SESSION 2b

ON FULL-SCALE WAVE DATA ACQUISITION AND ANALYSIS

Discussion Chairman: Dr. N. Hogben

Recorder: Mr. B. Forsman

2b-1. Introduction of the Subject

N. HOGBEN - NMI Ltd, Feltham, Middx, United Kingdom.

CHAIRMAN'S INTRODUCTION

The interest of the ITTC in full scale wave data relates to modelling of sea conditions in tanks and use of model test results for predicting behaviour in service. These questions are of particular concern to both the Ocean Engineering and Seakeeping Committees. I have accordingly invited representatives from each of these committees to make prepared contributions indicating their views on current problems. Meanwhile in this short introduction it may be helpful if I enumerate what I consider to be key problem areas drawing attention where appropriate to relevant recent work reported in the literature. The following are some topics which I believe should be discussed during this session.

1) Availability of Data

Knowledge of wave conditions representative of given areas or shipping routes is needed for both the design and interpretation of model experiments. Useful recent documentation of the availability of both wave and wind climate data on a worldwide basis may be found in the proceedings of a Symposium [1] held in London in April 1984. Data can be derived from measurements (including remote sensing), hindcasting and visual observations. Though measured data are generally regarded as most reliable, hindcast and visual data are widely used because of their greater availability. The questions of the relative merits of these various sources of data and what can be done both to establish and improve the level of reliability may be useful topics for discussion. In this connection it may be of interest to mention recent work at NMI [2] on validation of methods for enhancing the reliability of visual data using a program called NMIMET.

2) Spectral Modelling

Spectral modelling has long played a key role in the design and interpretation of laboratory experiments in the fields of naval architecture and ocean engineering. In 1972 [3], the ITTC Seakeeping Committee recommended use of a Pierson-Moskowitz form of spectrum with associated advice regarding the relation between the relevant wave height and wave period parameters and the wind speed as well as the form of directional spreading where required.

It would seem useful to discuss in this session what advice should now be given in the light of the most recent knowledge. A number of variants of the Pierson-Moskowitz spectrum including the ISSC and Bretschneider forms as well as variants of the JONSWAP spectrum which is applicable to limited fetch situations and other models, are currently used. A review of the relevant formulae may be found in reference [4].

3) Wave Grouping

Considerable attention has been devoted in recent years to the question of wave grouping. Mr. Rye of the River and Harbour Laboratory in Trondheim, who is a leading expert on this subject, has kindly agreed to make a prepared contribution to the discussion so I shall only briefly indicate my views on the significance of grouping to the ITTC and the questions which should be discussed.

One question of particular importance is whether grouping properties of a seaway can be adequately modelled by use of spectra. Work at NMI [5] has demonstrated the critical effect of spectral modelling techniques and specially the frequency spacing on this question. Grouping can also be important in the different context of wave climate statistics, where serial correlation in the data can critically affect estimates of extreme values.

4) Directionality

The question of directionality has aroused greatly increased attention in recent years and there have indeed been a number of international conferences [6] to [8] entirely devoted to this subject. In considering data requirements it is important to distinguish between the need for knowledge of the directional spreading of waves in a seaway as described by a directional spectrum and the need for long term statistics of dominant direction.

Advice regarding modelling of directional spectra is an important question for discussion in this session. A $\text{Cos}^n\theta$ spreading function as recommended by the ITTC [3] or the alternative $\text{Cos}^{2s}\frac{1}{2}\theta$ are commonly used and field data, [9], [10], have been invoked as a basis for choosing suitable values of s. This model implies a single directional mode which may be appropriate for the limited fetch conditions in which the field data were collected. It cannot however adequately represent conditions in areas exposed to swell in which there will typically be more than one mode of direction.

