well as short waves decay along tank length and long waves reflection can distort the form of spectral curve, which is essential for proper modelling of energy distribution. This can introduce errors in control signal synthesis, as operation with nonlinear transfer function in combination with often empirical corrections for wave distortion at propagation is difficult.

Measurement. Uncertainties here are connected with:

1. Physical (operational) effects, such as wire probe moistening, surface distortion at speed and motion, vibrations of probe supporting arm or carriage, transmission, etc. Most of these effects appear in case of contact probes and can be corrected by dynamical calibration;
2. Instrumental accuracy (linearity, hysteresis, sensitivity, signal conditioning, A/D conversion, trend, etc.);

3. Calibration accuracy (range, number of steps, accuracy of reference measure, etc.).
4. Commonly accepted limiting value for combined effect of abovementioned factors on measuring accuracy is 0.5-1.0% of the range value.

5.1 Measurement devices, their limitations and uncertainties

There are a variety of measurement devices for making full-scale measurements of waves, wind and currents in the marine environment. Broadly they can be split into two categories; those that provide point measurements over a volume or area that is measured in centimetres (ie. small in comparison to the spatial variation of interest) or at most a few metres; and those that provide spatially averaged measurements over regions measured in kilometres. Many of the former types of device have been used to collect data for over 50 years whereas the latter, based on land and satellite EM devices (HF, SAR, scatterometers, SSM/I, etc) have only become generally available in the last 10 years.

The former devices include anemometers for wind speed and direction; propeller, electromagnetic and acoustic current meters; wave staffs, wave altimeters and wave pressure sensors. These devices can be attached to fixed or floating structures such as ships and buoys. Wave buoys (that may sense wave direction) often have current meters, anemometers and other instruments attached. On floating structures compensation is needed to allow for the motion relative to earth fixed axes and, for wave measurement, relative to the sea surface. If the scale of the horizontal motions of the buoy or vessel are of the same order as the wave length then the recorded surface elevation does not correspond to a single fixed point (e.g. Seymour and Castel 1998). These relative motion problems affect the accuracy of wave buoy measurements and makes them unsuitable for examining the non-linearities in waves (Tucker 1991). In the comprehensive WADIC project (Allender el al 1989) at the Edda platform in the North Sea seven types of wave buoys were compared against a “base data set” obtained with an array of EMI laser altimeters and an array of bottom mounted pressure transducers. Typically wave buoys were found to give estimates of significant waveheight with biases up to around 0.25m, and estimates of wave direction with biases averaging 9 degrees. However when measurement devices are mounted on fixed structures then the presence of the structure may effect the flow field. Thus data for some directions from current meters mounted on jacket structures can may have significant errors, as may wave height meters that are in the lee of a structure where there may be spray (e.g. Cardonne et al 1995). Anemometers are affected by the surrounding structure unless mounted on high masts and those mounted on wave buoys may find themselves in the shadow of large crests when the buoy is in a trough leading to significant underestimates (up to 20%) of extremes (Cardonne et al 1995).

The latter devices based on radar, including satellite-borne Synthetic Aperture Radar (SAR) and land and ship based HF (High Frequency) radar provide spatial averages, and these are usually calibrated against the temporal averages (typically of the order of an hour) obtained from point measurement devices within, or close to, the area. Such calibrations with wave buoy data show root mean square errors of around 1.5 to 2m/s in wind velocity and 10^0 to 20^0 in wind direction measurements (Cardonne et al 1995, Chang and Li 1998); and around 0.3m in Hs and 0.8s in Tz (Cotton 1997). Young 1999 has compared Hs satellite data from three sources GEOSAT, TOPAX and ERS1 with buoy data and obtained regression lines that vary significantly with SAR type. However wavebuoy data, as noted above, has its own random errors and biases and these errors must be interpreted as relative rather than absolute. In addition current interpretation algorithms are not good for wind speeds above 15m/s (Rufenach 1998) and high wave heights. Currently radar data are usually analysed using algorithms based on linear, Gaussian assumptions and for waves the output is usually presented in a spectral form. However non-linear statistics are recovered and steeper wave environments can be distinguished from others (Eltoft and Hogda 1998), holding out the possibility that non-linear wave statistics may be recovered in the future. The advantage of the satellite data is that it has world-wide coverage and estimates of wave spectra, mean wind speeds and directions and surface currents and direction can be obtained for any offshore location. The disadvantage is that the spatial resolution is of the order of tens of kilometres and thus point estimates for near shore locations where the topology is variable will be poor and the non-linear characteristics of individual storm waves and wave groups (and wind gust behaviour) are not recoverable. Indeed such data can only usually be recovered using Metocean sensors mounted on fixed structures from which there are comparatively few data.

