

## SESSION 1b

## ON NEW WAVEMAKER DESIGN AND EXPERIENCE

Discussion Chairman: Prof. B. Johnson

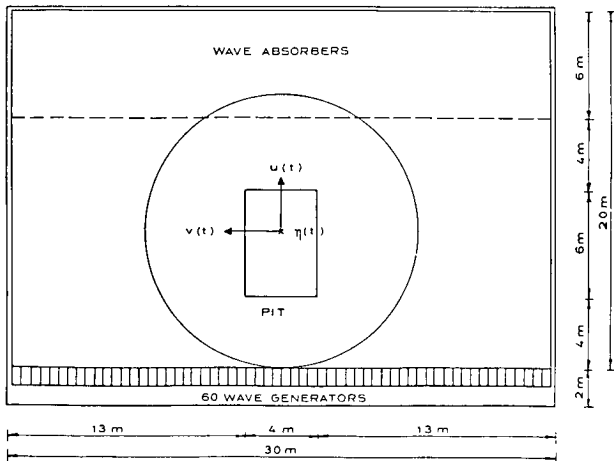
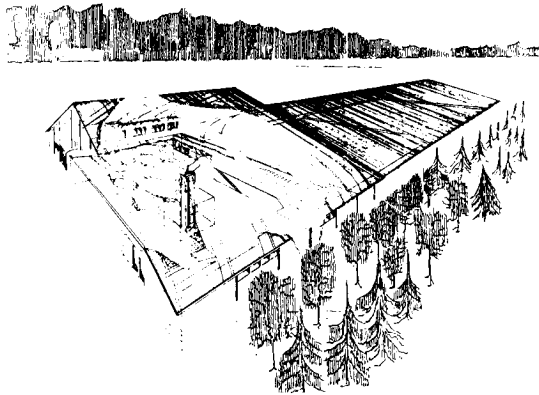
Recorder: Mr. B. Forsman

The Group Discussion was organized around a list of discussion topics sent by the Chairman to those Member Organizations, which have recently installed or have under construction computer controlled multi-element wavemakers or double flap wavemakers.

1 b-1. The discussion topics for multi-element wavemakers were as follows:

- a. Guidelines for tank dimensions: width and number of independent wavemakers required to achieve desired wave characteristics in a specified test area of the basin.
- b. Design tradeoffs concerning hinge depth, moving element mass, frequency response, wave height capability, and servo-electric vs. servo-hydraulic drives.
- c. Advantages and disadvantages of dewatering behind the waveboard (see applicable topics above).
- d. Wavemaker controls.
- e. Active wave absorption techniques.
- f. Methods for generating oblique waves, multi-directional waves, specified directional spectra, and extreme waves.

The first invited discussor was *Mr. Peter Kjeldsen* of the Norwegian Hydrodynamic Laboratories, whose presentation on their experience in 3-D wave generation is summarized in Appendix A. The second discussor was *Dr. Hiromitsu Kitagawa* of S.R.I., Japan, who presented the material of *Mr. Iwao Watanabe* concerning the remodeling of the S.R.I. wave basin to include microprocessor controlled 24 element wavemaker (Appendix B). The contribution of *Mr. M. D. Miles* concerning the 180 element wavemaker for the new 75m by 32m Seakeeping Basin at the NRC Institute for Marine Dynamics (IMD) was presented by *Mr. David Murdey* of IMD (Appendix C). *Mr. Steve Chislett* of the Danish Maritime Institute presented an oral discussion describing the new 3-D Wave Basin built at DMI, which is used for testing fixed and floating offshore structures.



Danish Hydraulic Institute  
3-D Wave Basin

The basin is 30m x 20m x 3m water depth with a pit 6m deep. The wave generator consists of 60 hinged flaps 1.5m deep x 0.5m with rolling fabric seals and a dry back. Waves of 0.5 to 4.5 sec period, up to 0.5m height, can be generated. A fan array is available for wind simulation and currents up to 0.2m/sec can be combined with wind and waves for offshore structure tests.

Mr. Steve Rowe of the National Maritime Institute briefly described the addition of a 90 element, hydraulically actuated dry back wavemaker to the 30m x 46m Tank No. 4 at NMI, Feltham. The elements are 2.3m deep and 2.5m

wide and can generate either regular, superposed sinusoids, or continuous wave spectra. Operation is planned for October 1984.

Mr. G. S Rodenhuis of DMI asked Mr. Rowe "what type of seals are used for the dry-back system". Mr. Rowe responded that Salter type fabric seals are used and that the flaps are connected in blocks of six with each block separately removable. Prof. Ferguson of the University of Glasgow asked whether a conventional beach will be used and the reply was yes. The Discussion Chairman volunteered that active wave absorbers had yet to be proven feasible for irregular 2 and 3D waves. Dr. Faresi of CETENA inquired as to the relation between the width of the flap and the direction of the waves. Mr. Murdey responded that the formulas by Biesel are used to calculate this relationship.

1 b-2. The discussion topics for double-flap wavemakers were as follows:

- a. Analysis methods and guidelines for selecting flap hinge depths as a function of desired wave characteristics.
- b. Waveboard materials: corrosion problems, paints, etc.
- c. Advantages and disadvantages of dewatering behind the waveboard: techniques for achieving hydrostatic head balance and upright rest position for dewatered double flap systems; the problem of side seal friction; the design

of hinge seals and side seals; guidelines for beach design behind a waveboard with water on both sides.

- d. Wavemaker controls: analogue vs. digital control; gain stability; starting and stopping problems; noise problems; trial and error tuning of electronic and servo-hydraulic systems; software control of amplitude and phase compensation; maintaining constant flap phase at various frequencies; methods for drive signal apportionment between flaps.

- e. Active wave absorption techniques.

Mr. Peter Kjeldsen of NHL used slides and a movie of breaking waves to describe the 50m wide double flap wavemaker installed in the ocean simulation test basin in Trondheim, Norway. (Appendix D). Dave Murdey also presented a description of the 12m wide double flap wavemaker being installed in the new towing tank at IMD in St. Johns, Newfoundland. In Appendix E, Mr. M. D. Miles of IMD discusses the design criteria and flap apportionment methods for double flap wavemakers.

Mr. Steve Chislett of DMI showed some sketches of the recently installed double flap wavemaker in their 240m x 12m x 5.5m deep towing tank. The wavemaker can deliver 91kW of wave-power so very high waves, limited only by the height of the tank wall above the still water surface, can be generated.

The Session Chairman then commented on some problems associated with the

generation of periodic irregular waves. (Appendix F). Because of time limitations, there was no further discussion concerning double flap wavemakers.

1 b-3.

The final discussion of the Session was made by Dr. P. Bogdanov of the Bulgarian Ship Hydrodynamics Centre who presented material concerning the new single flap wavemaker installed at Varna. (Appendix G).

