SESSION ON OCEAN ENGINEERING

Chairman: Dr. M.W.C. Oosterveld

Ocean Engineering Committee Memberships: G. van Oortmerssen (Chairman) - S. J. Rowe (Secretary) - J.-L. Armand - R. A. Barr - M.-X. Gu - A. Ivanov - B. Kofoed Jacobsen - M. Takagi - A. Tørum

Discussion of the Report and the Draft Recommendations of the Ocean Engineering Committee. (Cf Proceedings, Volume 1, p. 535-588, and separately distributed "A Comparison of Methods for Calculating the Motion of a Semi-Submersible", subsequently published in Ocean Engineering, Vol. 12 (1985):1, p. 45-97.)

I. DISCUSSIONS

R. G. STANDING - NMI Ltd, Feltham, Middx, United Kingdom

ON A COMPARISON OF METHODS FOR CALCULATING THE MOTION OF A SEMI-SUBMERSIBLE

The authors faced a difficult task in presenting results from 34 different computer programs and 3 experiments in this short paper, and inevitably the results pose a number of unanswered questions. Setting aside discrepancies due to input data errors or misunderstandings, I would like to draw attention to an important difference between two groups of results in Figure 12. This figure shows the dependence of heave amplitude on wave period, and the results fall into two distinct bands: one obtained using three dimensional wave diffraction theory, and the other by use of Morison's equation and empirical coefficients. The second group agrees better with experimental measurements than the first. The reasons for this result are far from clear, and both the figure and accompanying text appear to present only part of the story.

I first note that the group 2 results in this figure relate to only 6 out of the total of 11 programs in this group, and ask whether there is anything special about these programs. Five are from Japan, and the sixth is British. The remaining five (not shown) come from all parts of the world. The text and Figure 16 (for a larger wave height than Figure 12) suggest that the results that are not shown agree better with the group 1 results than with others from group 2. Are these variations fortuitous, or is there some basic difference between the two subgroups? Or is there in fact a continuous range of results, only one part of which is shown?. The evidence is incomplete and not clear. All we have is an oblique reference in the text to the importance of "the Keulegan--Carpenter number, etc".

Figure 12 shows a difference of about 0.2 seconds between the cancellation periods for groups 1 and 2, and a similar difference between the natural periods. If this shift is attributed entirely to a change in the vessel's heave added mass, then the group 2 programs require an added mass that is some 25% smaller than the group 1 programs. I then ask whether it is reasonable to attribute a change of this kind to a variation with Keulegan-Carpenter number, or to some other difference between the purely theoretical diffraction theory and the empirical Morison approach.

The added mass in heave comes almost entirely from forces acting on the two horizontal pontoons. These are rectangular in cross-section, with rounded corners, and the Keulegan-Carpenter number, K_c, is in the range 0.5-1.0 when the wave height is 0.046 m. Appropriate experimental data on added mass is not easy to find. Bearman and Graham (ref 1) however, presented results from a U-tube experiment, in which measurements where made on cylinders of circular, square and flat-plate sections. These results were for values of K_c above about 3, and Bearman and Graham also presented formulae for extrapolating to lower K_c. These formulae were based on theoretical vortex-flow considerations, but contain coefficients fitted to the experimental data. I have used these formulae to prepare the following table. It shows the ratio of added mass to displacement mass extrapolated to K_c = 0 and 1, together with values based on an entirely theoretical, inviscid, potential flow approach (ref 2)

Cross-section	Inviscid theory	Experiment: $K_c=0$	$K_c=1$
circular	1.0	1.0	0.99
square, diagonal to flow	1.19	1.18	1.10

Bearman and Graham also presented results for a square-section member, facing the direction of flow, but in a form less readily used. All these results support the following conclusions:

a) experimental measurements agree very well with theory at low values of K_c

b) the added mass (at least in these examples) tends to decrease as K_c increases, but the reduction is far too small to explain the discrepancies in Figure 12

So where do the discrepancies in Figure 12 come from?. What values of C_m were used in these calculations, and why were they chosen? The authors of this paper stress the significance of this result, but suggest that it can be accounted for simply by including viscous effects. My evidence suggests otherwise. I recommend that the matter should be investigated further by the Committee, as a matter of importance to all concerned. The differences, if not merely fortuitous, are too large to ignore.

References

1. Bearman, P. W. and Graham, J. M. R., "Hydrodynamic forces on cylindrical bodies in oscillatory flow", Proc 2nd Conf. Behaviour of Offshore Structures (BOSS '79), London 1979.

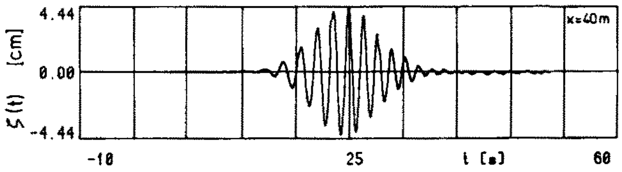
2. Myers, J. J., Holm, C. H. and MacAllister, R. F., "Handbook of Ocean and Underwater Engineering", MacGraw-Hill, 1969.

G. F. CLAUSS and J. BERGMANN -
Institut für Schiffs- Und Meerestechnik,
Technische Universität Berlin, Berlin,
Federal Republic of Germany

ON SEAKEEPING TESTS OF OCEAN STRUCTURES WITH GAUSSIAN WAVE PACKETS

As a special technique for the investigation of ocean structures in the seaway a transient wave method was developed at the Technical University of Berlin using Gaussian wave packets.

Transient wave techniques have succesfully been used by Davis and Zarnick /1/ and Takezawa /2/. Special applications are proposed by Kjeldsen /3/. The following technique is based on the Gauss-modulated amplitude spectrum (see Coulson /4/). Figure 1 shows a typical wave train with its mathematical description, the wave elevation depending on time and location. Any superposition of Gaussian wave packets is possible. On its way through the wave tank the actual surface elevation is a function of the characteristics of every single wave packet and of their initial time lag. As illustrated in Figure 2 a long-period wave train overtakes a



$$\zeta(x,t) = \zeta_0 \sqrt{\frac{1}{1+is^2Bt}}$$

$$\exp\left[-\frac{1}{2}\,\frac{s^2}{1+s^4B^2t^2}\,(x-At)^2\right]$$

$$\exp\left[i\left(k_0x-\omega_0t+\frac{1}{2}\,\frac{s^4Bt}{1+s^4B^2t^2}\,(x-At)^2\right)\right]$$

Fig 1 Definition of the Gaussian wave packet

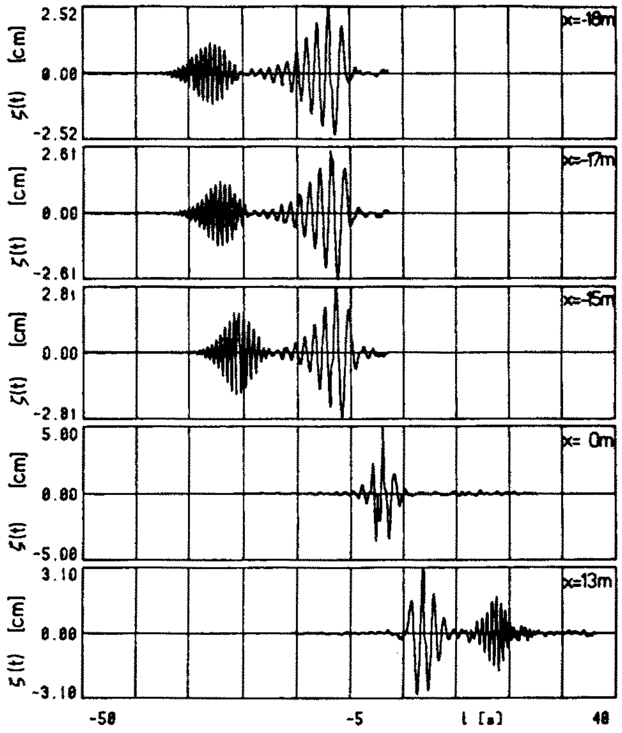


Fig 2 Registration of Gaussian wave packets passing successive locations along the tank