5.2 Uncertainty in spectral estimation

Many of the models of the scalar spectrum and of the directional spreading functions have been derived from experiments but there has been an increased awareness of the effect of the analysis procedure on the shape of the estimated spectra. This is a problem both for full scale and for laboratory generated spectra.

Young et al., (1995) have discussed the problem of the confidence limits associated with estimates of the spectral peak period. While this work and earlier publications, addressed the statistical uncertainty in the estimation of spectral parameters, Rodriguez et al. (1998b) have studied the uncertainty that results from that adoption of different methods of spectral estimation. They concluded that only the peak period was significantly affected by the estimation method.

Gomes and Guedes Soares, (1997) have used the Maximum Entropy approach for the spectral estimation and have found that it tended to produce better results than other methods but there was the drawback of requiring the choice of the appropriate order of the autoregressive model. Kim et al., (1994), have compared the performance of two different versions of the maximum entropy method concluding that the one of Kobune and Hashimoto, (1986) performed better for double-peaked spectra than the one of Lygre and Krogstad, (1986).

Hashimoto et al., (1994) have developed an extension of the maximum entropy method that is able to deal with more than three simultaneous measurements and applied it to data from 5 mixed instrument array measurements, obtaining very good results. Fujiwara and Isobe, (1996) proposed a method based on a standardised distribution, which is able to deal with bimodal directional spectra. Yokoki and Isobe, (1996) proposed a method of estimating directional spectra in a field of incident and reflected waves, which was shown to be very practical for estimating spectra in model basins.

Brissette and Tsanis, (1994) compared five different directional spectrum estimates for both synthetic and field data. They used the conventional Fourier analysis, the Maximum Likelihood, the Iterative Maximum Likelihood, the Eigenvector Maximum Likelihood and the Maximum Entropy methods. They concluded that the Maximum Likelihood method, although not an optimal estimator, gives the most consistent and predictable results. The other methods were found to have unwanted features, such as wave number dependence, high sensitivity to noise or numerical instability.

Benoit and Teisson, (1994) have studied laboratory data from directional sea states measured by three different systems and analysed by seven different methods of spectral estimation. One of the methods was an array of five resistive type wire probes mounted on a frame and equally spaced of 72 degrees. Other was the heave, pitch and roll sensor that is used in waverider buoys and the last one used a wave probe for the free-surface elevation and a

3D acoustic velocimeter for the two horizontal components of the velocity.

Comparing with the methods considered by Brissette and Tsanis, (1994), they have not considered the Eigenvector method that Benoit, (1993) found not to be good. However they also adopted the Bayesian method, the parametric bimodal Gaussian model, and the Variational method. Benoit and Teisson, (1994) have concluded that some of the methods of estimation produced similar results.

An interesting study has been reported by Hawkes et al., (1997), which involved several wave basins that have generated a set of sea states with different properties and have analysed the generated samples with different methods of estimating the directional spectra. The results provided some guidance about the situations in which the simpler methods provided good results and the situations that required more sophisticated approaches.

Benoit et al., (1997) describe several methods in present use and remark that they are very different with respect to implementation effort and computing time, with a ratio that can be up to 10,000 between the quickest and the less sophisticated one. The method to adopt should depend on the type of measuring device

As to the methods of recording waves Benoit and Teisson, (1994), concluded that for unimodal sea states the single point measurements with three signals were enough, being the heave-pitch-roll sensor probably better. However for bimodal sea-states the gauge array was necessary, but it required more complex methods of analysis, such as the Maximum Entropy or the Bayesian method, in order to obtain reliable results.