5) Extreme Conditions

Estimation of extreme conditions to be

assumed for design purposes is an important engineering requirement. This is a controversial subject because of the inherent difficulties in both the definition and determination of extreme conditions. In practice it is the extreme severity of the response rather than the magnitude of the relevant wave parameters which must be considered and this will be highly dependent on the type and size of structure. Waves of extreme height are commonly used for design purposes but since by definition they occur very rarely methods of estimation cannot be verified with any reasonable level of confidence. Wave height moreover is by no means the only consideration and questions for discussion could include advice regarding the choice of associated wave period, the modelling of breaking waves, the influence of currents on the form of extreme waves, the special risks due to crossing seas, grouping effects and the modelling of typhoons conditions. Guidance on most of these problems may be found in the reports of the Environmental Conditions Committee of the International Ship Structures Congress (ISSC) [11]. Mention may also be made of recent work at NMI [12] on environmental aspects of ship safety and of work in Norway under the heading "Ships in Rough Seas" [13] to which I hope Mr. Rye will make some reference.

6) Interpretation of Wave Periods

The interpretation of wave periods is another controversial subject. An excellent account of the problems of defining and interpreting wave periods has been given by Goda [14]. There are many different ways of defining wave period and Goda's paper includes a tabular summary of available data on the relationships between them.

Questions for discussion include advice on the preferred definition of wave period and its relation with other forms of period. The period recommended for use in the ITTC spectrum [3] is the so called first moment period T_1, widely regarded as corresponding roughly with visually estimated periods T_V. Goda recommends use of modal period T_p (corresponding to the peak of the spectrum) which he considers is more nearly equivalent to visual period. Recent work at NMI [2] has shown that such correspondence between visual and measured periods can be very misleading and demonstrates that more reliable wave period statistics can be derived from visual wave height data by use of a joint probability model.

I note in passing that I recently analysed joint probabilities of wave period and wind speed derived from instrumental data and obtained empirical formulae for the mean value of zero crossing period T_z as a function of the wind speed W in knots, as follows, [15]:

TYPE OF AREA	FORMULA
Oceanic	$T_z = 9.5 + 1.3W^3 x 10^{-5}$
Offshore	$T_z = 7.5 + 0.08\|W-20\|$

In both cases the standard deviation of T_z about the mean was about $1\frac{1}{2}$ seconds.

In this introduction I have offered my

own assessment of some of the key problems in the hope that it will stimulate expression of other views and lead to a useful discussion.

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2b-2. Invited Contributions

The Chairman introduced the three contributors invited, Drs. van Oortmerssen and Rye, and Mr. Andrew.

G. van OORTMERSSEN - Maritime Research Institute Netherlands, Wageningen, The Netherlands.

THE NEED FOR FULL-SCALE WAVE DATA, AND WAVE CLIMATE RESEARCH IN THE NETHERLANDS

In this contribution I should like to discuss two entirely different topics. In the first place, I will discuss the need for full scale wave data as felt within the Ocean Engineering Committee. In the second place, I want to say something about the Dutch efforts in the field of wave measurements and wave forecasting.

Need for full scale wave data

One of the recommendations of the previous Ocean Engineering Committe, as accepted by the 16th ITTC in Leningrad, stated that "wave group phenomena and description of multi-directionality should receive special attention".

In the meantime, much progress has been made in the research of wave grouping phenomena, which led the present Committee to conclude that there seems enough evidence now to assume that, at least in deep water, wave groups at sea are consistent with the groups that would be expected from Gaussian wave elevation. The need for more data on multi-directional wave fields still exists. Both the growing number of model basins with directional wave capability and the increasing attempts to include wave directionality in computer simulation models (see for instance ref. [1] for a review of numerical modelling techniques), require more knowledge of multi-directional seas and the associated phenomena such as kinematics, grouping etc.

Breaking waves in deep water and so-called freak or episodic waves also appear to require considerable further study.

Finally, I want to emphasize the need for combined wave/wind/current statistics, which enable the determination of the joint probability of extreme wave, wind and current conditions.

Wave climate research in the Netherlands

Wave climate research activities in the Netherlands focus on the North Sea and are motivated by the need for accurate and reliable wave data for reasons of safety and economics.

Since 1983, a computerized measurement system is in operation in the North Sea for the collection of oceanographical and meteorological data. This system is jointly operated by various governmental agencies and the Royal Netherlands Meteorological Institute (KNMI). Offshore oil production platforms at various locations in the North Sea and special measurement platforms along the coast provide the basis for sensors to monitor the water level, wave height and direction, temperature of air and water, and various meteorological data. The on-line data processing is carried out on a central computer.