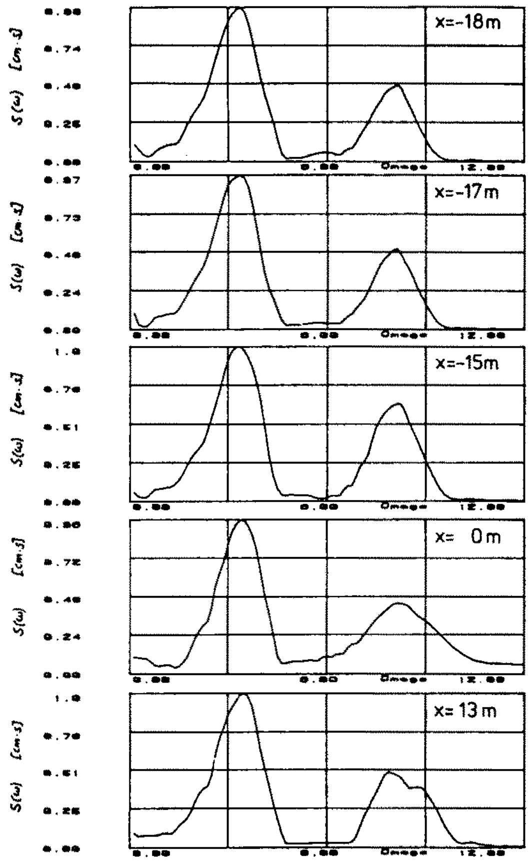


Fig 3 Fourier spectra of Gaussian wave packets at successive locations

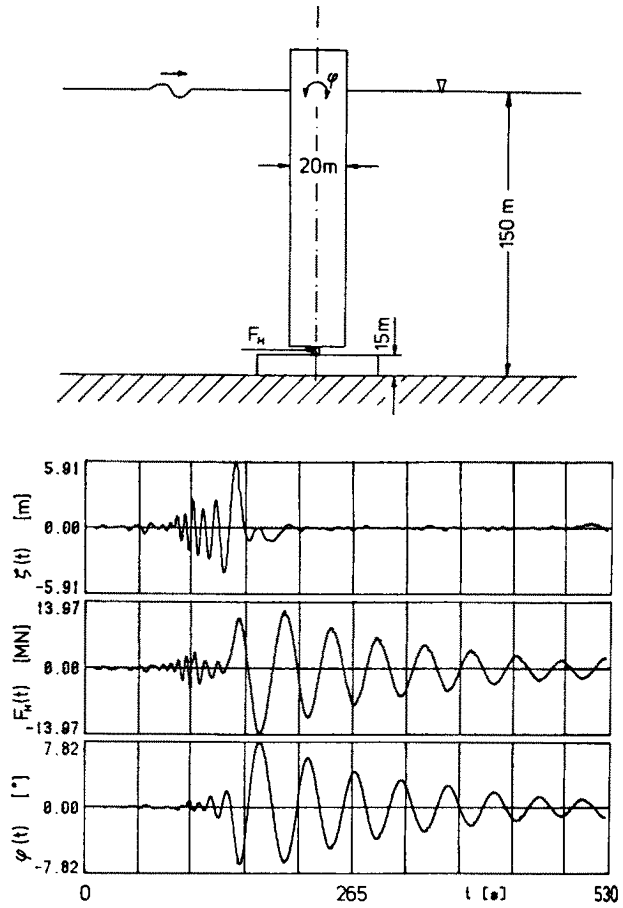


Fig 4 Registration of a wave train and related horizontal force and pitch motion of an articulated tower

short-period wave train according to its higher group velocity. At a certain position both groups are colliding, but separate again into the original packets at a later location. The related spectra in Figure 3 show that these interactions have little effect. Even at the collision position both wave packets can be identified clearly. The application of this technique is illustrated by the following three cases presenting an articulated tower, a floating and a fixed structure. Figure 4 shows the registration of a wave train and the related horizontal force and pitch motion of an articulated tower. As the wave train passes the structure little

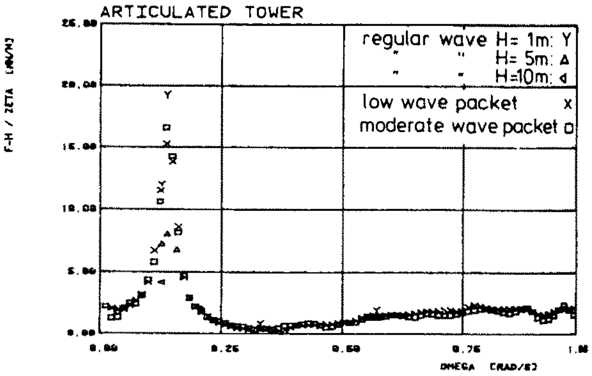


Fig 5 Horizontal force transfer function of an articulated tower - comparison of wave train data with regular waves

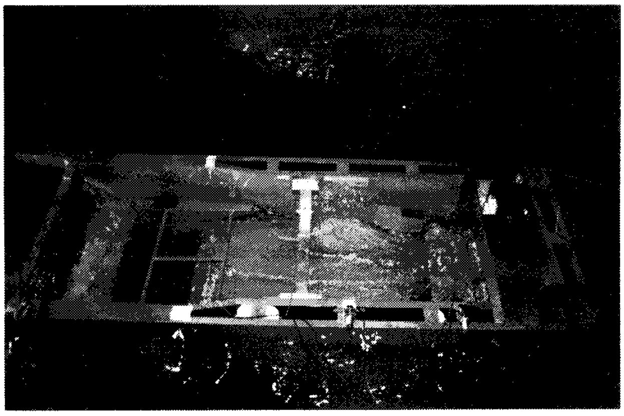


Fig 6 ERNO - oil skimming system

reactions are observed, but later the response resonance motion governs the characteristics. The related horizontal force transfer function shows clearly the resonance peak (see Figure 5). The wave group results yield a high resolution and show good agreement with regular wave tests. This is very favourable with complicated structures like the floating oil skimmer (see Figure 6). The related pitch transfer function in Figure 7 shows many peaks which are easily detected by the wave group technique. Again the comparison with regular wave tests looks satisfactorily. The last case deals with a flat foundation structure shortly before touching down. Figure 8 shows the registration of the wave packet as well as the vertical force and the pressure in the gap. The wave train method yields again a highly resolved transfer function with a short run (see Figure 9).

The technique has the following advantages:

- the wave train is well defined at any location of the tank
- the wave elevation and spectrum can

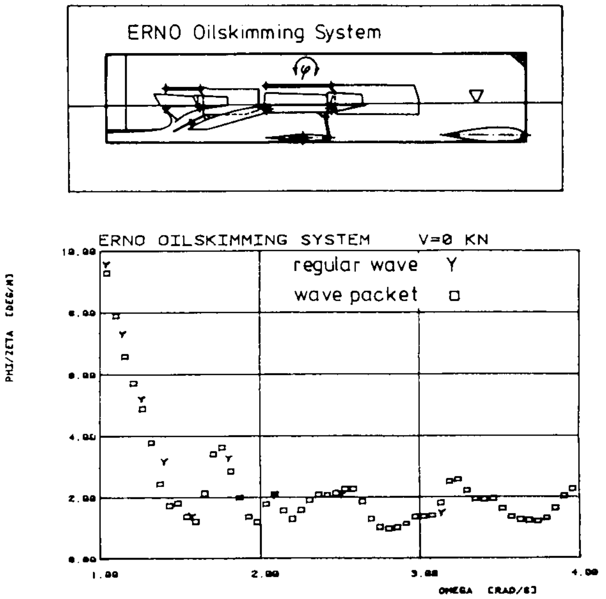


Fig 7 Pitch transfer function of oil-skimming vessel - comparison of wave train data with regular wave data

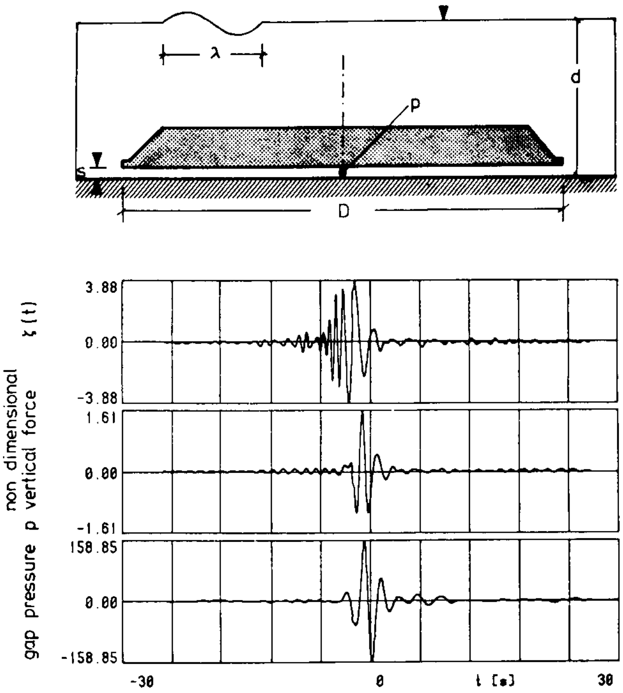


Fig 8 Registration of wave group and related pressure and vertical force on a flat deep sea foundation structure

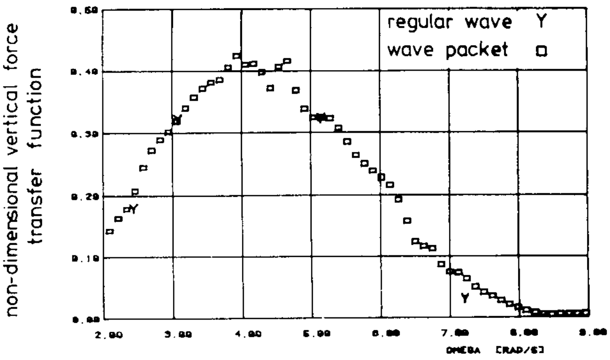


Fig 9 Non-dimensional vertical force transfer function of a flat deep sea foundation structure - comparison of wave train data and regular wave data

be standarized or easily adapted to any specific problem

- the duration of the test is very short; reflections do not affect the results
- the results show high resolution and are in good agreement with regular wave tests

Summarizing, the Gaussian wave packet method is a highly versatile technique yielding extensive and comprehensive results in short time.

References

/1/ Davis, M. C., Zarnick, E. E.: "Testing Ship Models in Transient Waves", 5th Symp. on Naval Hydrodynamics, 1964.

/2/ Takezawa, S. et al.: "Advanced Experiment Technique for Testing Ship Models in Transient Water Waves, Part I and II", 11th Symp. on Naval Hydrodynamics, 1976.

/3/ Kjeldsen, S. P., Myrhaug, D.: "Breaking Waves in Deep Water and Resulting Wave Forces", Proc. 1979 Offshore Technology Conference, Vol. IV (OTC 3646), May 1979.

/4/ Coulson, C. A.: "Waves, a Mathematical Account of the Common Types of Wave Motion", Oliver and Boyd, Intersc. Publ. Inc., N.Y. 1949.

H. TANIBAYASHI - Nagasaki Experimental Tank, Mitsubishi Heavy Industries, Ltd., Nagasaki, Japan

ON THE PREDICTION METHOD OF EXTREME VALUES

The Report of 17th ITTC Ocean Engineering Committee neatly summarizes state-of-the-arts of vast activities in the research of Ocean Engineering. I deeply appreciate this precious work.

However, it seems to me that the Committee has regrettably dismissed one trend in the pursuit of method to predict extreme values. In fact, many people are trying to define "Design Irregular Waves" for each catastrophic phenomenon of floating structure, which is briefly touched in Reference [1].

The Committee Report indicates "Design (Regular) Wave" concept has shortcomings mainly because it does not explicitly consider probabilistic characteristics of sea waves. As the direction to proceed, the Committee seems to suggest something like "Design Spectrum" concept with extrapolation technique to longer period assuming the form of probability distribution function. This method will work in the cases where non-linearity of the referred system is weak or takes effects gradually. However, many of the phenomena we deal with have strong or abrupt non-linearities.