#### Appendix A

S. P. KJELDEN - Norwegian Hydrodynamic Laboratories, Div. Ship and Ocean Laboratory, Trondheim, Norway.

#### NEW WAVEMAKER DESIGN AND EXPERIENCE

##### Multi-element wavemakers used for three-dimensional generation

In nature wave-wave interactions play a dominant role in the generation of whitecaps together with the wind. In a simulated 3-dimensional sea state in the laboratory, the effects of wave-wave interactions alone on the formation of whitecapping was studied. Only at one particular scale, whitecapping of the same magnitude as that observed in field data were found. At all other scales a superior deterministic technique for superposition of breaking waves in a stochastic sea state is needed in order to reproduce the nature. Both synoptic wave lengths and crest lengths of breaking waves in 3-dimensional seas was found to be

functions of the fourth moment of the wave spectrum. A correct reproduction in the laboratory then demands, that effects of truncation of wave spectra are taken into account. The amount of breaking waves contained in a simulated sea state is a crucial parameter to consider. The previous constructions of large wind-wave flumes in different parts of the world was initiated based on a design philosophy, that stated that only the wind applied in combination with mechanical wave generation could lead to:

- a) Wave asymmetry and
  - b) The amount of breaking waves that is contained in a natural sea state
- As outlined by KJELDSSEN & MYRHAUG 1980 a) and b) in a natural sea state may vary, depending on local conditions, in particular the presence of transient or persistent ocean surface currents. The present trend in design philosophy for large ocean basins, simulating directional seas, seems to have neglected the fact, that a superimposed wind influences the generated waves. Thus a potential danger exist, that 3-dimensional sea states are generated in the laboratories, that contains less wave asymmetry and a less amount of breaking waves, than the natural sea state, they are supposed to model. However, the techniques for the synthetic creation of wave trains in laboratory wave basins now also contains a method that provides control over asymmetrical wave parameters. This method is based on a non-linear transformation to a Gaussian time function without affecting the amplitude spectrum significantly, see FUNKE, MANSARD & BARTHELL 1982.

For the naval architect the crest front steepness of the waves is a parameter as important as the wave height itself. The joint probability density functions of crest front steepnesses and wave heights is the tool for assessment of the severity of sea states, see KJELDSSEN 1981. The responses of vessels in directional seas is of particular interest in Norway. Here extreme steep waves and freak wave events has resulted in the capsizing and loss of not less than 26 Norwegian trawlers and freighters over a period of 9 years. 72 lives has been lost. It is then the most extreme and breaking waves contained in a directional sea that is of interest here. Survival tests where rolling motion of vessels are measured in beam seas becomes most important. The proper generation and simulation of the directional sea and in particular the correct amount of breaking waves in the simulated seas becomes crucial for the final results for such survival tests, because the breaking waves can attain a nearly vertical front, and drastically changes kinematics within the oscillatory flow from laminar to turbulent conditions. Shipping of green water on deck and events of extreme rollong can thus only be mapped correctly if the amount of breaking waves contained in the simulation of the 3-dimensional sea is realistic. One very important parameter for the response in survival tests is the crest length of the breaking wave relative to the total length of the ship, see KJELDSSEN 1983. A shift in the wave crest from a laminar to a turbulent condition in the crest of breaking waves is most important, because the drag- and lift-coeffi-

cients for horizontal, inclined and vertical slender cylinders are highly affected by the local turbulence level, as shown by KO & GRAF 1972. Thus the marine civil engineer should expect different results, depending on the amount of breaking waves contained in a laboratory simulation of a sea state. The marine civil engineer involved in pipeline design in conditions where the oscillatory wave motion reaches the sea bottom, has also a great interest in 3-dimensional seas. For him the problem is, that a design criteria based on a 2-dimensional wave train acting perpendicular on the pipeline trace, probably is too conservative. In a natural sea state wave forces measured simultaneously at different positions along a pipeline, will have a certain correlation length, that is connected to the crest length of the waves in this sea state. Thus forces measured under laboratory conditions could be influenced by a truncation of correlation lengths. Then a correct laboratory simulation of the parameter  $m_4$  is essential, as shown by KJELDSSEN & PRICE 1982. Further an experimental investigation of 3-dimensional breaking waves has been performed with the following 3 scopes:

- Mapping of the amount of whitecapping as a function of directional spread for several prescribed standard spectra (Pierson-Moskowitz and Jonswap) simulated in a large ocean basin with directional spread prescribed and controlled.
- Mapping of crest lengths of the most extreme breaking waves in such directional seas.
- Investigate the effects of truncation of wave spectra on the simulated seas in particular with respect to scale effects connected to wave crest lengths.

The experiments were performed at the large sea-simulating basin at Norwegian Hydrodynamic Laboratories, division Ship and Ocean Laboratory. This basin has the main dimensions length 80 m, width 50 m and it is equipped with an adjustable bottom, that makes it possible to perform experiments at all water depths in the range 0-10 meters. At the 80 m long side 144 individually controlled single flap type wave generators of the rolling seal type is installed in an array. Each flap is a "Belofram" sealed membrane hinged 1.02 m below mean water level. At the 50 m long side a 50 m wide double-flap type wave generator is installed and hinged 2.6 m below the mean water level. At the other sides are efficient energy absorbing parabolic beaches. In addition ocean currents with mean velocities up to 0.17 m/sec. can be superposed upon the mechanical generated wave patterns.

For observations of whitecapping experiments were performed in which two different types of generation of 3-dimensional sea states were applied namely:

- a) Pierson-Moskowitz wave spectra with spreading parameters  $n$  from 2-10 were simulated with the snake method (2 corresponds to a wind driven sea while 10 corresponds to a longcrested swell).

b) Jonswap wave spectra with a spreading parameter  $n = 4$  were simulated with the diffraction method.

The snake method gives energy at discrete frequencies. The diffraction method gives a continuous angular distribution.

For further details concerning photographic methods for observation see KJELDSEN 1984 a. Results from simultaneous measurements of directional spectra are presented by HASLE & STANSBERG 1984. Numerical simulations of 3-dimensional sea states is further treated by STANSBERG 1984.

No field data and no experimental data from laboratory investigations are at present reported, elsewhere in which whitecapping are observed under controlled conditions, where also simultaneous measurements of directional wave spectra are available.

Photographic observations of whitecapping are reported from the Atlantic Ocean, MONAHAN 1971 and from the Pacific Ocean, TOBA & CHEN 1973. In both investigations the area of the sea covered by whitecapping were related to the wind velocity 10 m above the sea level by a formula of the form

$$W = \delta \cdot U_{10}^{3.75}$$

$W$  is the whitecapping factor measured in ppm (the ratio between the area covered by whitecapping compared to

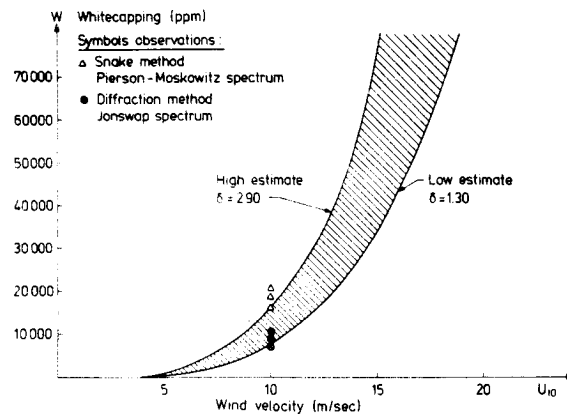


Fig. 1. Comparison between observed whitecapping in 3-dimensional synthesized sea states and field measurements. (From KJELDSEN 1984a).

the total area of the sea, parts per million).  $\delta$  is a coefficient, that was found to be in the range  $1.30 < \delta < 2.90$  depending on the local meteorological conditions. Then a stable, neutral or unstable local meteorological situation can be identified mainly from evaluations of the temperature difference between the sea and the atmosphere.