The data are used for various operational purposes, among which:

- an early warning system for high waves and storm surges for safeguarding of the dikes and operation of storm surge barriers

- a warning system for long waves occurring at the approach channel of Europort, which may cause too large vertical motions of deep draft tankers

- operational wave forecasts for coastal construction activities and offshore industry.

In addition, the data are applied for research purposes. Wave and wind data, for instance, are used for the development of numerical wave models.

Among the sensors, employed in the measurement system in the North Sea, the WAVEC buoy should be mentioned in particular. This buoy measures wave height as well as directionality by relating these quantities to the heave, roll and pitch motions of the buoy. This buoy was developed by the Delft University of Technology, the Institute for Applied Physical Research (TNO), the Department of Public Works and the firm which produce the buoy, Datawell. More details of the WAVEC buoy are given in [2].

An example of directional spectra as measured with the WAVEC buoy is given in Figure 1.

An important recent accomplishment has been the development of a numerical wave model for the North Sea, which is called GONO (see ref. [3]).

This wave model was developed by the Delft Hydraulics Institute and the Dutch Meteorological Institute.

GONO is based on a hybrid approach. On the one hand, waves under action of wind are assumed to have a spectrum of invariant shape. An empirical model describes the growth of wind sea energy. On the other hand

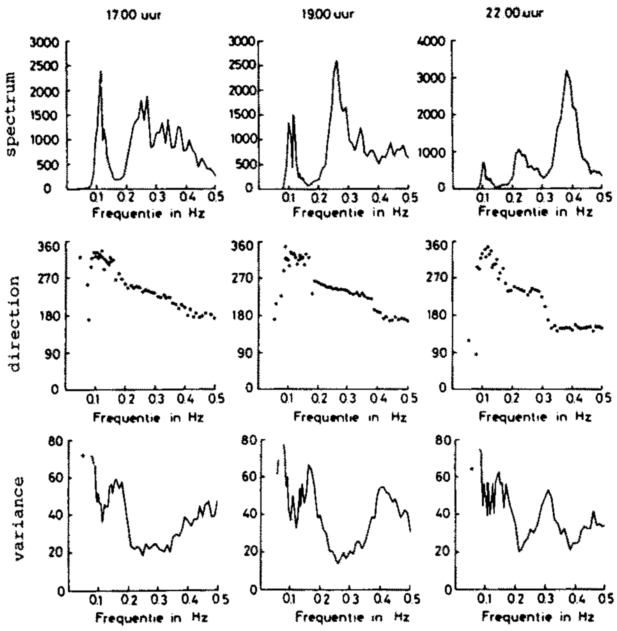

Fig. 1 Directional wave spectra as measured by WAVEC buoy

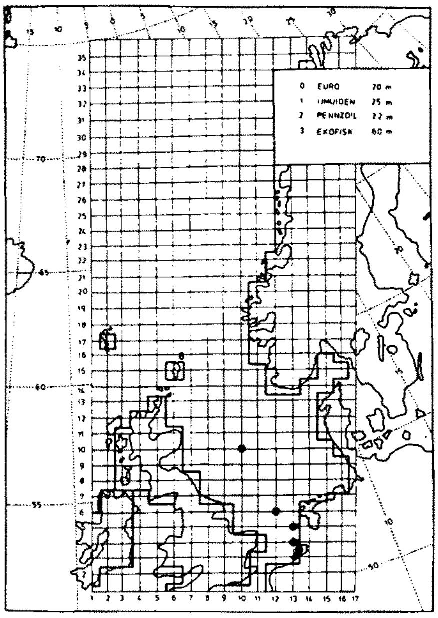

Fig. 2 Grid of GONO

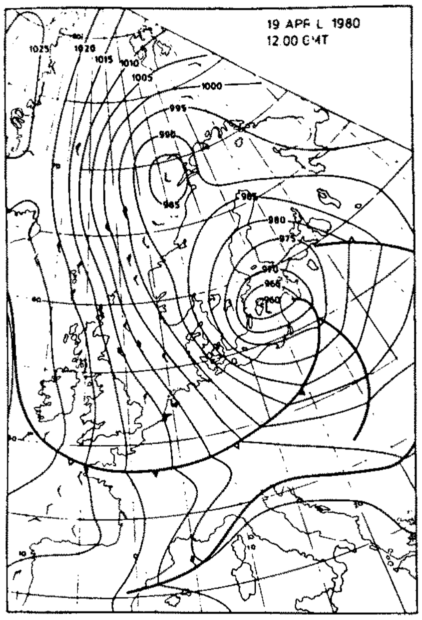

Fig. 3 Weather map, 19 april 1980

swell has no invariant shape and therefore the swell is treated by means of spectral techniques.
The basis of the GONO program is the energy balance equation for the variance spectrum F:

$$\frac{\partial}{\partial t} F + c_g \nabla F = S_{inp} + S_{nl} + S_{diss}$$

in which c_g is the phase speed of the waves and S_{inp}, S_{nl} and S_{diss} represent the rate of change of energy of the wind input, non-linear interaction and dissipation (including wave breaking). This equation is transformed for the evolution of the wave energy spectrum and then solved by a first order finite difference scheme. The model grid of GONO for the North Sea is displayed in Figure 2.

GONO is operated 4 times a day giving each time a 12 hours and a 24 hours forecast of the wave heights at the grid points. The model uses a 4-layer atmospheric wind model as input.