For examples, motions and mooring forces of dolphin-moored floating structures, large amplitude rolling with the danger of capsizing, underdeck slamming of semi-submersibles and so on. In these cases, extrapolation technique will not work successfully.

To overcome this difficulty, "Design Irregular Wave" concept arises as another deterministic approach which tries to specify a few time-histories of irregular waves as "Design Waves" based on some probabilistic consideration. My colleague Toki [2] proposed one approach for this concept assuming that "Design Wave Spectrum" can be defined by the survey of wave statistics data, while the procedure to define "Design Irregular Waves" can be various. Flow chart of his concept is shown in Figure 1.

Many researches on breaking or freak waves [3] seem to have been carried out on the assumption that such waves are the main reason of sea disasters. In a distinct case, Kjeldsen [4] has a clear intention to define "Design Irregular Waves for capsizing of small ships" by certain combinations of wave height and crest front steepness values. Researches on wave groupiness [5] also seem to have the same intention being based on another assumption that successive high waves mainly cause sea disasters.

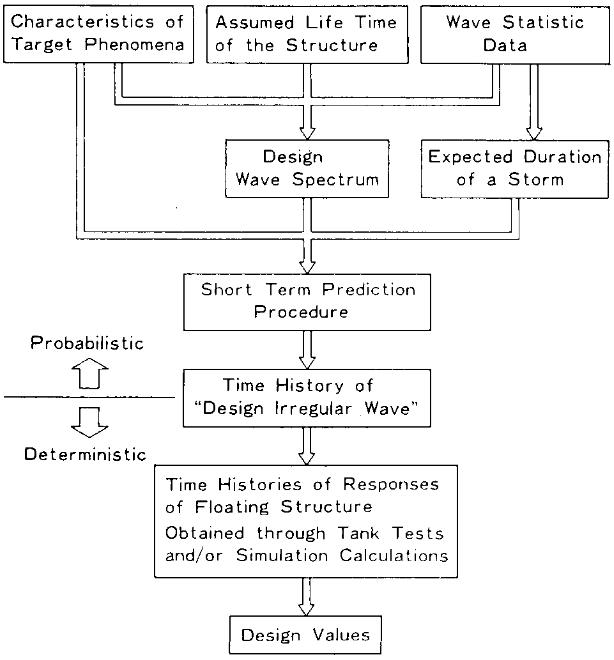


Fig 1 A Flow Chart of "Design Irregular Wave" Concept

Even if the same "Design Spectrum" is given, "Design Irregular Waves" can be different in the shape of time-history or space wave shape depending on the characteristics of target catastrophic phenomena. In this context, Toki [2] proposed a numerical model to find episodic events in irregular wave time-history. He considers that this can be a tool to define "Design Irregular Waves" for each catastrophic phenomenon.

References

[1] Couch, R. B., Troesch, A. W. and Ashcroft, F. H., "The Use of Model Basins in the Design of Ships and Marine Structures"
Proceedings of SNAME 9th STAR Symposium (1984).

[2] Naoji Toki, "Preliminary Study on the Concept of 'Design Irregular

Waves' with Emphasis on the Generation of It"
Report of Dep. of SNAME of the Univ. of Michigan, No. 252 (1982).

[3] References [1.8] ~ [1.15] of the Committee Report.

[4] Kjeldsen, S. P. "Design Waves" (Probably the same as Reference [1.15] of the Committee Report and [17] of the present Seakeeping Committee Report)
Report of Norwegian Hydrodynamic Laboratories, NHL 1 81008 (1981).

[5] References [1.4] ~ [1.7] of the Committee Report.

S. E. SAND, Invited Discusser - Danish Hydraulic Institute, Horsholm, Copenhagen, Denmark

ON WAVE GROUPING AND MODEL WAVE GENERATION
(Shortened version presented by G. Rodenhuis)

I thank you for having been given the opportunity to comment on the Committee Report, mainly as a Member of the IAHR Working Group on Wave Generation and Analysis. My comments refer to the appropriate Sections of the Report.

2.2.1 Wave Groupiness - To the review of the possible grouping measures (factors) I think you could draw the connection to the bounded long waves (set-down) by means of Ref. /4.2/ in the Report. It is shown there that a grouping factor can be produced solely on basis of long wave computations (a physical measure), and that an analytical transfer function converts this factor to the SIWEH GF-factor by Funke and Mansard, Ref. /1.5/. Thus, the bounded long waves can obviously be used as a grouping measure because of the group-bound character and the quadratic relation to the short waves.

2.3 Wind - The lower frequency range ($f < 10^{-2}$ Hz) seems to be of great interest for several reasons. As mentioned in the Report this range is needed for proper determination of wind forces on offshore structures. However, as a supplement to this application it is mentioned also in Ref. /4.2/ that the influence of these wind fluctuations on the generation of free long waves must be significant. Thus, such long waves must clearly be important for mooring systems, vessel motions, etc.

3.1.2 and 3.1.3 Wave Generation - I expect that you will not be surprised that my main comment, on behalf of DHI, is related to the deterministic versus stochastic recommendations in the Report. I wish to consider 2-D and 3-D wave generation techniques separately.

In 1970 DHI initiated the deterministic reproduction of 2-D (uni-directional) wave trains. At that time very little was known about grouping characteristics, phase distributions, etc., and therefore by reproducing existing realizations from nature it seemed that all the possible information (of which much was not fully understood) was transferred to the model. Today, however, much work has been done on phase problems, groupiness, etc. It seems that the phase distributions of limited wave elevation time series can be characterized as random. Still, we and also our clients are aware that now and then the generation of a time series from a given spectrum supplied with random phases can turn out to give very odd (and unrealistic) distributions of the crest elevations, which might in nature be eliminated by physical processes. So, apparantly even this method just produces one simple (random) realization of the stochastic process without any full guarantee for representativeness.

Anyway, for 2-D wave generation we apply both principles, i.e. the stochastic (random phases) and the deterministic one, whereas for 3-D wave field generation we mainly apply the linear deterministic theory (Refs. a. and b. below) also briefly described in the Report. We believe that the 3-D research is now roughly at a stage similar to that of 2-D wave generation in 1970. There is still very much to learn about the character of the 3-D wave field, the 3-D group pattern, phase relations, etc. Again, to us it seems safe to represent the "unknowns" also in the models by deterministic methods, since it is not yet shown that directional spectra (of parameterized kind?) supplied with random phases will fully and satisfactorily describe the directional group character of ocean waves.

These rather brief remarks are to say that I do not quite agree on the recommendation of only the stochastic approach and a description of the deterministic one as being debatable on the basis of what is presented in the Report.

3.2.1 Set-Down or Group-Induced Long Waves - To this section with the description of the need for second-order control signals I would like to add a couple of references showing the transfer functions involved and a verification in a wave flume of the effects of compensation; see Refs. c. and d. below. Since committee work often becomes standard of reference, and as that also applies to terminology I would like to discuss the use of the word "set-down" for the long waves. Due to variations in the radiation stress in a grouped wave train a set-down appears beneath groups of high waves, but when small waves appear between the groups a "set-up" is created. So, as I see it the phenomenon could be called set-up as well as set-down. However, since the oscillations really behave as a group-bound long wave I hope you will consider the introduction of a more physical (or logical) word, e.g. to change the set-down to either group-bound long wave or group-induced long wave. In IAHR's list of wave parameters we have introduced the group-bound long wave.

References

a. Sand, S.E. (1984): "Deterministic Decomposition of Pitch-and-Roll Buoy Measurements". Journ Coastal Engineering, Elsevier, Vol. 8" No. 2.

b. Sand, S.E.,Brink-Kjaer, O. and Nielsen, J.B. (1981): "Directional Numerical Models as Design Basis". Proc. Intern. Conf. Wave and Wind Directionality with Applications to the Design of Structures, Paris, pp. 403-426.

c. Barthel, V., Mandard, E.P.D., Sand, S.E. and Vis, F.C. (1983): Group Bounded Long Waves in Physical Models", Journ. Ocean Engineering, Sept. Issue, pp. 40, Joint Publ. by Danish Hydraulic Institute, Delft Hydr. Lab. and National Research Council, Canada.

d. Sand, S.E. (1982): "Long Wave Problems in Laboratory Models". Journ. of the Waterway, Port, Coastal and Ocean Div., ASCE, Vol. 108, No. WW4, pp. 492-503.

M. TAKAGI - Technical Research Institute, Hitachi Zosen Corp., Osaka, Japan
S. NAKAMURA and K. SAITO - Department of Naval Architecture, Osaka University, Osaka, Japan.

ON THE LOW-FREQUENCY DAMPING FORCES ACTING ON A MOORED BODY IN WAVES

1. Introduction

The low-frequency damping forces on a moored body in waves increase when it is compared with the ones in still water [1,4,7,8,9]. Wichers et al. [7,8] proposed a kind of added damping force due to the drifting of the body among the waves, which was referred to as "wave damping". On the contrary Kato and Kinoshita [4] showed an increase of the decay of the low-frequency motion coupled with the wave induced motions due to the nonlinear viscous damping forces.

In this paper. the authors investigate the above two damping mechanisms experimentally and theoretically. For this purpose, two kinds of model experiments with a slender body were conducted. The first series of experiments was concerned with the surge motions of the body and the second one was with the sway motions as shown in Figure 1 and Figure 2 respectively.