Assuming a fully developed sea with a wind velocity corresponding to the significant wave height we are now able to plot experimental results on the graph in Fig 1. It is observed that the level of whitecapping fits in with the level observed in field data, provided that wind velocity is close to 10 m/sec and thereby from eq. (4.3) from KJELDSEN 1984 a, the linear scale used to convert experimental data to full scale values is 1:11.

These results has some important applications for testing of models of offshore structures in such basins. If the scale in a model experiment is chosen near 1:50, which is very often

the case in practise, the amount of whitecapping and thereby the content of breaking waves in the mechanically generated sea state is too low. The only available solution to this problem is then to superpose a 3-dimensional deterministic freak wave, that strikes on the structure, generated as described by KJELDEN 1982.

The next important conclusion that can be drawn from the present experiments, is that wave-wave interactions alone in a 3-dimensional sea state can give rise to a significant amount of whitecapping in the complete absence of the wind, a fact that not before has been realised. This means that during gales at sea the observed amount of whitecapping is not created by the action of wind alone but by the combined actions of wave-wave interactions and the wind.

Now Fig 2 shows experimental results of whitecapping for the JONSWAP-spectra plotted against the significant steepness calculated from the actual measur-

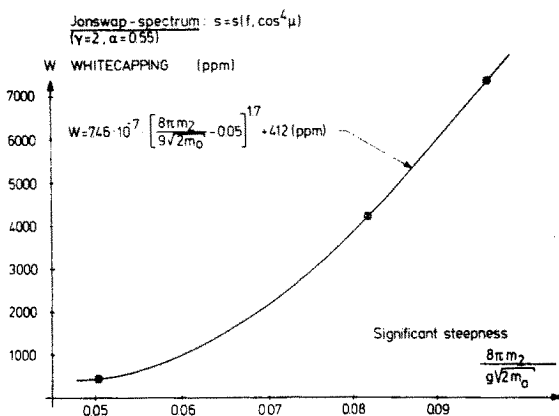


Fig. 2. Whitecapping caused by wave-wave interactions for synthesized JONSWAP-spectra with directional distribution  $\cos^4 u$ , shown as a function of significant wave steepness as calculated from the spectral moments  $m_0$  and  $m_2$ . (From KJELDEN 1984a).

ed moments in the obtained spectra in the wave basin. However, the generated spectra are truncated in this case with a cut-off frequency at 2 Hz.

- 1) The main result of this investigation is then as Fig. 2 shows, that whitecapping caused by wave-wave interactions is strongly correlated with a significant steepness, as it can be calculated from the measured spectra. Further it was found that the following empirical relation fits the experimental results, and thus express whitecapping caused by wave-wave interactions as a function of moments in the wave spectra, in parts per million:

$$W = 7.46 \cdot 10^{-7} \left[ \frac{8 \pi m_2}{9 \sqrt{2} m_0} - 0.05 \right]^{1.7} + 412$$

$g$  is the acceleration of gravity.

- 2) The ratios of observed maximum synoptic crest lengths of whitecaps,  $\lambda_{W \max}$ , and average crest lengths of all waves in the sea state was the following:

a) Pierson-Moskowitz spectrum:  $\frac{\lambda_{W \max}}{\lambda} = 1.56$

b) JONSWAP-spectrum:  $\frac{\lambda_{W \max}}{\lambda} = 1.34$

- 3) The snake and the diffraction methods for generation of directional seas gave different results with respect to whitecapping. The choice of wave generation technique is important, and the effects

of such a choice on whitecapping should be further investigated.

- 4) At a scale 1:11 both the snake method and the diffraction method of wave generation produced seas with an amount of whitecapping comparable with field observations. At all smaller scales (for instance 1:50) the amount of whitecapping in the basin was smaller than observed in nature. The correct reproduction of a fair amount of breaking waves in a 3-dimensional sea state is most important for testing of stability and shipping of water on deck on vessels. Further it is also important when drag forces on offshore structures are considered, due to the shift from a laminar to a turbulent regime in the crests of the waves. Therefore at scales smaller than 1:11 a deterministic non-linear generation of 3-dimensional breaking waves as described by KJELDSEN 1982 will be superior to a stochastic generation in order to reproduce the nature.
- 5) The practical applications of this research in Norway is connected to the scheme for forecasting of breaking waves dangerous to smaller vessels in shipping lanes and specially exposed areas along the Norwegian coast, see KJELDSEN, LYSTAD, MYRHAUG 1981

Acknowledgements are given to CHEVRON OIL FIELD RESEARCH COMPANY that was sponsor for this research work.

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## Appendix B

I. WATANABE - Ship Research Institute, Tokyo, Japan.

EXPERIENCES OF A MULTI-ELEMENT WAVE-MAKER IN SHIP RESEARCH INSTITUTE. GENERATION OF BI-DIRECTIONAL WAVE

### 1. Foreword

Much attention has been given to bi-directional waves with emphasis on two swells propagating at a sharp angle to each other in connection with casualties in the Pacific of the coast of Japan. This is based upon a hypothesis that such a wave might have caused the severe slamming experienced by a bulk carrier in fully loaded condition in the area. In effort to verify the hypothesis, it was felt indispensable to do experiments to measure wave loads in the bi-directional waves.

It was under this circumstance that remodeling of a wavemaker in our 80m square tank took place last year. The main part of the remodeling consisted of introducing microprocessors as a control device for the multi-elemented plunger type wavemaker which is one of two wavemakers in the tank. By virtue of this renovation, it became possible for the wavemakers to generate bi-directional waves which is a combination of irregular and regular waves at a prescribed crossing angle.

## 2. Outline of the facility

Two kinds of wavemaker are installed in our 80m square tank as shown in Fig. 1. A wavemaker (NO.1) extending from side to side is of flap type. It can generate both regular and irregular waves which propagate in the orthogonal direction to the wavemaker. Maximum waveheight available is 0.6m.

The other wavemaker (NO.2) which is in the middle of the adjacent side is a plunger type wavemaker comprised of 24 elements which became possible to be controlled independently by the remodeling. This wavemaker can generate waves such as oblique or concentrating waves using a system to be stated in Sec. 3. Each plunger element is 2.24m long, 0.5m wide and 1.5m deep and its section has a triangular shape. They are driven by DC motor of 6 Kw each and are capable to produce waves of 0.5m to 10m in wavelength and 0.3m in max. height when all the elements are driven in phase

The reason that the plunger is terminated in the middle of the tank side

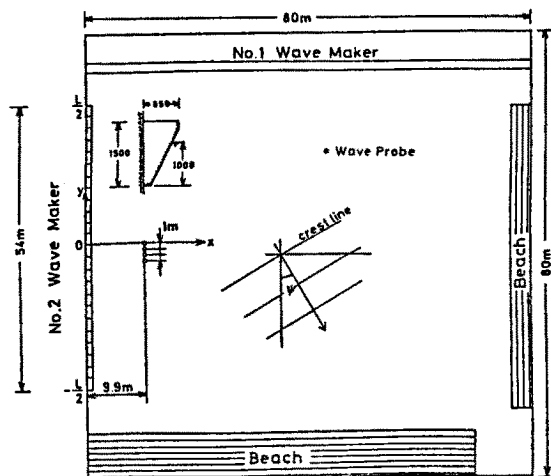


Fig. 1 General arrangement

is to prevent waves from unwanted reflection by the sides when generating oblique waves.