GONO is validated against field measurements since 1979. An example of the correlation between prediction and measurement is given in Figure 4 for a storm which occurred in April 1980 (See Figure 3). As can be seen from these results, GONO gives a fairly accurate estimate of the wave height parameters.

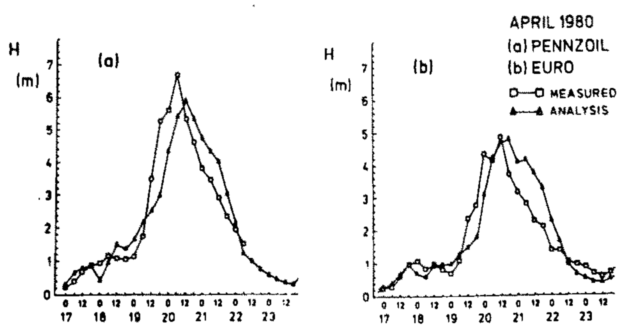

Fig. 4 Comparison of wave spectra measured at two locations with numerical predictions using GONO

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FIELD DATA, WAVE GROUPS, DETERMINISTIC WAVES AND DIRECTIONAL SEAS

1. Field Data Collection

Since 1969, NHL has been engaged in wave measurements on the Norwegian Continental Shelf. More than "40 years" of routine Waverider measurements from various locations have been collected. The results are presented in data reports, including calculations of the zero-up-cross wave parameters as well as spectral parameters for each of the 8x365 time series for each year. In addition, a large number of storm waves has been analyzed for zero - down cross wave statistics as well.

2. Field Data Applications

This data base has found a large variety of applications. One of the more recent applications is an evaluation of the extreme wave conditions (wave height, corresponding wave period and spectral shape) on the Continental Shelf [1].

Other applications are studies of particular wave conditions of engineering interest. One example is the occurrence of a 20 second peak period sea state with a significant wave height close to 10 m on the Halten Bank. This particular sea state caused some unexpected heave motion on a drilling rig under operations [2].

3. Wave Group Statistics

Further applications are directed towards simulation of waves in a wave flume or on a computer. By comparing simulated and recorded wave conditions, it will be possible to determine whether the waves are similar in a statistical sense. One such study was directed towards a comparison of wave group characteristics in numerically simulated waves and in field data [3]. A number of wave group parameters were examined, including the correlation between succeeding zero-up-cross wave heights, succeeding zero-up-cross wave periods and the length of wave groups. It was found that although the wave groups may vary from one time series to another, the statistical expectation of the wave group parameters were all governed by the wave power spectral shape. This result is applicable to deep water conditions, only.

Ambiguities due to high-frequency cut-off choices were removed by choosing proper wave parameters. The numerical simulated waves compared to the field data when a white noise phase spectrum was applied.

Effects from choice of simulation techniques were considered. It was found that equidistant frequencies worked well, provided that the resolutions were sufficient.