Lin et al., (1996) have compared the performance of a point gauge system consisting of a pressure transducer and a biaxial current meter with a slope array consisting of four pressure transducers and they concluded that the first system performed better

Guedes Soares and Cavaco, (1997), have compared different methods of estimating the directional spectrum using measured time series from the Portuguese coast. They have also considered different theoretical models for describing the spreading function and have concluded that the variability that results from adopting different estimation methods is larger than the differences in shape among the theoretical spreading functions.

Statistical sampling fluctuations in the cross-spectra and in the estimated 3D spectra and parameters are commented in Hawkes et. al. (1997), indicating larger scatter with single-summation than with double-summation generation. The problem is further documented in Stansberg (1998b). Fluctuations are expected to increase with decreasing record duration.

5.3 Uncertainty in extremes

Extreme values of significant wave height or of individual heights are of importance for model tests since often these conditions are necessary to be reproduced in model tests. The work in this topic is vast and there is no space for a full account. Some recent reviews are by Goda et al., (1993).

One problem that has been identified in this approach is the pooling of data sets that are not from the same population and thus do not satisfy the basic statistical requirement of "independent and identically distributed samples from the same population". Guedes Soares and Nolasco, (1992) have shown that the samples of double-peaked sea spectra have different statistical behaviour than single peaked ones. Guedes Soares and Henriques, (1996) have shown that there are significant changes in the statistical descriptors of data along the different seasons of the year. Guedes Soares and Ferreira, (1995) have shown that even for consistent seasons of the year there are often a too large yearly variability for the data sets of different years to be considered from the same population. Despite some increased understanding of the underlying problem it is felt that there is not yet available a definite answer of a practical method to model this situation.

In addition to the problem of the choice of the data set the choice of the probabilistic model to adopt also introduces uncertainty. The traditional approach is to pool all available data and fit a distribution to it. Typically the log-normal and the Weibull distributions have been used and experience has shown that the first one is a better model for low to moderate significant wave heights while the second fits better the tails. However these models are sometimes not good ones and efforts have been made to use alternative models such as the Gamma and the Beta distributions by Ochi et al., (1997), Ferreira and Guedes Soares, (1999) and Leyden and Dally, (1996).

An alternative approach to fitting the whole data set is to concentrate only on the upper tail and to adopt the method of the Peaks Over Threshold (POT). Only the data that exceeds a certain level is considered and this solves some problems of independence of data and of belonging to the same population. The data is then fitted by the Generalised Pareto distribution. Examples of applications of this method to modeling of waves can be found in Ferreira and Guedes Soares (1998) and Elsinghorst et al (1998). An interesting comparison of predictions by several methods including POT can be found in van Vledder et al., (1993), which provides an idea of the uncertainty involved in such predictions.

Heideman et al 1995 show that data sets of many years duration are statistically necessary to obtain tight confidence intervals for extreme value estimates.

GENERAL TECHNICAL CONCLUSIONS

Many studies have shown that the high frequency tails of deep-water spectra are close to the minus 4th power, but the current practice is to adopt the Pierson-Moskowitz and JONSWAP models that have a minus 5th dependency.
Two peak spectra have been shown to occur relatively frequently in different locations, which may lead to responses that are different to those in single peaked spectra.

Satellite observations are creating a growing body of field data on directional waves, surface currents and wind, which provides a comprehensive coverage of The World's oceans and hence will lead to a better understanding of environmental conditions.

Most of the reported work concerning the interaction between waves and current are for shallow water scenarios. Little has also been published about currents in deep-water, especially concerning their vertical profile. It is recognised that these conditions may be difficult to reproduce in laboratories.

Extreme individual wave heights more than twice Hs have been measured at several locations offshore.

There is no generally accepted model for the joint distributions of several environmental parameters and for the joint properties of short-term sea states.

Many properties of shallow water systems are well known in the coastal engineering community, but it seems that there is not much experience within the ITTC in testing in these conditions.