## 3. Control of the plunger elements by means of microcomputer

Control signals for the elements are synthesized in a microcomputer and stored in a data file of its floppy disk. The floppy disk, then, mounted in another microcomputer which directs D/A conversion for 24 channels to the servo-mechanisms. Standard data rate per a channel is 100 data/sec and since two byte make one data, 480 kByte is amount of data for generating input signals of 100 seconds for 24 channels

## 4. Oblique regular wave

Before proceeding to the bi-directional waves, discussions on the regular waves will be made since they are bases for multi-directional waves.

### 4.1 Driving signal

The oblique regular wave which travels at  $\psi$  to the plunger can be produced by moving each element sinusoidally with specified phase shift among the elements as

$$s(t, y_i) = A \cos(\omega t + ky_i), \quad (1)$$

where  $y_i$  indicates the location of the  $i$ -th element along the tank wall,  $A$  is the amplitude of the plunging motion and

$$k = \omega^2 \cos \psi / g. \quad (2)$$

#### 4.2 Effect of the plunger element length

One may generate waves with arbitrary combination of  $\lambda$  and  $\psi$  if the plunger element is much smaller compared to wavelength of interest. However, due to the tank size or other practical reasons, the element has to have a finite length  $l$  and thus a limitation arises for the combination. The limitation comes from the requirement that phase differences between adjacent elements be less than by the analogy of the sampling theorem in the Fast Fourier Transform. The condition is expressed using  $\lambda$ ,  $\psi$  and  $l$  as

$$\lambda > 2l \cos \psi \quad (3)$$

Clearly, a shorter element has more freedom in generating oblique waves and thus multi-directional waves. In our case, the minimum wavelength of the wave which travels along the plunger at  $\psi = 0$  is 4.5m since  $l = 2.25\text{m}$ .

#### 4.3 Effects of finiteness of the plunger

The plunger is arranged in the middle of the tank wall and not extended to the sides due to the reason mentioned before. Owing to this arrangement, effective area to the experiment in the tank varies according to  $\psi$ . Fig. 2 shows theoretically estimated wave contours in order to give schematic view of the effective area where prescribed wave exists. The estimation was made by calculating composed 3-D wave pattern from a line source with a constant density in the place of the plunger at  $\psi$  is the effective water for the prescribed wave condition. In the other zone, the

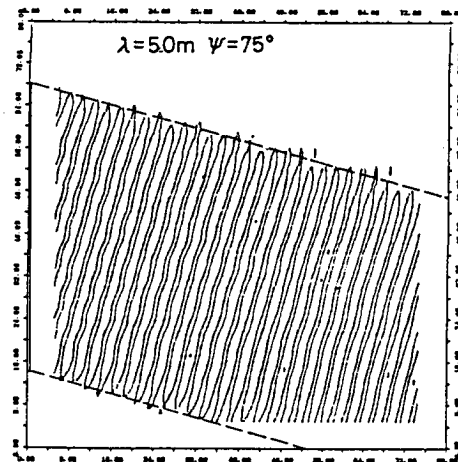


Fig. 2 Wave pattern estimated by 3-D line source method

wave heights are getting smaller than expected. It is seen easily that longer arrangement of the plunger is necessary to have sufficient water in experiments with smaller  $\psi$ .

There is another by-product from the arrangement of the plunger, namely fluctuation in wave amplitude in frequency domain, as an example of Fig. 3 shows. While 2-D estimation does not show such tendency, 3-D

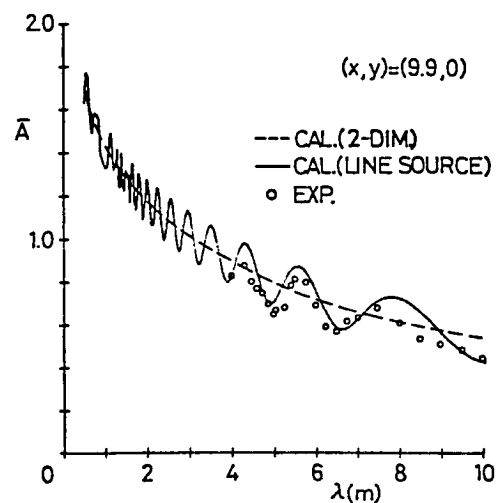


Fig. 3 Wave amplitude vs wavelength  $\psi = 0$

estimation stated in the previous section has given values in good agreement with the measurements. Reasons for the fluctuation may be attributed to the end effects since these patterns of fluctuations were found through calculation to be very sensitive to the source strength at the ends.

References:

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Appendix C

M. D. MILES - Institute for Marine Dynamics, National Research Council, St Johns, New Foundland, Canada.

WAVEMAKER DESIGN CONSIDERATIONS FOR THE NEW LABORATORIES OF THE NRC INSTITUTE FOR MARINE DYNAMICS - SEGMENTED WAVE-MAKER DESIGN

The new IMD Seaking Basin is 75 m by 32 m with a maximum depth of 3.5 m(3). It will be used for two main types of tests:

- Seakeeping tests of moving models in oblique waves in deep water (primarily long-crested waves).
- Tests of moored or bottom-founded structures in both long-crested and short-crested waves at various depths.

These tests will require an advanced type of segmented wavemaker with the following features:

- Long-crested wave generation with directional control up to 60 degrees from the normal.
- Short-crested wave generation over a reasonably large area.
- Variable depth capability from 0.4 to 3.5 m.
- Regular wave height up to 0.6 m and significant wave height up to 0.3 m.
- Wave absorption capability to reduce unwanted reflections and control energy build-up in the basin.
- Proper control of long wave generation with suppression of spurious free-running long waves (of particular importance for moored structures with low resonant frequencies).
- Advanced microprocessor-based control system to enhance reliability, simplify maintenance and provide a growth path for future advances in wave absorption techniques.

The wave generator will consist of

approximately 180 segments with each waveboard being 0.5 m wide and 2 m high. Segment width was selected using Biesel's criterion (2) to allow angles up to 60 degrees for  $\lambda > 1.2$  m. Each segment must be able to operate in a hinged flapper, piston or combination mode to produce well formed waves over a range of depth/wavelength ratios from 0.02 to 12. The segments will be grouped in modules of four for vertical adjustment and to allow them to be exchanged with passive beach modules. Thus, an L-shaped configuration can be used for tests of moving vessels and a U-shaped configuration for improved boundary conditions when testing moored structures as shown in Fig. 1.

The required performance curves for regular wave generation normal to the wall can be obtained with a flap angle of  $\pm 15$  degrees and a piston displacement of  $\pm 0.3$  m.

The maximum piston displacement has been set at  $\pm 0.4$  m, however, to ensure that the compensation signals required for suppression of spurious long waves can be accommodated (1, 5).

A design study has been carried out to investigate various mechanical configuration, actuator and control system options for this type of wavemaker and a 3-segment developmental model has been built and tested. The design study has recommended the use of a wetback glider and hinge configuration with linear hydraulic actuators. The option of two actuators per segment to provide independent control of the top and bottom of the waveboard was considered but found to be prohibitively expensive. One actuator per segment will therefore be used with simple mechanical selection of the various articulation modes.

Although geared DC servo motors were also potential candidates, linear hydraulic actuators were recommended on the basis of greater reliability and mechanical simplicity and because hydraulic power supplies could be shared with the towing tank wavemaker. A wetback design was chosen mainly to avoid seal maintenance problems and difficulties in designing reliable low cost seals which could accommodate the multiple articulation modes and the vertical adjustment requirements. Some form of partial seal may be used to reduce leakage between segments, however, since even small gaps can cause significant attenuation at low frequencies (6).