The simulation runs indicated that the resolution should be of order 10-20% of the peak frequency. This conclusion seems to correspond well to what was found in [4]. Possible effects from introducing a statistical variation on the amplitudes as well were considered also. The possible influence from this effect has been considered in [5]. However, no significant effect was found. The conclusion was therefore that provided the spectral shape is known and a sufficient spectral resolution is applied, you should have the information sufficient for a proper reproduction of the expected statistical properties of the wave groups.

4. Individual Wave Studies

Sometimes, deterministic waves are required for reproduction in a flume. Recently, methods have been developed which are able to reproduce a particular deterministic event in a given location in a wave flume [6].

The wave data base has also been applied to study individual wave properties. A number of different wave shape parameters, mostly height to length ratios, were defined in order to arrive at relevant wave steepness parameters for the study of capsizing of small vessels and fishing boats.

It was found that the joint probability of high waves and the "crest front steepness" parameter derived from the zero-down--cross analysis was of particular significance. In order to simulate particular dangerous situations in a wave flume, the spectral approach was abandoned. Further details are given in [7].

A study of breaking waves has also been made in the Ocean Basin in Trondheim [8]. Reference is also made to the presentation by S. P. Kjeldsen at this conference.

5. Directional Studies

During the winter season 1984/1985, a field research program on directional seas will be carried out from a platform on the Ekofisk oil field in the North Sea. An intercomparison between different methods to measure directional seas will be undertaken. Remote sensing techniques as well as fixed probes and different kinds of surface following buoys will be included for the intercomparison. The project is denoted the Wave Directional Calibration project (WADIC) and is carried out as contract research for the oil companies.

The information that will be available from this project will serve as an important input for the simulation of the directional seas in wave basins. A study of the directional wave properties in the Ocean Basin in Trondheim has been undertaken [9]. The controlled conditions that are possible to obtain in wave basins lead to the fact that we at present seem to know more about wave directionality in the Ocean Basin than we know about wave directionality in the field!

6. References

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ON WAVE DATA FOR USE IN THE SEAKEEPING FIELD

Since the Seakeeping Committee has devoted a large proportion of its Report to the question of the natural environment - wind and waves - I do not intend to cover this ground again. Rather, in the short time available I propose to say a few words about the sort of data which are required in the seakeeping field, and to give an example of their use.

Broadly speaking seakeeping is concerned with the performance of vessels transiting the world's oceans and seas and thus there is little interest in site-specific data. Since the response of a ship in irregular waves is governed by the frequency response characteristics of the ship and the wave auto-spectral density function it is not surprising that information is required concerning the latter. The ITTC recommends spectral formulations for open ocean and fetch-limited situations. From the point of view of seakeeping performance assessment these are quite adequate and it is unlikely that there will be any pressure for a change in the foreseeable future. The ITTC spectra are formulated in terms of a characteristic waveheight and a characteristic wave period. There is an important requirement for information on the frequency of occurrence in nature of the values of these reflecting both geographical and seasonal variations. One immediately thinks of the Hogben and Lumb wave atlas in this context but this has - dare I say - been largely discredited in recent years due to the predominance of obscure visually-observed data. More recent developments include the DTNSRDC Hindcast Climatology - developed by seakeeping specialists for seakeeping specialists - based on the US Navy's Spectral Ocean Wave Model (SOWM), and NMIMET. The latter is unique in having the potential to develop wind and wave environments for many widely dispersed sea areas (the DTNSRDC climatology currently covers the North Atlantic only).

Seakeeping performance is also sensitive to wave direction relative to the longitudinal axis of the ship. It is usual to adopt a mean wave direction (from which the most wave energy arrives) and a spreading function. The latter distributes wave energy over a range of directions relative to the mean direction. Some important ship responses such as roll are very sensitive to wave spreading and a relatively small change in spreading function can greatly affect estimated response. At present the ITTC recommends a cosine-squared spreading function over a 90 degrees sector either side of the mean direction. It is to be hoped that a better knowledge of the characteristics of spreading including geographical and seasonal variations will come from both the analysis of the DTNSRDC climatology, and from deployment of the rapidly increasing number of directional wave buoys becoming available.