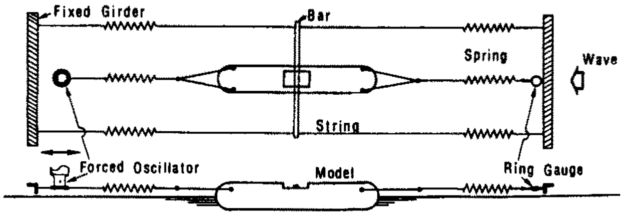


Fig 1 Test set-up for the surge mode experiments

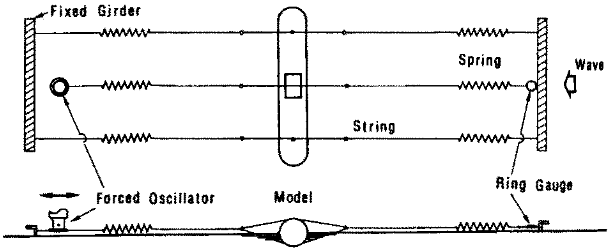


Fig 2 Test set-up for the sway mode experiments

2. Wave Damping

2.1 Concept of the Wave Damping

As is shown in Figure 3, the wave drifting force acting on a body is related with the added wave resistance. We assume that the wave drifting force F_D is approximated by a linear relation with the low-frequency motion velocity $\dot{x}$ (see Figure 4),

$$F_D = b_W\dot{x} + F_{D0} \tag{1}$$

Then the equation of surge motion is given as

$$M\ddot{x} + b_W\dot{x} = F_0 - F_{D0} \tag{2}$$

where M = mass of body
F_0 = general hydrodynamic forces
F_{D0} = constant wave drifting force
b_W = wave damping coefficient

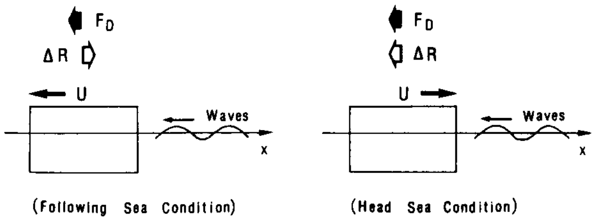


Fig 3 Relationship between the wave drifting forces and the added wave resistances

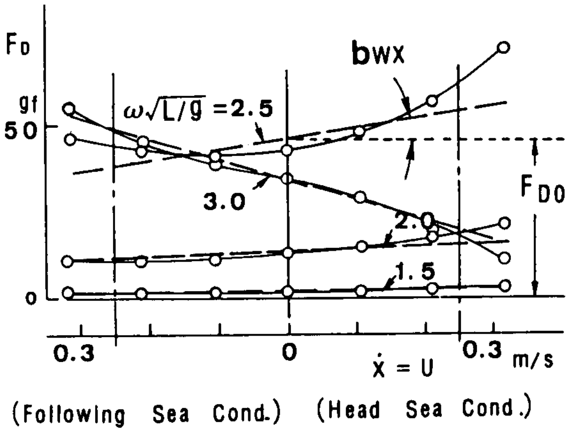


Fig 4 Linear approximation of the wave drifting forces at low advance speed

Therefore, it is found that a kind of added damping force due to the drifting of the body in waves is appeared in the equation of motion and the "wave damping" is obtained as the derivative of the added wave resistance to the low-frequency motion velocity.

2.2 Added Wave Resistance

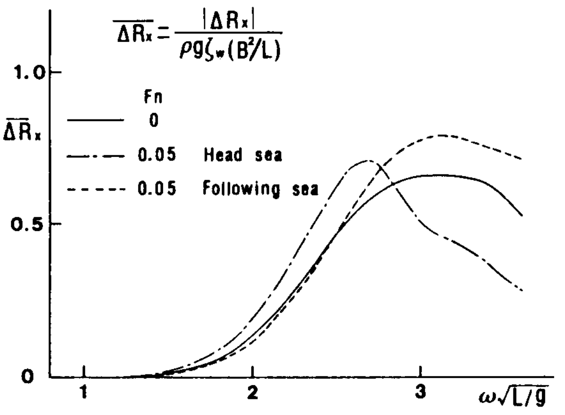


Fig 5 Calculated added wave resistances for the surge mode

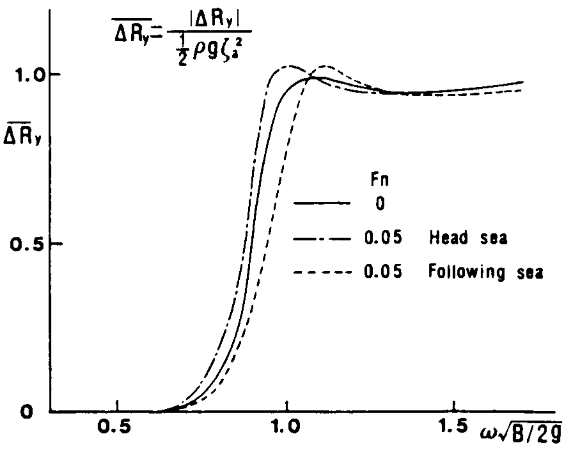


Fig 6 Calculated added wave resistances for the sway mode

For the surge motion, the added wave resistance can be estimated by using the practical formulae given by Gerritsma [2] and Maruo [5]. Numerical results for the model shown in Figure 1 are given in Figure 5, where L, B are the length and breadth of the body and ζ_W is the wave height.

For the sway motion, the added wave resistance can be estimated by solving the problem of the 2-D body advancing in waves. For this purpose the formula given by Higo et al. [3] is used. Numerical results for the model shown in Figure 2 are given in Figure 6.

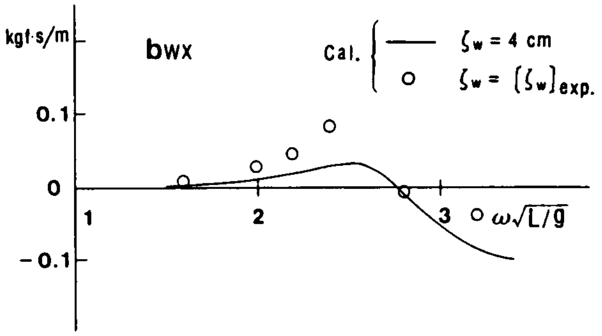


Fig 7 Calculated "wave damping" coefficients for the surge mode

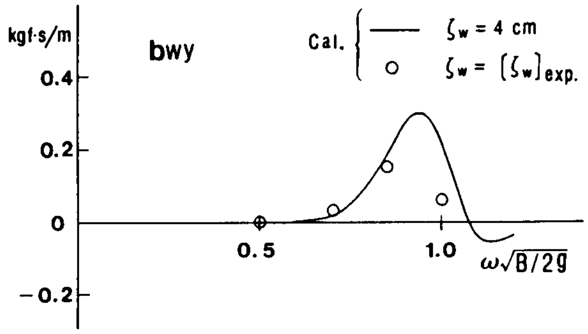


Fig 8 Calculated "wave damping" coefficients for the sway mode

2.3 Wave Damping

From the discussions in 2.1, the "wave damping" can be predicted as the derivatives of the calculated added wave resistance to the low-frequency motion velocity. In the calculation the wave height is assumed as 4 cm. Numerical results for the surge and sway motions of the slender body are shown by the solid lines in Figure 7 and Figure 8 respectively. The circle marks in the figure show the numerical results corrected for the respective measured wave heights.

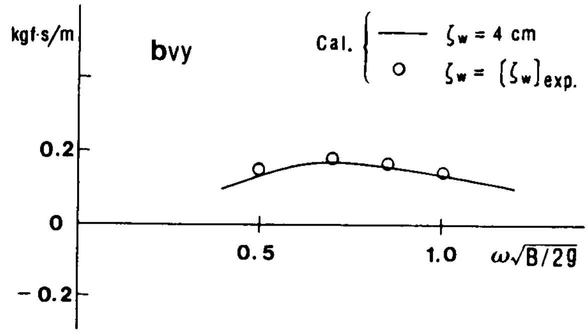


Fig 9 Calculated equivalent linear sway damping coefficients corresponding to the decay increase in waves

3. Increase of Decay in Waves

For the surge motion of the slender body, it is found that the contribution of the quadratic viscous damping is negligibly small and the nonlinear viscous damping force can be neglected. On the contrary for the sway motion, the nonlinear viscous damping force is effective and therefore the decay increase of the low-frequency motion in waves has to be taken into account. The decay increase is estimated in the form of linear damping force coefficient from the numerical time histories of the nonlinear equation of motion. Figure 9 shows the calculation results of the equivalent linear damping coefficient corresponding to the decay increase in waves. The circle marks in the figure show the results corrected for the wave heights.

4. Comparisons between Calculations and Experiments

Figure 10 gives the results for the surge damping force coefficients as a function of a non-dimensional wave frequency. The marks of triangle and

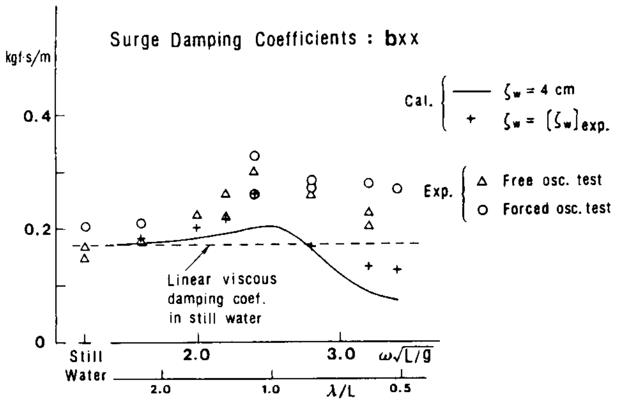


Fig 10 Comparisons between measured and calculated low-frequency damping coefficients for the surge mode

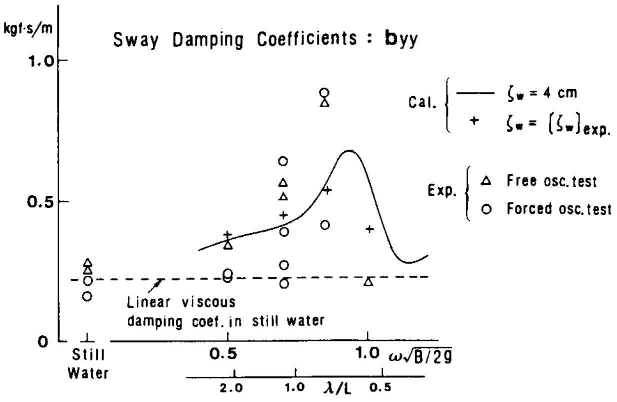


Fig 11 Comparisons between measured and calculated low-frequency damping coefficients for the sway mode

circle in the figure show the measured values obtained from the free and forced oscillation tests in waves. The solid line in the figure is obtained by adding the calculated wave damping (ζ_W = 4 cm) to the measured linear viscous damping in still water and the cross marks show the calculated values corresponding to the respective measured wave heights. It is shown from the figure that there is fairly good agreement between the measured and calculated values except for the values in the higher frequency range.