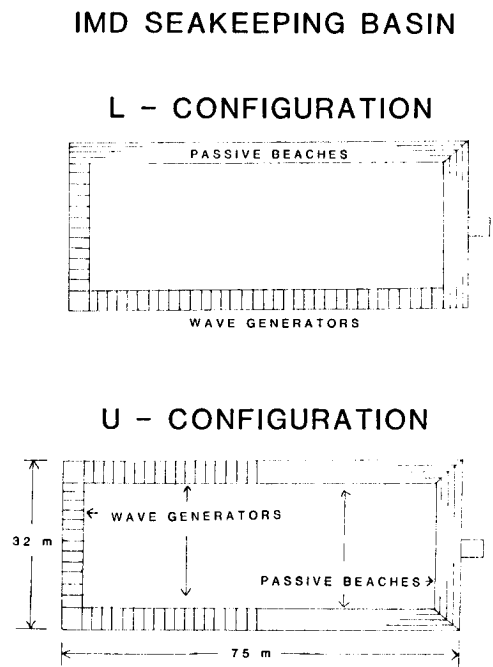


Fig. 1

Force and velocity feedback have been used for wave absorption on segmented wavemakers (4) but this technique has phase problems whenever the resistive force does not dominate the inertial force, particularly at high frequencies. Forces from the water behind the waveboard in a wetback design would cause further problems. It has therefore been decided to use wave height measured on the board and velocity for wave absorption control. The basic principle is to drive the wave board to match the horizontal velocity of an incident wave as estimated from the measured wave height. The wave absorption algorithm will be developed on the basis of hydrodynamic testing and will be a function of frequency, depth and mode of articulation.

A variety of control system options have been considered including centralized and distributed systems with analog, digital and hybrid controllers. Manual tuning adjustments must be kept to a minimum for reliability and ease of maintenance due to the large number of segments involved and automatic calibration must be provided for all analog feedback sensors. The most effective solution appears to be an all digital distributed system with three levels of control. A Micro-Vax host computer will be linked in a local area network to several Module Control Computers which will provide host communications and other services for each group of 16 segments. At the lowest level, a segment control processor will provide the real-time control loops required for wave generation and absorption for each pair of segments. Since the control

loops will be implemented in software, it should be relatively simple to optimize them for changes in parameters such as depth, frequency and wave amplitude. This approach also provides the flexibility required to implement new wave absorption algorithms in the future.

Wave synthesis will be done by the host computer and drive signals for each segment will be downloaded to the module controllers prior to starting the wavemaker. This will leave the host free to perform other data acquisition and control tasks during the run.

A 64-segment prototype wave generator based on this concept is currently being developed by the NRC Hydraulics Laboratory and will form the basis for the subsequent IMD production model.

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Appendix D

S. P. KJELDSEN - Norwegian Hydrodynamic Laboratories, Div. Ship and Ocean Laboratory, Trondheim, Norway.

EXPERIENCE WITH DOUBLE FLAP WAVEMAKERS

The hydraulic driven hinged double flap type wavemaker is installed at the new ocean simulation test basin at NHL in Trondheim, Norway. The main dimensions of the basin is 80 x 50 meters and the basin has an adjustable bottom that permits experimental work on any depth between 0-10 meters. Further at a depth of 3 meters a steady ocean current with a mean velocity 17 cm/sec. can be superposed upon the generated wave patterns in order to simulate natural conditions. The double flap wavemaker is hinged 1.05 m and 2.62 m below mean water level respectively, see Fig. 1. The back side of the wavemaker is kept dry by means of spring-loaded water lubricated bars of nylon type material. The wavemaker has a total length of 48.4 m. At a maximum angular amplitude of  $\pm 12$  degrees its total "displace-

ment" is about  $\pm 37 \text{ m}^3$  and in this respect it is probably the largest wavemaker in the world till now. The total power for the hydraulic pumps is 715 kW. After installation the calibration of this wavemaker showed that it produced non-linear gravity waves. This is documented by the sequence of plots shown in Fig. 2, 3 and 4. Fig. 2 shows the spectrum of our command signal supplied to the wave generator for a regular wave with a frequency 0.4 Hz. Fig. 4 shows the spectrum of the obtained gravity waves measured in the middle of the ocean basin 35 m from the wave generator. The spectrum shows a secondary peak at the second higher harmonic as large as 6% of the peak value. Fig. 3 shows a filtered time series obtained of the front of a train of regular waves. A phase locked second harmonic oscillation dispersing with the group velocity of the basic wave is clearly visible. Freely travelling second harmonics disperses with another group velocity and is not yet arrived. These results were obtained for a water depth 3 m,

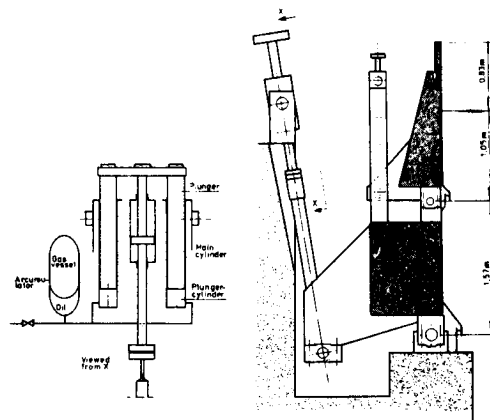


Fig. 1. Double flap hydraulic wavemaker showing principle of balancing static water load (From EGGESTAD 1981).

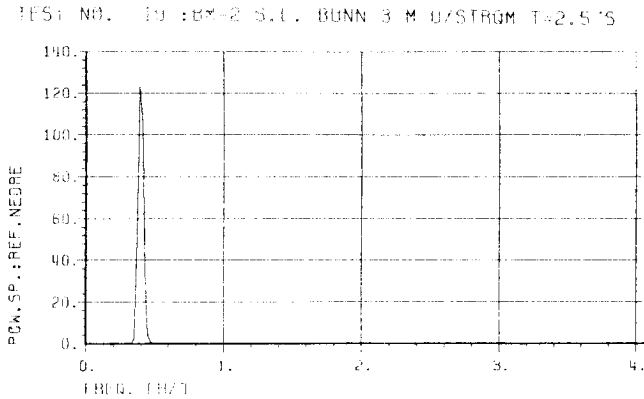


Fig. 2. Spectrum of input signal for regular wave train.

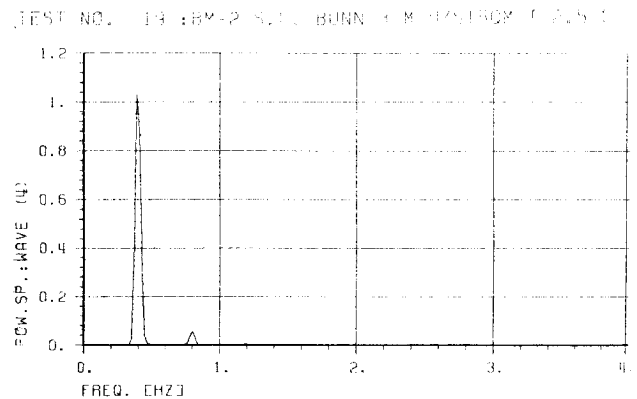


Fig. 4. Spectrum of gravity waves measured 35 m from the wave generator.