Turning now to application of wave data, one aspect of seakeeping analysis is to assess the performance of a ship, or to compare the relative performances of two or more ships, in an unambiguous way. This is not easy since ship responses depend on speed and heading as well as wave conditions (waveheight, period and spreading). What combination of parameters should be chosen?.

The answer is really quite simple now that practical ship response prediction computer programs and wave climatologies are well established - determine seakeeping performance in all likely combinations of speed, heading and wave conditions and look at the answers in the light of how often each combination is likely to occur during operation of the ship. Such a procedure has been developed at ARE and is currently being evaluated: early results are encouraging. Details can be found in the proceedings of the RINA Symposium on Wave and Wind Climate Worldwide held in London in April.

In conclusion then I feel that analyses such as this are going to become increasingly popular and will generate a continuing requirement for practically useful full-scale large area wave data reflecting geographical and seasonal variations.

2b-3. Additional Prepared Contribution

The additional Contribution below is printed as condensed by the Discussion Chairman.

P. TRUIJENS - Department of Naval Architecture, University of Ghent, Ghent, Belgium.

PARAMETRIC MODELLING OF WAVE AND WIND STATISTICS

(Presented by V. Ferdinande, University of Ghent.)

This contribution concerns the fitting of mean lines through the scatter of data relating wave height and wind speed, which can play a useful part in the modelling of wave climate. It devotes particular attention to evaluation of a formula, which in combination with a modelling of the associated scatter about the mean, is an important component of the NMIMET program for wave climate synthesis (see reference [1] below) mentioned by Dr. Hogben in his introduction.

The data used were measurements of waves (collected by Haecon NV) from 5 sites near the Belgian Coast (see accompanying table) and visual observations of wind speeds based on the Beaufort Scale. Various different formulae were fitted to values of the mean significant wave height (here denoted by H_m) derived for each of a series of classes of wind speed U. Some selected results are shown in the accompanying table and figures.

For all 5 sites it was found that the form of relation used in the NMIMET program, namely

$$H_m = [H_o^2 + (aU^n)^2]^{\frac{1}{2}}$$

(where H_o, a and n are the fitting parameters) yielded the best (least squares) fit (see Figs. 1 and 2).

The concept underlying the above formula is that the total energy (proportional to H_m^2) is the linear sum of independent contributions from swell (proportional to H_o^2) and wind sea (proportional to $(aU^n)^2$). The results in the table and accompanying figures serve to confirm the validity of this formula not only in relatively deep water, as already established by Dr. Hogben, but also at the sites in much shallower water where bottom effects are known to have a large influence on the wave height.

It is of interest to note moreover that the numerical values of the fitting parameters are in line with the corresponding values derived by Dr. Hogben from measured wave and wind data at a number of other sites (as listed in Table 6 of reference [1]) especially with respect to H_o.

When comparing values of a and n it

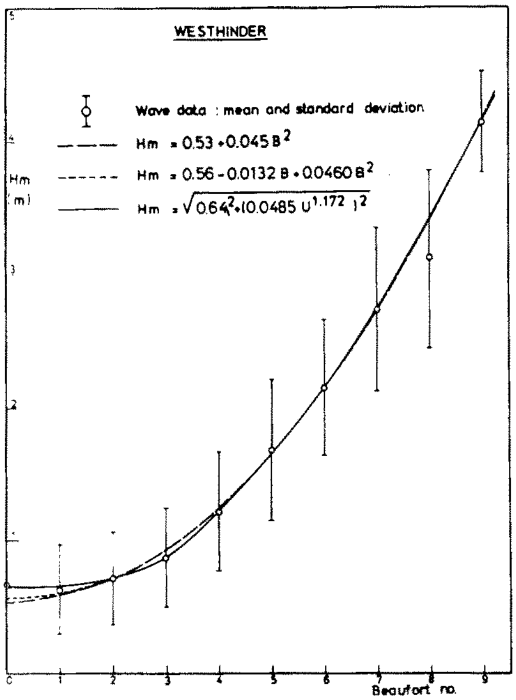

Fig. 1 Comparison of experimental points with some results obtained from regression analysis