Same representation for the sway damping force coefficients is shown in Figure 11. In this case, some measured values of the forced oscillation tests are scattered depending on the test conditions, while the free oscillation tests give the steady values. The comparisons between the calculated values and the measured ones of the free oscillation tests show good agreement.

5. Conclusions

1. The increase of the low-frequency damping forces in waves can be explained by the "wave damping" and the nonlinear viscous damping. The "wave damping" is obtained as the derivatives of the calculated added wave resistance to the low-frequency motion velocity. The decay increase due to the nonlinear viscous damping forces is estimated from the numerical time histories of the nonlinear equation of motion.

2. The comparisons between calculations and experiments show that the estimation method presented herein for the "wave damping" is acceptable except for the high frequency wave ranges and that in the sway motion both the "wave damping" and the decay increase due to the nonlinear viscous damping force play an important role while the latter is less effective in the surge motion.

References

1. Ando, S. and Kato, S. "On the Hydrodynamic Forces at the Low-Frequency Motion of Moored Floating Structures", Proceeding of the 7th Ocean Engi-

neering Symposium, Soc.of Nav. Archit. of Japan, 1984 (in Japanese).

2. Gerritsma, J. and Beukelman, W. "Analysis of the Resistance Increase in Waves of a Fast Cargo Ship", I.S.P., Vol. 19, No. 217, 1972.
3. Higo, Y., Nakamura, S. and Takagi, M. "A Study on the Resistance Increase of a Towed Pontoon Among the Waves", J. Kansai Soc. N. A., Japan, No. 174, 1979 (in Japanese).
4. Kato, S. and Kinoshita, T. "On the Effect of Exciting Short Period Disturbance on Free and Forced Oscillation for the System with Nonlinear Damping", 36th Performance Subcommittee of Ocean Engineering Committee, the Soc. of Nav. Archit. of Japan, 1983 (in Japanese).
5. Maruo, H. and Ishii, T. "Calculation of Added Resistance in Head Sea Waves by Means of a Simplified Formula", J. Soc. Nav. Archit. Japan, Vol. 140, 1976.
6. Takagi, M., Saito, K. and Nakamura, S. "Comparisons of Simulation Methods for Motions of a Moored Body in Waves", Proceeding of the ASME 3rd Offshore Mechanics & Arctic Engineering, 1984.
7. Wichers, J. E. W. and Slujis, M. F. "The Influence of Waves on the Low-Frequency Hydrodynamic Coefficients of Moored Vessels, O.T.C. paper No. 3625, 1982.
8. Wichers, J. E. W. "On the Low-Frequency Surge Motions of Vessels Moored in High Seas", O.T.C. paper No. 4437,1982.
9. Wichers, J. E. W. and Huijsmans, R.M.H. "On the Low-Frequency Hydrodynamic Damping Forces Acting on Offshore Moored Vessels", O.T.C. paper No.4813, 1984.

J. E. W. WICHERS - Maritime Research Institute Netherlands, Wageningen.

ON THE LOW-FREQUENCY DAMPING FORCES ACTING ON A MOORED BODY IN WAVES

This contribution gives some results of recent studies on the low frequency wave damping forces.

Since the low frequency response of a moored vessel in an irregular sea is concentrated around the resonance frequency of the system a good knowledge of the damping mechanisms is essential to determine the magnitude of the motion amplitudes.

From the results of computations based on potential theory and of model tests for a moored tanker in head waves it is shown [1] that at resonance three damping terms can be distinguished:

1. The linear wave radiation part.
2. The viscous damping.
3. The damping caused by the presence of the waves (designated wave damping).

The damping force due to the linear wave radiation is negligibly small and the important parts will be contributed by the viscous and the wave damping. The viscous force is proportional to the surge velocity, while the wave damping force is wave frequency dependent, proportional to the square of the wave

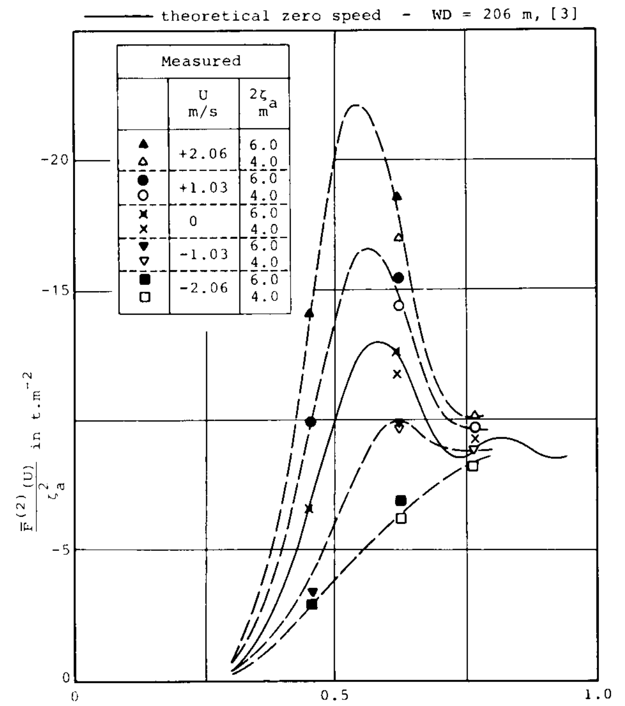


Fig 1 Wave drift force quadratic transfer function as functions at low vessel speed, in regular head waves. (Wave frequency ω is with regard to the earth)

height and to the surge velocity.

The importance of the wave damping force on the low frequency surge motion of a tanker moored in high seas is clearly demonstrated in [2].

Since the wave damping coefficient is dependent on the wave frequency and proportional to the square of the wave height similarity can be found with the wave drift forces. Because the wave damping force is linearly proportional to the vessel velocity attention is paid to the velocity dependent wave drift force or added resistance in waves at low speed, [3].

Towing tests have been carried out in regular waves with a tanker at low speeds to measure the velocity dependent mean wave drift forces, see Figure 1. The results show a significant influence of the low vessel speeds on the magnitude of the wave drift force quadratic transfer function.

Considering the low frequency oscillating surge motion in waves alternating low vessel speeds occur. According to the extensive treatment in [3], the equation of the low frequency surge motion in a regular wave can be written as follows:

$$(m + a)\ddot{x} = - b\dot{x} - cx + F + \dot{x}\,\frac{\partial F}{\partial \dot{x}}$$

where m = mass tanker
a = added mass at low frequency
b = viscous damping coefficient in still water at low frequency
c = spring coefficient
F = mean wave drift force
and $\frac{\partial F}{\partial \dot{x}}$ = $-b_W$ = wave damping coefficient

From Figure 1 the derivative of the mean wave drift force to the low frequency surge motion has been determined. The results are shown in Figure 2, from which the mean wave damping quadratic transfer function is derived and compared with the data derived from the extinction tests in waves, see Figure 3.

It may be concluded that the wave damping coefficient can be derived from the mean wave drift forces at low vessel speeds. In order to solve the problem the 3-dimensional diffraction

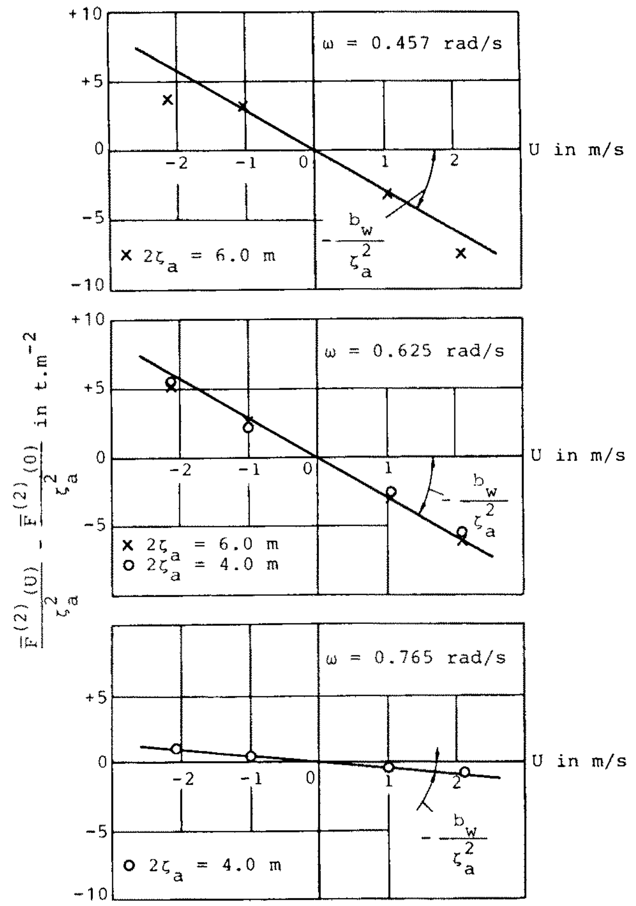


Fig 2 The derivative of the mean wave drift force to the low frequency surge motion as derived from towing tests for low vessel speeds

potential theory, which takes into account low speeds, seems to be necessary to apply.

The direct pressure integration method as given in [4] should be extended for the low speed case.

Due to the significant effect of low speeds on the wave drift forces the same should hold true for the wave drift forces for vessels moored in waves and in current.