There is strong evidence that wave non-linearities are present in severe random seas in deep water and many of their properties can be well modelled mathematically by second order wave theory (this can lead to increases of wave crests up of 15% relative to linear theory). These second order effects are well represented in model tests. However, full-scale data shows significant differences between wave front and back steepnesses, which is not modelled by second order theory.

Little has been published regarding the documentation of wind and currents generated in laboratories. Although information is available on full-scale characteristics of wind, namely spectra and vertical profile, it seems that it is not modelled very often in laboratory tests.

Transient wave modelling is shown to be an efficient tool to study the linear response of floating bodies. It can also produce very large, steep and breaking waves that can be used in deterministic studies of non-linear wave-structure interactions.

In laboratory tests, statistical properties of irregular waves, including the directional properties and resolution in 3-D systems, should be properly documented. If pre-calibration is performed repeatability of the calibrated conditions is essential.

During the recent past many developments have occurred on active 3D wave absorption.

Due to water depth limitations, laboratory modelling of deep water currents must often be made using simplified tools and combined with computer simulations (hybrid testing).

RECOMMENDATIONS TO THE CONFERENCE

There is growing evidence of instabilities in the generation of waves in space and time especially downstream in long tanks. Thus in laboratory tests the wave time history should be measured at the point of interest.

When performing models test in irregular wave conditions, consideration should be given to include cases of double-peaked spectra, since these have been shown to occur relatively frequently in full-scale and to involve specific problems.

Further work is necessary to understand the probabilistic nature of extreme seaways synthesized from controlled superposition of deterministic high transient waves with random seas.

RECOMMENDATIONS FOR FUTURE WORK

It is recommended that situations should be identified in which shallow water wave conditions need to be modelled in laboratory. The compatibility of ITTC and coastal engineering practices for modelling shallow and finite water depth should be investigated.

To gain a better understanding of the limitations of present practice, it is recommended that studies on the uncertainty of different aspects of wave modelling should be undertaken.

It is recommended that the use of simplified tools and combinations of experiments and computer simulations used to model deep water environmental conditions should be evaluated.

Further work is necessary to improve the understanding of the interaction between wind, waves and current and to assess the features of the laboratory simulation of these combined situations, before specific recommendations can be made.

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The Specialist Committee on Environmental Modelling

Committee Chair: Prof. Günther F. Clauss (Tech. Univ. of Berlin)
Session Chair: Dr. Arne Hasle Nielsen (Danish Maritime Institute)

I Discussions

Remarks based on 22nd ITTC 1999 report on Environmental Modelling

by Jaap-Harm Westhuis, MARIN/Univ. of Twente, The Netherlands

Numerical simulation of water waves.

Although BEM based solvers are mostly used for fully nonlinear (potential flow) free surface simulations, FEM based methods are becoming increasingly popular. The mentioned FEM based method by Clauss and Steinhagen (ITTC p.7) has been previously reported by Wu and Eatock Taylor [5] and Westhuis and Andonowati [4]. The latter have extended their method to including several types of wave makers, several types of efficient beaches and the inclusion of captive ship sections.

Wavegroup Instability

Although quasi analytic numerical codes that solve transient wave problems of approximating non linear equations can provide useful insights, several severe instability effects, as have been reported (Stansberg, ITTC p.10), do not occur correctly in these models. The fully nonlinear numerical code currently developed at MARIN however, is able to quantatively predict this wave group instability (see also figure 1 in which the spatial spectral evolution of the original bichromatic wave (T_1 = 1.9 s, T_2 = 2.1 s both 8. cm in amplitude). Recent publications on this subject (see Tulin [3] and references therein) may serve as a good starting point for further research into these phenomena. In a previous presentation [2] it is shown that the equations derived by Krasitskii [1] seem to provide the best suited approximating model for quantatively simulating these instabilities.