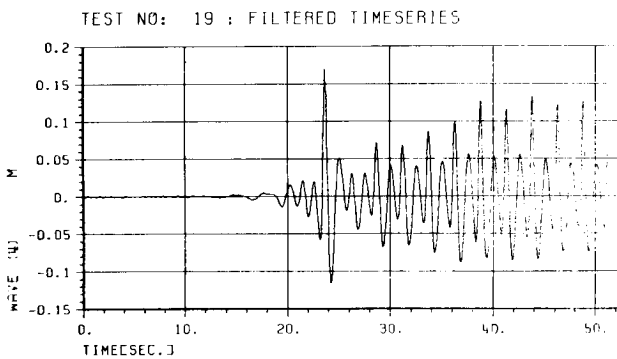


Fig. 3. Filtered time series showing the content of higher harmonics in the front of a regular wave train.

indicating that the non-linear waves should be regarded as Stokes waves. Phase-locked higher harmonics was also discovered for deep water conditions, where the obtained non-linear waves also can be regarded as Stokes waves. In very shallow water the non-linear waves produced in the sea simulating basin should be regarded as sinoidal waves. The transfer function for this particular wavemaker is thus a doubled valued function. Non-linear dispersion properties of these waves has been utilized to develop a non-linear technique for generating of freak waves, that appears as violent plung-

ing breakers in deep waters, see KJELDSEN 1982. The non-linear sweep frequency modulation applied is more efficient, than linear sweep frequency modulation applied by other investigators. This is due to the fact that within a given sweep time, the non-linear technique uses waves with shorter wave periods and thus obtains a higher number of interacting waves, than the linear technique. Thus the resulting plunging breaker becomes more violent, see KJELDSEN 1984 a. The particle kinematics in the crest of the non-linear generated freak wave has recently been mapped, see KJELDSEN 1984 b. Simulation of natural conditions involves in many cases simulation of a steady ocean current with a wave pattern superposed. Fig. 5 and 6 shows results from calibration of wave patterns superposed upon a mean current 0.17 m/s. Regular waves with a frequency of 2 Hz were generated. The obtained spectra displayed in Fig. 5 and 6 shows a significant downshift in wave frequency. This is a demonstration of a non-linear wave-current

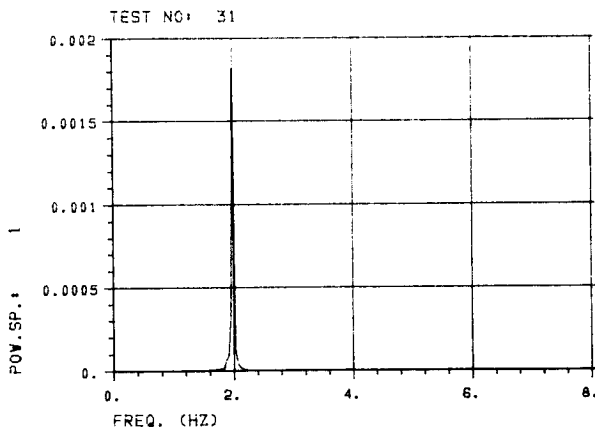


Fig. 5. Wave pattern superposed on ocean current. Spectrum of gravity waves 10 m from wave generator.

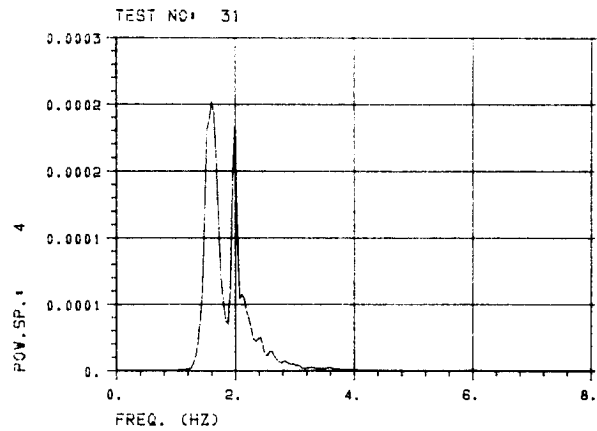


Fig. 6. Wave pattern superposed on ocean current. Spectrum of gravity waves 35 m from wave generator.

interaction and can not be explained by linear assumptions. Results of this kind has important applications for basic oceanographic science. Further such results can help to estimate the truncation limit for wave spectra to be simulated in ocean basins, under conditions where also steady ocean currents are present. For further details, see KJELDSEN 1983 and KJELDSEN & PRICE 1982.

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Appendix E

M. D. MILES - Institute for Marine Dynamics, National Research Council, St Johns, New Foundland, Canada.

WAVEMAKER DESIGN CONSIDERATIONS FOR THE NEW LABORATORIES OF THE NRC INSTITUTE FOR MARINE DYNAMICS - DOUBLE FLAP WAVEMAKER DESIGN

(Presented by Mr. D. Murdey)

The new facilities currently under construction for the NRC Institute for Marine Dynamics (IMD) in St. John's, Newfoundland [5] will include a 200 m by 12 m towing tank with a normal operating depth of 7 m. An analysis of the model testing requirements for this facility has indicated that wavelengths from 0.5 to 40 m must be generated with the wavemaker design optimized for minimum harmonic distortion over the range from 2 to 25 m. The maximum regular wave height required is 1 m and the maximum significant wave height in irregular waves is 0.5 m.

A double flap wavemaker configuration has been selected in order to minimize distortion over the rather broad range of wavelengths required and to reduce the generation of spurious transverse waves at high frequencies. The relative merits of dryback and wetback designs were considered and a dryback was selected primarily because of greater operating efficiency, reduced inertia, greater freedom in locating actuators and because the design of suitable seals for this configuration did not seem to pose any serious problems.

Hydraulic actuators were chosen for reliability and because of the relatively large power requirements. Each flap has three actuators; an active one in the centre for dynamic control and separate passive ones on each side with gas accumulators for hydrostatic balance. The hydrostatic compensation force was specified to vary less than 10% over the full stroke of each flap.

Linear wave theory [2, 4] has been used to optimize the design and select the hinge depths. Five basic modes of articulation were considered where  $\alpha$  = angle of lower flap relative to vertical and  $\beta$  = angle of upper flap relative to lower flap:

MODE A - Upper Flap Fixed ( $\beta = 0$ )

MODE B - Lower Flap Fixed ( $\alpha = 0$ )

MODE C - Upper Flap in  
Piston Mode ( $\beta = -\alpha$ )

MODE D - In-Phase Mode

MODE E - Linear Regression Apportionment

Mode D is the in-phase mode defined by Dalzell [2] for transition between modes A and B in which both flaps are driven in phase but with different amplitudes based on the velocity profile for a deep water progressive wave. Mode E uses the linear regression flap angle apportionment technique of Clark and Menken [1] in which the flaps are driven either in-phase or 180 degrees out of phase depending on frequency. Clark and Menken do not give any quantitative measure of distortion for their apportionment

scheme but Dalzell's Figure of Merit for harmonic distortion [2] has been extended to cover the cases of Modes C and E in Reference [1]. This Figure of Merit is greater than one by definition and should be kept as close to one as possible to minimize distortion. Distortion can be minimized by using different modes for different wavelength zones as indicated in Figure 1 for the case of the IMD wavemaker.