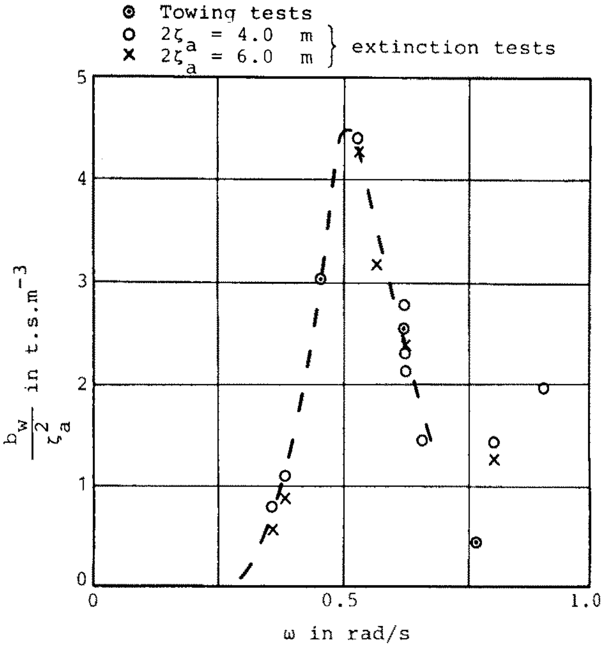


Fig 3 The mean wave damping quadratic transfer function derived from extinction and towing tests

References

[1] Wichers, J. E. W. and Sluijs, M. F. van "The Influence of Waves on the Low Frequency Hydrodynamic Coefficients of Moored Vessels", Proc. 1979 Offshore Technolgy Conference, Vol. IV (OTC paper No. 3625), 1979.

[2] Wichers, J. E. W. "On the Low Frequency Surge Motions of Vessels Moored in High Seas", OTC paper No. 4437, 1982.

[3] Wichers, J. E. W. and Huijsmans, R. H. M. "On the Low Frequency Hydrodynamic Damping Forces Acting on Offshore Moored Vessels", OTC paper No. 4813, 1984.

[4] Pinkster, J. A. "Low Frequency Second Order Wave Exciting Forces on Floating Structures", N.S.M.B. publication No. 650, 1980.

G. F. CLAUSS - Institut für Schiffs- und Meerestechnik, Technische Universität Berlin, Berlin, Federal Republic of Germany.

ON DYNAMICS OF SEMISUBMERSIBLES AFTER ACCIDENTAL DAMAGE

Damage stability requirements of semisubmersibles are related to the behaviour of the structure in still water. As the position of the lowest opening above the water surface is of significant importance additional seakeeping tests of the semisubmersible in various heavily listed positions are recommended. Due to significant motions in high waves seawater will intrude the first opening at a much earlier stage as compared with the still water case.

The following Figures 1-2 show the variation of heave and pitch transfer functions of a 35000 t semisubmersible (Figure 3) in different stages of damage (Figure 4). Note that the motions increase significantly in the 10-15 s period range /1/.

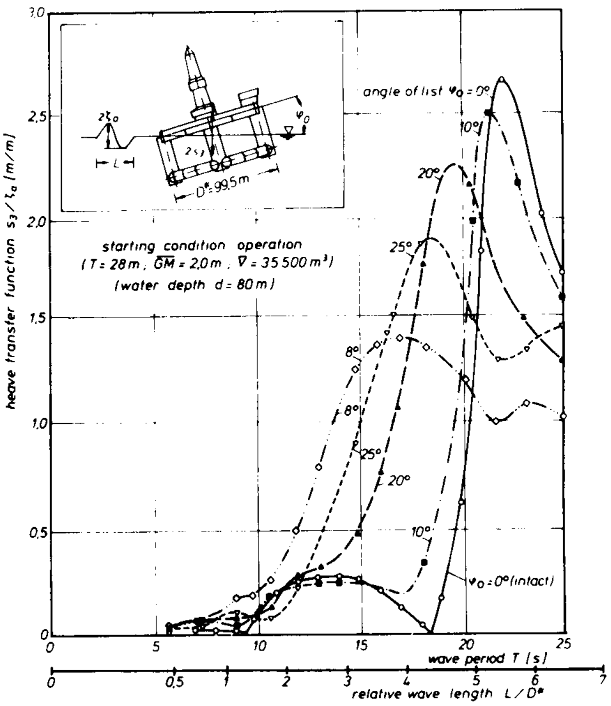


Fig 1 Heave motion behaviour of damaged semisubmersible

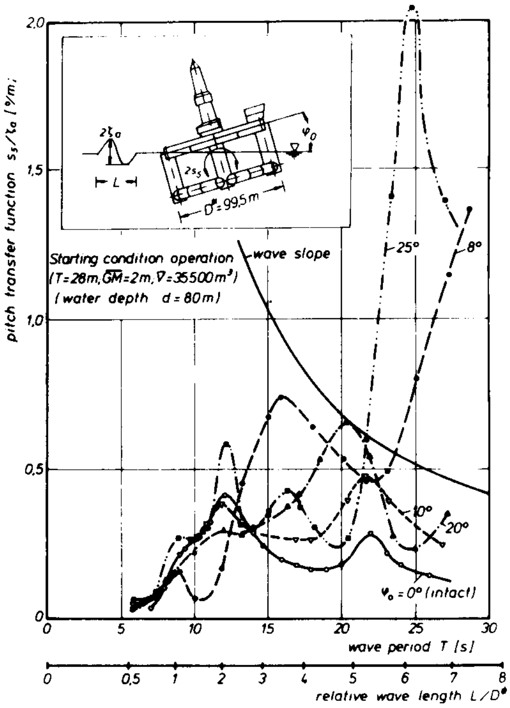


Fig 2 Pitch motion behaviour of damaged semisubmersible

Reference

/1/ Clauss, G. F. "Stability and Dynamics of Semisubmersibles after Accidental Damage, OTC 4729, 1984.

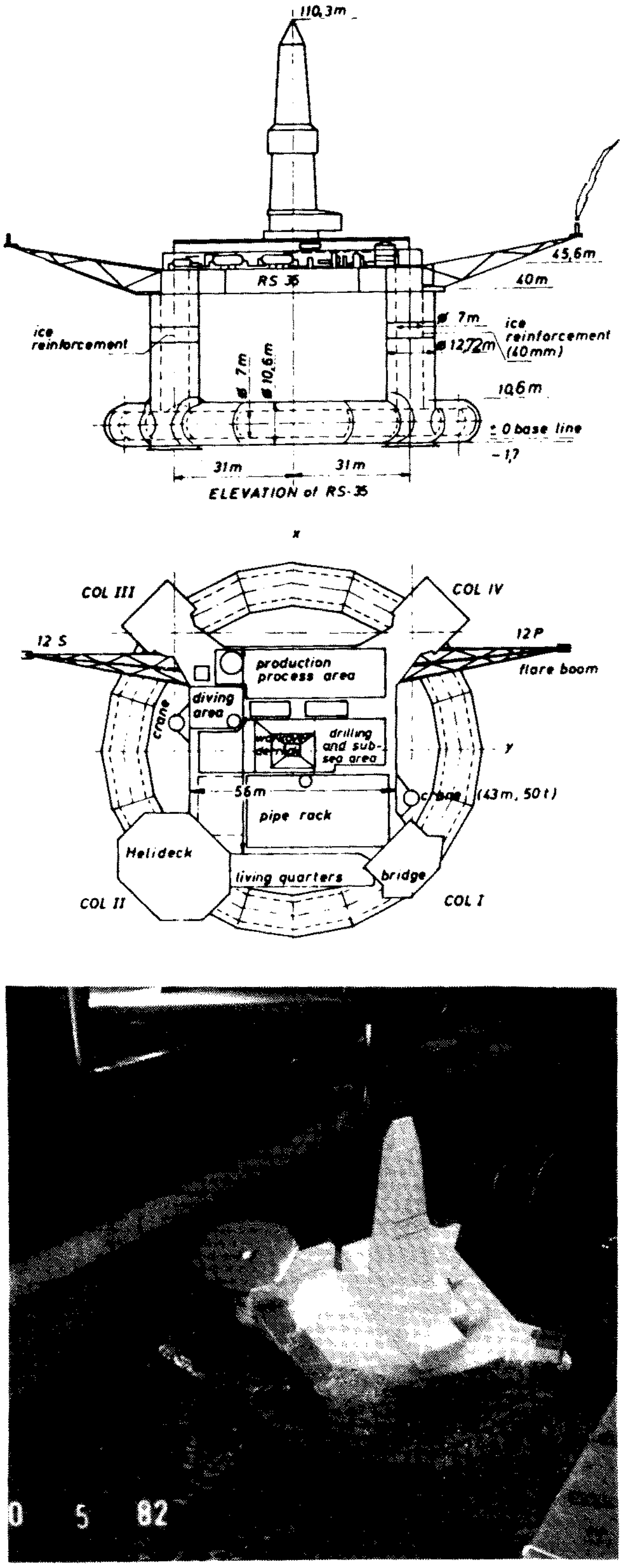


Fig 3 Semisubmersible RS 35 - Main dimensions and damage stability test in waves

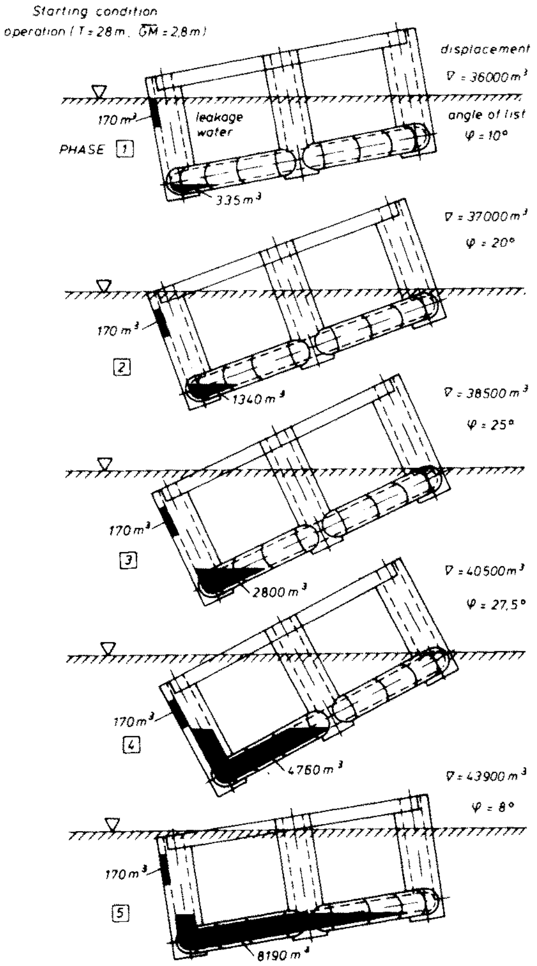


Fig 4 Damage stability - intermediate phases

Y. D. MIROSHNIC and V. N. TRESHCHEVSKY - Krylov Shipbuilding Research Institute, Leningrad, USSR.

ON AERODYNAMIC FORCES UPON THE HULLS OF MOBILE DRILLING UNITS

Determination of wind rolling moment is one of the main problems related to provision of mobile drilling units stability. The difficulty of precise determination of the rolling moment value as a function of drilling unit inclination is due to the fact that the aerodynamics of such structures is still not clearly understood.