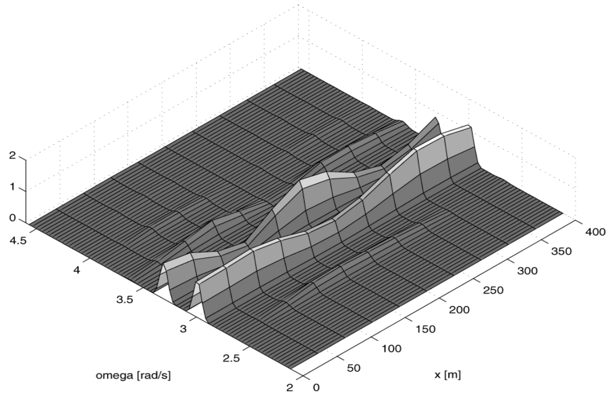

Figure 1: Spatial evolution of the spectrum showing wavegroup instability and ‘recurrence’

Comment on the Recommendation to the Conference

by Prof. Marc Vantorre, Univ. of Ghent, Belgium

The committee recommends to measure wave time history at the point of interest. On the other hand, such wave measurements are very likely to be affected by interference with radiation and diffraction waves. For this reason, I would like to suggest a more general formulation for this recommendation: one should be able to determine the time history of the undisturbed incident wave at the point of interest.

Seakeeping tests in Oblique Wave Groups

by Dr. S. Cordier, Bassin d'Essais des Carènes, France

I would like to thank the committee for a very informative report. The committee is very enthusiastic about the use of transient waves to identify the RAOs of floating structures. Our experience with this method is quite powerful and efficient, and further gives results which are identical to an RAO generated in irregular waves or in regular waves. All these tests have concentrated on vertical plane motion and without speed of advance. Could the committee comment on the possibility of using this techniques for other degrees of freedom (roll, yaw,…) typical of oblique wave response.

II Committee Replies

Reply of ITTC Specialist Committee on Environmental Modelling to Dr. Westhuis.

The committee thanks Dr. Westhuis for his interesting remarks, and for the presentation of new results on the problem. It is believed that the described wave group instability may play a role in the formation of particularly large extreme waves in a wave field propagating over some area, and has been observed in wave tank measurements such as Stansberg (1998). In particular, instabilites in bichromatic wave tests similar to those presented by Dr. Westhuis were observed. Similar observations were also made in irregular wave tests, and are believed to be formed by the same mechanisms. Further studies on this field, theoretically as well as by full scale and laboratory measurements, are recommended.

Reply of ITTC Specialist Committee on Environmental Modelling to Prof. Vantorre

The Committee completely agrees, and would like to thank Prof. Vantorre for his improved and more precise formulation.

Reply of ITTC Specialist Committee on Environmental Modelling to Dr. Cordier.

The committee is pleased that the transient wave technique has also successfully been applied at the Bassin d'Essais des Carènes, confirming our excellent experience with this method (Clauss 1999)). Model tests with self-propelled ships in oblique waves have been reported by Clauss and Kühnlein (1995). In this case the ship model sails along the tank wall, crossed the tank at a selected location, and meets the tailor-made wave train at a preset course angle (Fig. 1). Wave generation and ship manouvering are computer-controlled. Two short tests are required to evaluate all motion RAOs: the first tests without waves gives the low frequency roll and yaw motions when the model changes it course and crosses the tank. The second test – with identical ship steering, however, superimposing the tailor-made wave train (following from the target spectrum) – gives the combined registration of wave and manouvering actions (Fig. 2). Due to high precision of the computer-controlled test procedures, the wave excited motions follow from the difference between the two registrations, and the vessel's RAOs are determined accordingly. In these tests the tank width and the ship model speed limit the maximum course angle to 20 degrees. Another, similar technique on the same problem was presented in Aanesland and Stansberg (1995). Tests with a free-running ship in a wide wave basin with oblique and head waves were then made, in which case a larger course angle could be obtained than in a tank. Promising results were shown. The committee encourages the discusser to provide his experience and to further develop this method for oblique waves.