Fig 1 indicates that Mode E does not offer any significant advantage over the other modes except at wavelengths greater than 25 m. This is coupled with a large reduction in wave amplitude capability so Mode C may be the most practical mode for long wavelengths.

The lower hinge depth was set at 4 m since this is sufficient to provide the required wave amplitudes with a moderate maximum angle of 14 degrees on each flap. (The actual maximum angle was set at 16 degrees to provide a safety margin on linear wave theory). Balancing harmonic distortion at wavelengths of 2 and 25 m gives an upper hinge depth of 1.3 m as explained in [6]. A rule of thumb to avoid generation of transverse waves is that the hinge depth should not exceed one-half of the wavelength so the upper hinge depth was set at 1.2 m as a compromise.

Conventional analog servo controllers will be used for each flap with position feedback on the primary loop and differential pressure and rate feedback for stability. A local microprocessor will provide digital storage of the drive

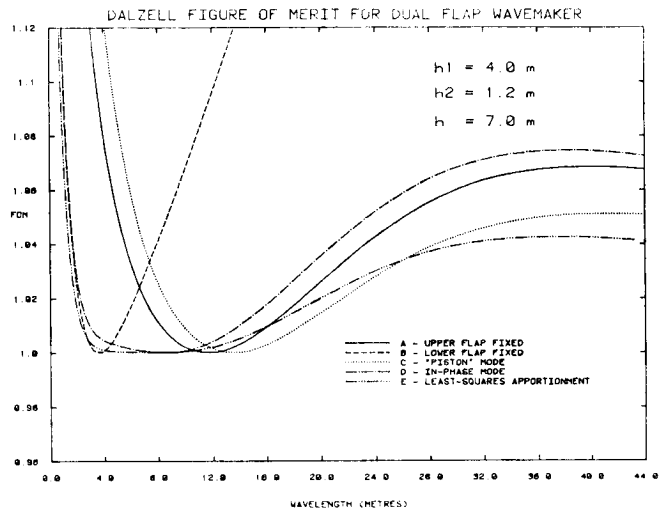


Figure 1

signals. These will be precomputed by the data acquisition computer on the carriage and downloaded via a radio modem and verified prior to starting a run. The drive signals will be computed at a 10 Hz sampling rate and the local microprocessor will interpolate to provide smoother output signals with an 80 Hz update rate. Wave synthesis software will be based on the NRC Hydraulics Laboratory GEDAP package [3] with extensions for double flap apportionment based on frequency zones. The final transition points between modes will probably be determined experimentally.

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lar waves still remain unsolved, however. Although the transfer function obtained by generating independent regular waves is a reasonably smooth curve, the transfer function obtained while converging on a specified irregular wave spectrum frequently appears to be highly non-linear with large deviations from the regular wave transfer function. Recent unpublished studies by the authors have shown the wavemaker transfer function to vary with the location of the wave probe in the tank and with the randomization "seed" used in randomizing the phases of the various harmonics. This observation tends to support the idea (mentioned by Kjeldsen in his group discussion paper at the 17th ITTC) that higher harmonics are "carried" by the longer wave compo-

LEGEND: --- = DESIGN SPECTRUM  
 \*-\*-\* = SPECTRUM AT PROBE 1 - 25% OF TANK LENGTH  
 ◆◆◆ = SPECTRUM AT PROBE 2 - 50% OF TANK LENGTH  
 x-x-x = SPECTRUM AT PROBE 3 - 75% OF TANK LENGTH

Appendix F

B. JOHNSON, L. WALLENDORF and J. DALZELL - Hydromechanics Laboratory, U.S. Naval Academy, Annapolis, Md, USA.

ON THE GENERATION OF COMPLEX PERIODIC IRREGULAR WAVES

Two double flap wavemakers have been in operation at the U. S. Naval Academy since 1977. The operational software for these machines has been described in the Proceedings of the 18th, 19th and 20th American Towing Tank Conferences. Several unresolved problems in the generation of periodic irregu-

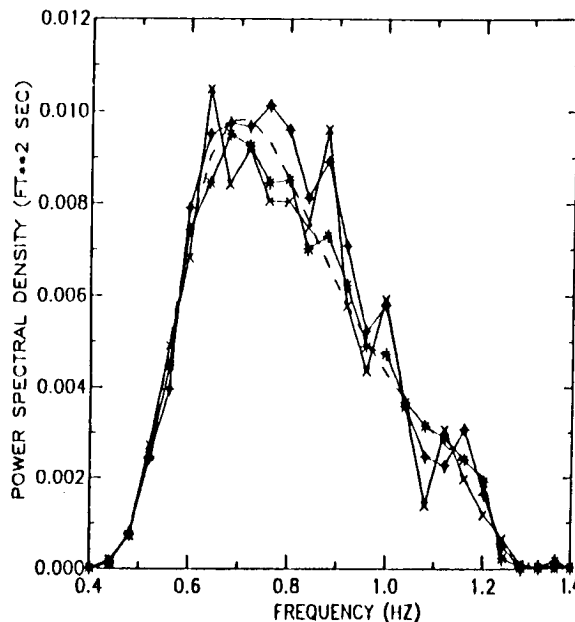


Fig 1 Breitschneider spectra at three tank locations

LEGEND. --- = DESIGN SPECTRUM  
 \*-\*-\* = TIME FRAME ONE  
 +--+ = TIME FRAME TWO  
 #-#-# = TIME FRAME THREE

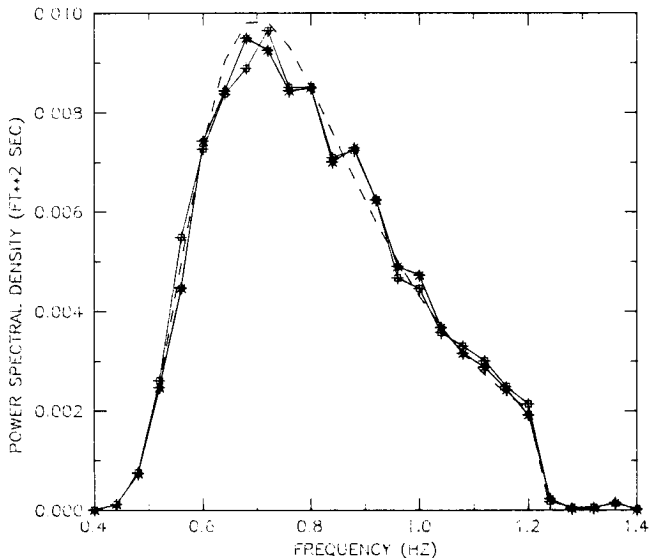


Fig 2 Breitschneider spectra - three time frames at probe one

nents at higher than normal phase velocities. Thus a given harmonic generated by the wavemaker can have its frequency "shifted" as it travels down the tank and thus cause a shift in the spectrum with distance down the tank.

Figure 1 shows the unaveraged analysis of a repeating Breitschneider spectrum with the sample frame length, 25 seconds, equal to the repetition period of the complex wave. As can be seen from the figure, the measured spectrum deviates further from the desired spectrum as the waves travel down the tank. To make sure this was not caused by time dependent factors such as beach reflections, the record at the forward probe was analyzed for three different overlapping 25 second periods. The results are shown in Figure 2, where the scatter is minimal.

This phenomenon may not be a problem in random wave generation as there are many harmonics contained in each analysis band width and the averaging process and limited statistical confidence masks the effect.