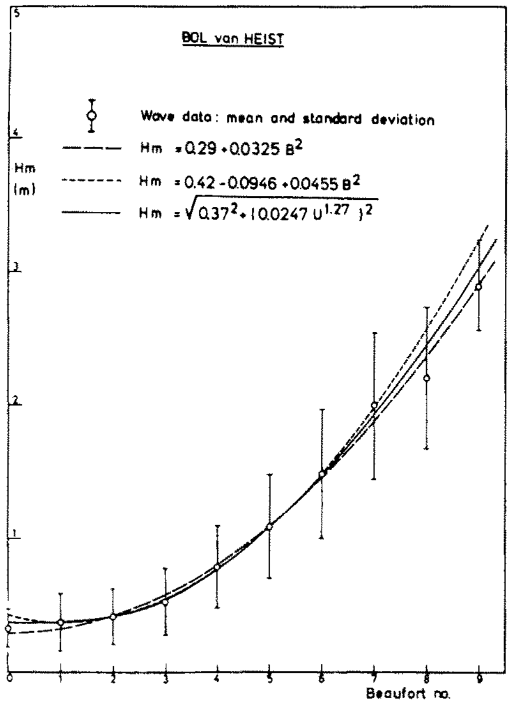

Fig. 2 Comparison of experimental points with some results obtained from regression analysis

is important no note as also discussed in reference [1] that n tends to decrease when the range of wind speeds covered is increased. This is because the relation of wave height and wind speed tends to be more nearly linear at high wind speeds. In shallow water this is indeed to be expected due to the effects of wave breaking.

From the fitting point of view, this reduction in n is not very important because it is accompanied by a compensating increase of a. Thus in the case of the results for Zand -1 and Bol van Heist the coincidence of the fitted mean lines shown in Fig. 3 is closer than comparison of the corresponding values of a and n in Table 1 might imply.

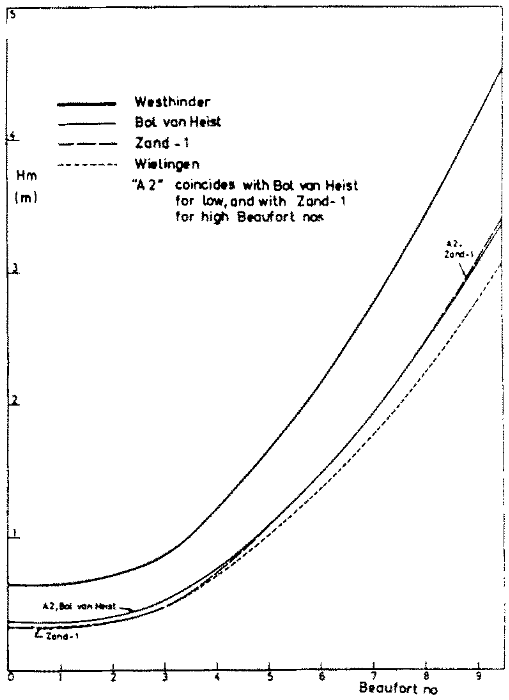

Fig. 3 Comparison of expressions according to Table 1

TABLE 1 DATA FOR BELGIAN STATIONS

RECORDING STATION	LOCATION	WATER DEPTH (m)	RECORDING PERIOD	NUMBER OF RECORDS	H_o (m)	a	n
Westhinder	51°23'03"N 2°26'30"E	17.0	Dec 79 to April 81	1659	0.64	0.0485	1.172
Bol van Heist	51°22'42"N 3°12'30"E	8.0	Dec 79 to Oct 82	3971	0.37	0.0247	1.270
Zand -1	51°21'25"N 3°11'30"E	7.5	Dec 79 to Oct 82	4997	0.32	0.0228	1.295
Wielingen -1	51°23'26"N 3°18'0"E	9.0	Dec 79 to Oct 81	1298	0.33	0.0246	1.245
A2	51°21'40"N 3°07'10"E	8.0	May 81 to Oct 82	1138	0.36	0.0240	1.280

The possibility of using the formula for extrapolation however must be approached with caution, as also explained in reference [1]. Use of a constant value of n based on fitting of data ranging up to Beaufort 6 or 7, to estimate values of H_m for Beaufort 10 or higher for example, could lead to serious overestimation of H_m at the higher wind speeds.