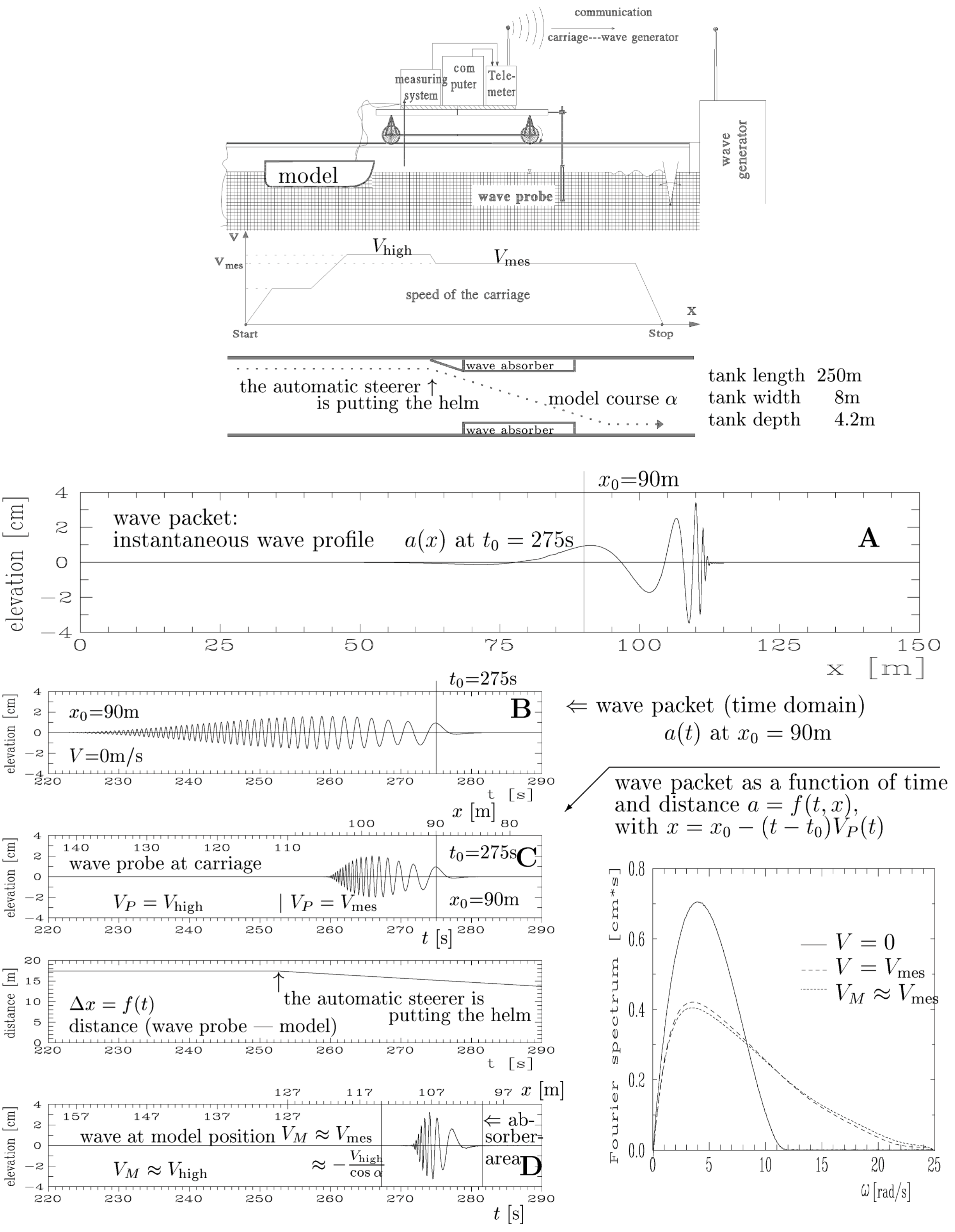

Figure 2: Set-up for model tests with a self-propelled vessel in oblique waves. Transformation of a transient wave packet (measured at a stationary position) to an encounter wave packet (measured with a wave probe on board of the moving carriage) and to an encounter wave packet at the model position (V_M = model speed, V_P= Wave probe speed = carriage speed)