#### Appendix G

P. BOGDANOV, ST. GEORGIEV -  
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#### HYDRAULIC SYSTEMS FOR DRIVING PLATE TYPE WAVEMAKER IN THE BSHC DEEP WATER TANK

The BSHC deep water tank is one of the basic experimental facilities of BSHC. It has the following dimensions: length - 200 m, width 16 m, depth 6.5 m and is equipped with plate-type wavemaker with a single plate, 16 m wide and 2.5 m high. This plate effectively generates waves with length from 1 to 10-11 m. With shorter waves, inadmissively large transverse waves are being generated as well. The most commonly used models are with 4-8 m length, for which the above-mentioned wave length range is adequate.

The initial driving system was of electromechanical type, realizing the well-known principle for converting the revolutions of an eccentric mechanism into a reciprocating motion. The change of the revolutions was used to change the frequency of the generated waves, and the change of the eccentricity the amplitude. To overcome the shortcomings of this sys-

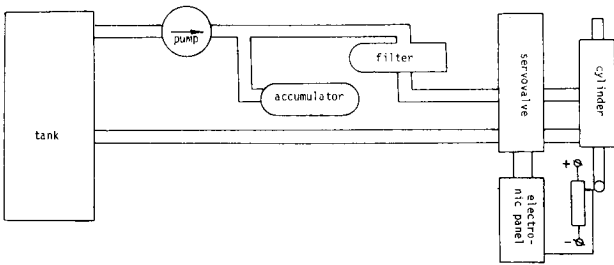


Fig 1 Scheme of the hydraulic section

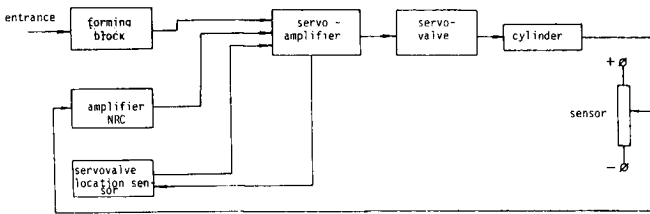


Fig 2 Block diagram of the electronic section

tem, a new one was designed and constructed at BSHC in the period 1982-1983.

Its scheme is shown in Fig. 1. The force moving the plate is generated by a reversible hydraulic cylinder. It is being controlled by a servovalve, coupled as a controlling element of the servosystem with displacement and speed of displacement feedback. The oil pressure is generated by 6 parallelly operating pumps. The system is equipped with 10  $\mu$ m filter and accumulator. The electronic block (Fig. 2) of the system incorporates filters for EMI suppressing, amplifiers for the feedback signals. The servo-amplifier realizes a proportionally differential control law. The oil tank is chosen with adequate capacity and free surface for effective deaeration of the oil.

The system has linear amplitude-frequency characteristic ranging from 0.2 to 2.5 Hz, and the maximum frequency is 5 Hz. From 2.5 to 5 Hz the characteristic is descending. This high frequency range for such a big plate has been chosen with an aim of obtaining considerable margin for ensuring linearity when generating sea waves. The tests proved that the expenses covering this margin have been expedient.

The maximum plate amplitude is  $\pm 270$  mm, restricted by the electronic block characteristics. The mechanical stoppers allow  $\pm 300$  mm amplitude to be reached.

In the course of the conducted tests have been obtained good results. Practically, waves with lengths from 0.8 to 12 m were generated. Amplitude stability accuracy measured for more than 50 waves was better than 3%, wave period stability accuracy - better than 1%, wave form deflection from the theoretical curve for more than 100 periods - about 3%. All measurements have been performed in the middle of the tank, at a distance of 100 m from the wavemaker with a stationary wave probe. The obtained data were processed following the standard procedure applied at BSHC by PDP 11/10 computer on board the towing carriage in the tank. Fig. 3 presents an example of the wave recording.

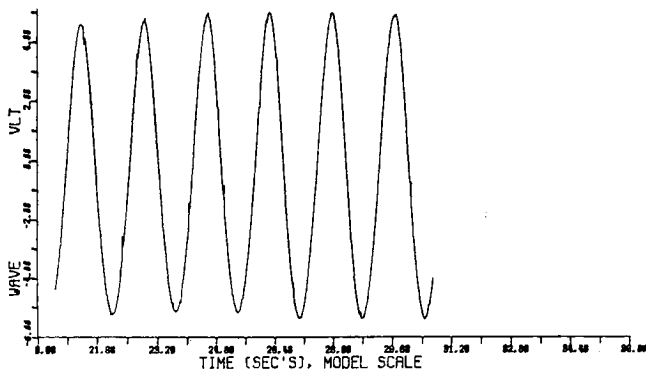


Figure 3

Upon sea wave generation, the wave spectra recommended by ISSC served as a basis. The signals were computer-generated and recorded on an analog tape recorder. The spectrum characteristics (average frequency and Beaufort rating) were entered into the computer before the tests. Each computer-generated record was run 12 times and from the measured data by Fourier analysis, amplitude and power spectra were drawn and the average Beaufort rating  $H_{1/3}$  was calculated. The obtained spectra exhibited good repeatability. The accuracy of the average Beaufort rating was better than 10%. (Values from 6% up to 9% were calculated). Typical spectra are shown in Figs. 4 and 5.

In April 1984 in the BSHC deep water towing tank were carried out tests of segmented models for determination of the bending moments and shearing forces. The sine and sea waves were generated using the new driving system of the wavemaker. The results obtained by processing on the towing carriage computer were very good.

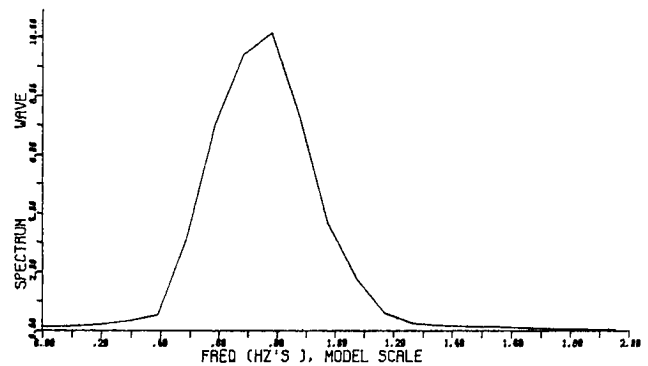


Figure 4

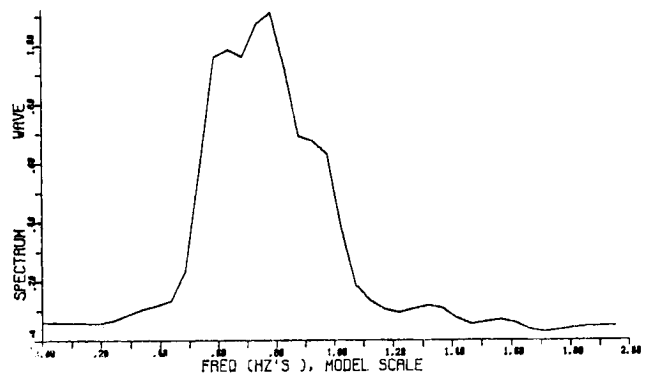


Figure 5

The future plans envisage wavemaker remote control by the towing carriage computer and investigation of the possibility for introducing negative feedback within the control system, using the actual values of the waves generated in the tank by the wavemaker plate.