The investigation being undertaken at Ghent is still in progress and further work is planned. In the first place a comparative study will be made of the effects of differences in the method of estimating H_o, a and n between Ghent and NMI Ltd. Afterwards the analysis of the data will proceed as far as applicable along the lines set forth in reference [1]. As for most of the records obtained in the Belgian wave recording programme, energy spectra have been computed and an attempt will be made to link "average" or standard forms to the corresponding H_m values especially in the higher wind speed classes.

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2b-4. Free Discussion (Chairman's Summary).

Following the presentation of the foregoing Contributions there was a period of free discussion which may be summarised under 3 main headings as follows:

1. Wave Crest Steepness

Prof. Johnson asked Dr. Rye for clarification of the methods used for deriving the wave crest steepness parameters discussed in his contribution. He was particularly concerned to know how the relevant length dimensions were estimated from the time domain recordings, bearing in mind that for steep waves linear dispersion theory could underestimate the phase velocity by as much as 20%.

The question was referred to *Mr. Kjeldsen* who explained that the required wave length information was derived by procedures involving zero downcross counting to derive the periods and assumption of a linear dispersion relation, which had been evaluated by analysis of photographs and records of laboratory waves (see Ref. [2]). He acknowledged that linear theory is not valid for steep waves but oted that it is a conservative ıpproximation as it leads to overestimation of the steepness. Prof.

Johnson felt however that more work was needed to establish a more reliable method.

2. Relation of Wave Height and Wind Speed

Mr. Rodenhuis expressed doubt about the validity of the formulae discussed in Prof. Ferdinande's contribution, as a basis for modelling the relation between wave height and wind speed in different areas.

Prof. Ferdinande replied that his findings, taken in association with the work of Dr. Hogben, showed a remarkable degree of consistency in the correspondence of the formulae with measurements and observations of waves and winds in many different areas. He emphasised that there is scatter about the mean lines and there are site dependent variations in the numerical values of the coefficients. He felt however that the Belgian work was particularly significant in showing the consistency of the values derived in shallow near shore areas with those derived by Dr. Hogben in deeper waters.

Dr. Hogben endorsed this reply and mentioned that the NMIMET wave climate analysis included a modelling of the scatter about the mean line as well as the line itself. He also noted that NMI experience based on analysis of measurements and observations in many different areas of the world (Ref. [3]) showed that site dependent differences in the coefficients were very systematic and that variations of H_o reflecting the differing degrees of exposure to swell were the most important index of site character. In the light of this experience it has been found that areas could be classified into types such as "Open Ocean", "Offshore" or "Coastal" for each of which specific sets of numerical values could be assumed for H_o, a and n and other relevant parameters.

3. Spectral Shape

Prof. Johnson raised questions concerning multimodal spectra. In particular he wondered how often they occurred and was concerned about the common assumption that bimodal non directional spectra can be modelled as bimodal unidirectional spectra though they may often represent crossing sea conditions. This concern was reinforced by *Mr. Cox* who noted the importance of realistic modelling of directionality in long term assessments of ship response such as had been described in the contribution by Mr. Andrew.

Dr. Hogben drew attention to published stratifications of measured non directional spectra by Yamanouchi (Ref. [4]), Walden (Ref. [5]) and Ochi (Ref. [6]) noting that they gave a useful indication of the incidence of bi-modality. They also showed that spectra at moderate wind speeds displayed relatively high variability of shape and tendency to bi-modality due to the influence of swell superimposed on wind sea. In more severe conditions due to the dominance of the wind sea the trend is towards more consistent unimodal spectra. At very low wind speeds dominance of swell may also lead to greater incidence of unimodal spectra in some areas.

Dr. Hogben concluded the session by thanking all the discussers for their interesting contributions.

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5. Walden, H. "Report of the Environmental Conditions Committee (Chapter 3.5)" Proc. 5th International Ship Structures Congress, Hamburg, 1973.

6. Ochi, M. K. "Wave Statistics for the Design of Ships and Ocean Structures" Papers presented to SNAME, November 1978.