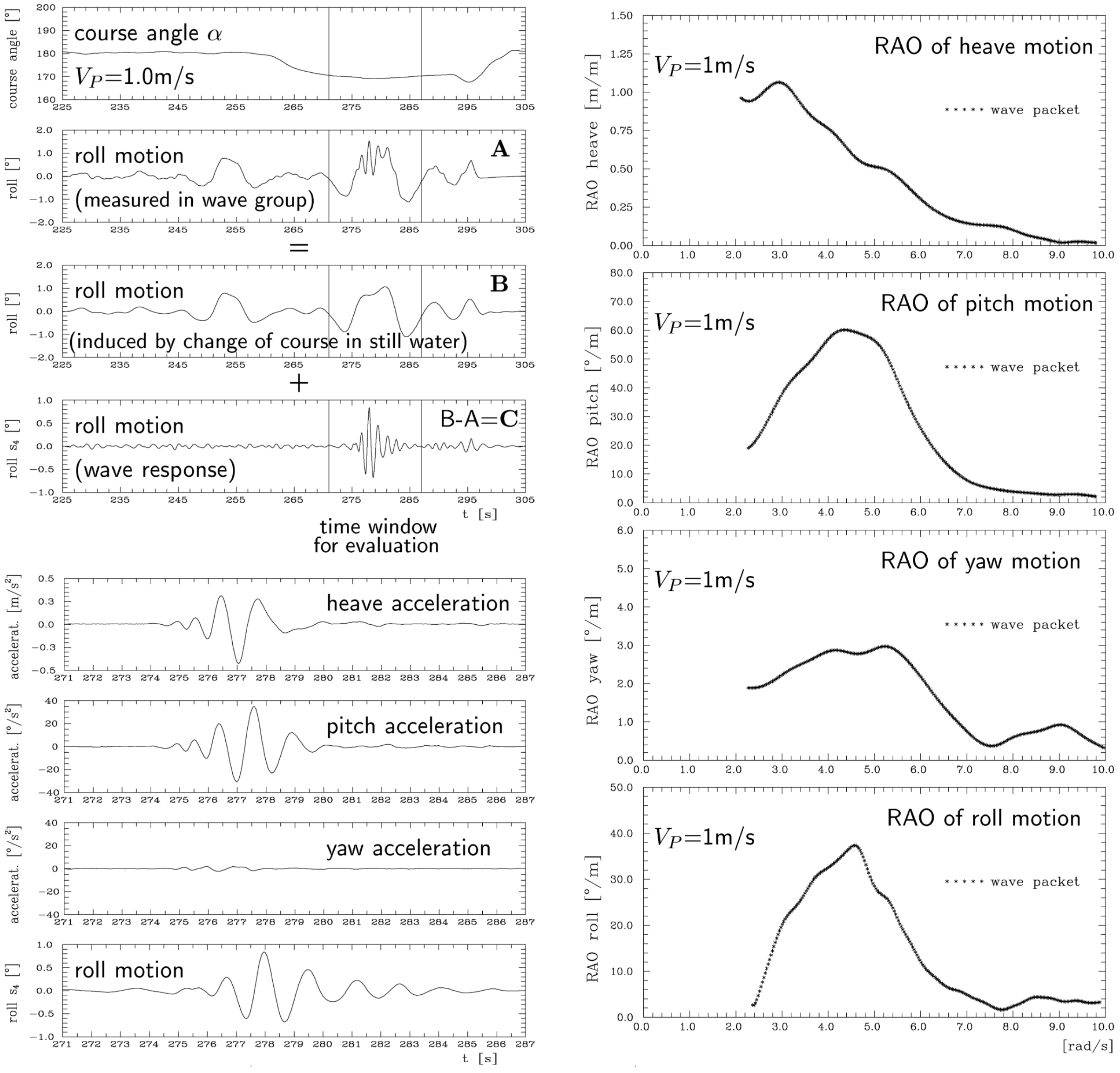

Figure 3: Registration (model motions and accelerations) of a typical seakeeping test with a self propeller monohull in an oblique wave group V_P= 1m/s (carriage speed) as well as the resulting RAOs for heave, pitch, yaw and rall (model scale 1:9; full scale: V=6kn; Fn=0.16)

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