Standards of various classification societies recommend to determine the wind rolling moment using the formula

$$M_z = q_{10} \sum_{i=1}^{n} C_{xi} K_{zi} A_{vi} Z_i \qquad (1)$$

where q_{10} = dynamic head at 10 m above the water level N/m^2

C_{xi} = aerodynamic resistance coefficient of the i-th element of the structure

K_{zi} = coefficient of dynamic head growth along the height for the i-th element of the structure

A_{vi} = above-water projected area of the i-th element of the structure with the account for shielding effect, m^2

Z_i = height of the center of gravity for the above-water projected area of the i-th element of the structure above the waterline, m.

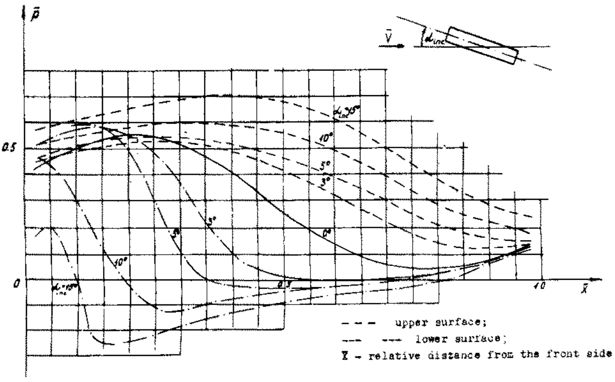


Fig 1 Pressure distribution in the longitudinal plane at the lower and upper surfaces of the hull model (L/B = 1.5) at various angles of inclination

The above formula makes it possible to determine quite easily only the rolling moment due to horizontal forces in the absence of inclination angles. Previously performed investigations indicated the necessity to take into account vertical forces generating an additional moment of comparable magnitude, commensurable with the part of the moment due to the horizontal component of the wind forces.

It is obvious, that the main contribution to the change of the wind rolling moment due to heeling comes from those structure members which have the large areas of the horizontal surfaces.

Figure 1 gives pressure distribution along the upper and the lower surfaces of the rectangular hull at various angles of inclination, indicating that refraction predominates at these surfaces and depends upon the angle of inclination.

As the areas of the hull horizontal surfaces are large, the loads acting upon them cause generation of an additional longitudinal moment depending also upon the location of the upper hull above the water surface.

The upper hull is one of the main elements of the mobile unit and plays the determining part in forming the flow around all the elements of the structure located on or near it. Up till now, however, little attention has been paid to the aerodynamic characteristics of the hulls of various forms. The architectural forms of modern mobile drilling units are versatile; therefore, to extend the element-to-element method for calculation of the wind moment (formula (1)) onto these structures, it is necessary to know resistance coefficients of the elements of new forms, the upper hull form including.

An experimental investigation has been carried out of a series of schematic hull models in the form of thick plates of various planforms: that is a regular triangle, a square, a regular pentagon, a regular hexagon, a circle and a rectangle with the side ratio L/B = 1.5.

Model tests have been carried out in a wind tunnel near a rigid ground plate simulating undisturbed water surface at the flow velocity V = 40 m/s. The angle of model inclination α inc varied from 0 to 24° at the directions of flow along the angle bisectrix and perpendicular to the windward side of the non-inclined model. The distances between the plate and the models corresponded to these in the unit transit position and when the unit is located above the drilling well.

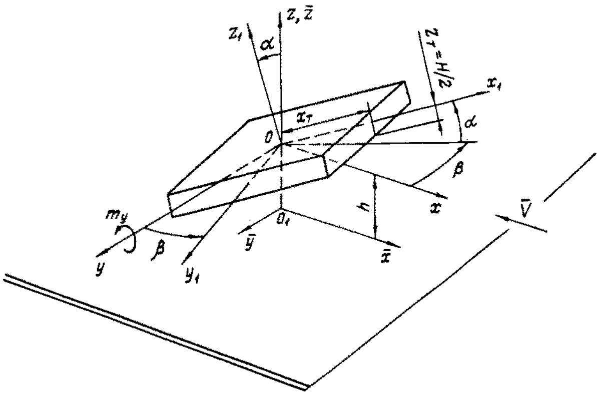


Fig 2 System of coordinates and main symbols

The resistance force X, the lift force Z and the longitudinal moment My were determined in the O X Y Z coordinate system (Figure 2), the origin of which coincides with the model center of gravity. The forces and moments are related to

$$\frac{\rho_o V^2}{2} \cdot S_{hull} \text{ and } \frac{\rho_o V^2}{2} \cdot S_{hull} L_{hull}$$

respectively,

where S_{hull} = model area in plan view

Table 1 gives resistance coefficients for hulls of various planforms obtained for a self-elevating drilling unit (at $\bar{h}_1 = 0$) and a semisubmersible drilling unit at $\bar{h}_1 = 0.33$, transit position

TABLE 1 - RESISTANCE FORCE COEFFICIENTS

NO.	HULL IN PLAN VIEW	WIND DIRECTION			
		ALONG THE ANGLE BISECTRIX		PERPENDICULAR TO THE SIDE	
		$\bar{h}_1=0$	$\bar{h}_1=0.33$	$\bar{h}_1=0$	$\bar{h}_1=0.33$
1	REGULAR TRIANGLE	0,54	0,65	0,91	1,01
2	SQUARE	0,66	0,78	0,82	0,93
3	REGULAR PENTAGON	0,67	0,76	0,6	0,7
4	REGULAR HEXAGON	0,64	0,71	0,5	0,63
5	CIRCLE	0,57	0,61	0,57	0,61
6	RECTANGLE WITH SIDE RATIO L/B = 1,5	-	-	$\frac{0{,}79}{0{,}73}$	$\frac{0{,}9}{0{,}91}$

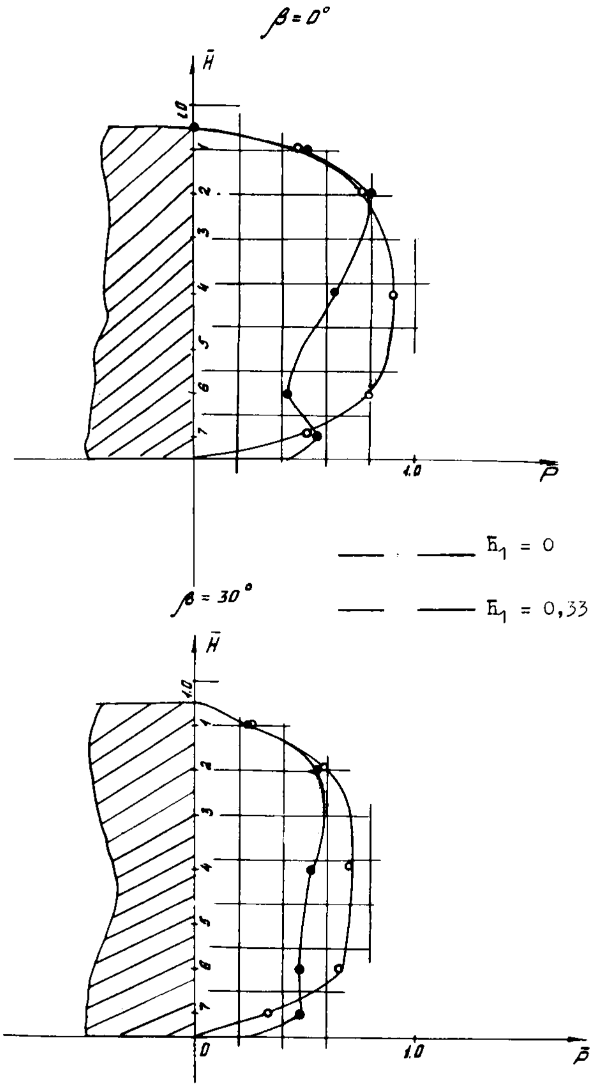


Fig 3 Pressure distribution along the front side height of a rectangular hull (L/B = 1.5) in the longitudinal centerline plane at various clearance values $\bar{h}_1$

in the absence of inclination, where $\bar{h}_1$ = relative clearance (relative height above ground surface).

The results obtained show that practically for all the hulls tested the aerodynamic resistance significantly decreases near the ground surface. The character of pressure distribution at the hull sides as compared to the flow around the hull at large $\bar{h}$ appeared to be the cause of this, and the drain rectangular model hull tests (model 6 Table 1) confirmed it.

The results of pressure measurements are presented in the form of non-dimensional coefficients

$$\bar{P}_{stat} = \frac{P_{stat} - P_o}{q}$$

The analysis of the data obtained has shown that near the ground plate the pressure distribution $\bar{P}$ at the windward sides of the hull greatly differs from that at large distance from the surface. The difference is in the decreasing the pressure coefficient values $\bar{P}$ in the points located nearer to the screen. Figure 3 gives the pressure distribution along the height of the front side of the hull in the longitudinal plane at the distances between the hull bottom and the screen $\bar{h}_1 = 0$ and $\bar{h}_1 = 0.33$. To find the causes of pressure decrease at the front side of the hull for $\bar{h}_1 = 0$, flow visualization was carried out at the wind and hydrodynamic tunnels when the hull was located near a ground plate, and this visualization has shown that a backwater vortex of large intensity forms before the front side of the hull (Figure 4) decreasing the pressure at the lower part of the hull.

Forming of a vortex is connected with the boundary layer separation at the ground plate due to the presence of positive pressure gradient in the direction of flow current and due to the friction on the plate.

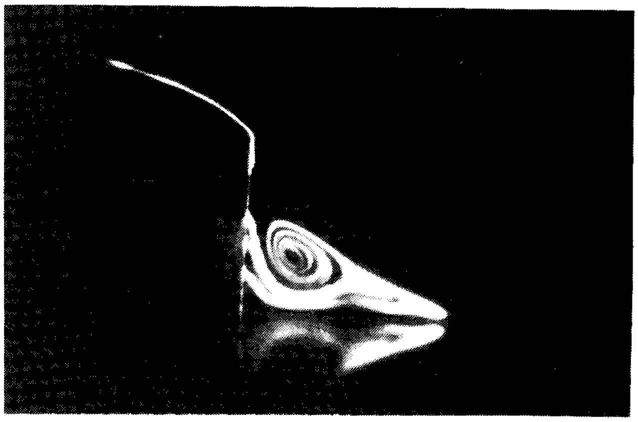


Fig 4 Backwater vortex before the front of the rectangular hull located at the ground plate ($\beta = 0^{\circ}$)

As an example Figure 5 gives some results of the pentagon plan form hull model tests obtained for various heights $\bar{h}$ and angles of inclination α inc. From available diagrams it is obvious that when the height $\bar{h}$ decreases the lift force coefficient value C_z increases, which is characteristic for all the models tested. The functions $C_z = f(\alpha\ \text{inc})$ and $m_y = f(\alpha\ \text{inc})$, however, differ for models with various planforms and various aspect ratio.

At small angles of inclination the arm of the vertical force has sufficiently large values, equal to $(0.15 \div 0.3)\ L_{hull}$, and depends upon the hull orientation. If the angle of inclination increases, the point of application of the vertical force shifts to the hull center of gravity and hull orientation is less critical.

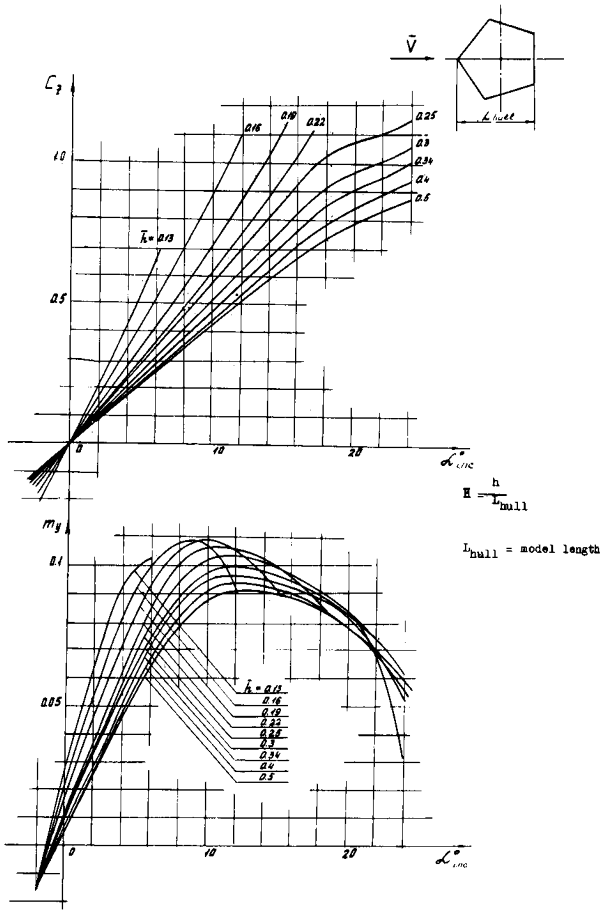


Fig 5 The aerodynamic coefficients of the vertical force Cz and the longitudinal moment m_y versus the angle of inclination α_{inc} and the height of the pentagon hull model above the ground surface (the direction of the wind is along the bisectrix of the angle)

On the basis of the data obtained, one can estimate the effect of loads acting on the upper hull at inclination upon the stability of the structure. In this case the ensemble of characteristics

$C_z = f(\alpha\ \text{inc})$ and $m_y = f(\alpha\ \text{inc})$

makes it possible to determine the most dangerous wind directions in terms of increasing the rolling moment due to vertical forces.

The results of investigations were used in development of a method for estimation of resistance to wind action of the "Shelf"-type semisubmersible drilling unit.

T. NAKAJIMA - Sumitomo Heavy Industries Ltd., Hiratsuka Research Laboratory, Japan.

ON THE PROBLEM OF MOORING SYSTEMS

The Committee is to be congratulated to a fine piece of work in the review of the problems and state of art in this field. I will briefly comment on the effect of mooring systems.

Today , petroleum exploration and production move into progressively deep water. A key problem for the deepwater structure is to design a reliable mooring system. Generally, it is quite reasonable that the effect of mooring line on the moored body in deep water becomes much larger than that of the shallow water case since the magnitude of total weight of the mooring line and the displacement of moored body become comparable. One of the results of Ref. [5.40] shows that the dynamic tension increases drastically due to the coupled motions between the moored body and the mooring lines in the case that the displacement of the body is comparable to the total weight of the mooring lines. This indicates that the dynamic analysis of the mooring line becomes important as well as the quasi-static analysis for the design of the deepwater mooring system.

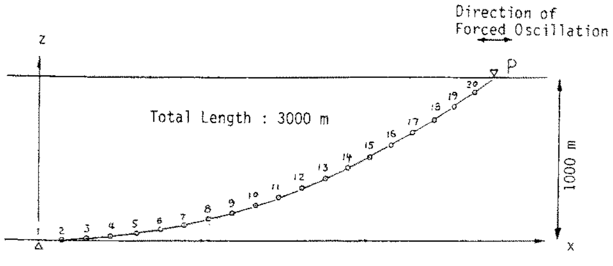


Fig 1 Cable configuration

Diameter (mm)	83
Area of Section (cm^2)	40.13
Weight per Length (kg/m)	
(in Air)	29.0
(in Water)	25.2
Breaking Tension (ton)	446.
Young Modulas (kg/cm^2)	800,000.

Table 1 Principal particulars of the cable

Another problem is the effect of the elastic stretch of the mooring line on the tensions in deep water. Generally, as the water depth increases, the effect of the elastic stretch on the tensions cannot be disregarded because of enlargement of line tension. Figure 1 shows the

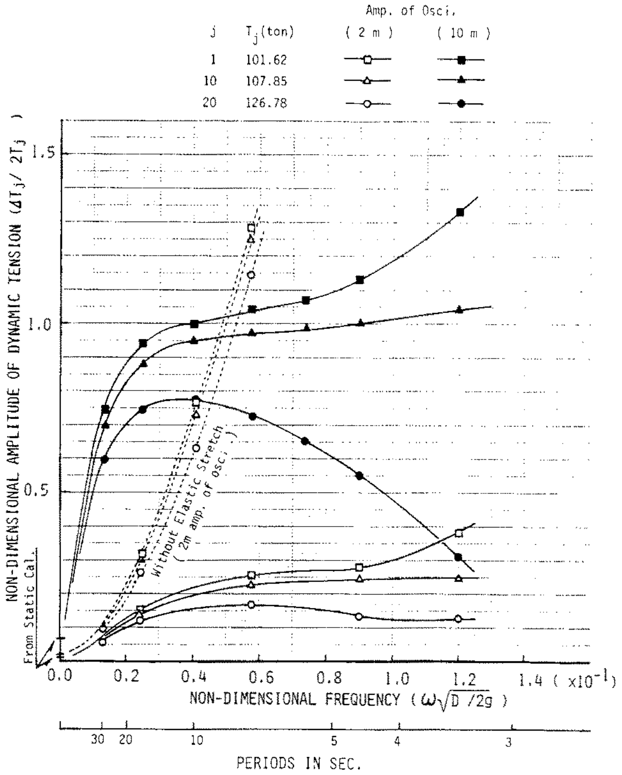


Fig 2 Results of dynamic tensions of forced oscillation in horizontal direction calculated by lumped mass method

typical example of deepwater mooring line (water depth = 1 000 m) while the principal dimensions of the cable are listed in Table 1. Figure 2 shows the numerical results of dynamic tensions of the same cable due to the forced oscillation of fairleader (upper end) in the horizontal direction. This is one of the results of three years study on deepwater mooring systems (SR 187) conducted by the Shipbuilding Research Association of Japan. From this figure, it is clarified that the effect of the elastic stretch of the mooring line on the dynamic tensions cannot be neglected for the analysis of deepwater mooring system. It is also found that the dynamic tension at the anchor becomes larger than that of upper portion as the frequency of forced oscillation increases. This interesting phenomena was explained by the other numerical method (FEM method) as the results of the effect of the elastic stretch of the mooring line, later.

E. HUSE - NHL, Trondheim, Norway.

ON MODEL TESTING AND NUMERICAL SIMULATION

The Committee has produced a very good report containing material which is valuable and relevant to the Ocean Engineering's activity. However, I would suggest that the next Committe address more directly the problems of model testing and scale effects for the various types of structures. After all, model testing is still a main field of interest of the ITTC.

Furthermore, I would like to see a discussion on the philosophy of model testing of offshore structures in direct combination with numerical simulation. For instance, what is the value of testing complete systems including risers, mooring lines and everything, compared to testing only parts of the system and relying on numerical simulation for the rest?

I hope the next Committee will address these questions.

H. MAEDA - Institute of Industrial Science, University of Tokyo, Tokyo, Japan

ON THE STATISTICAL RESPONSE OF AN OFFSHORE STRUCTURE TO ENVIRONMENTAL LOADS

The Committee has pointed out the importance of the fluctuations in wind speed, and that the statistical response of an offshore structure is a complex function of the joint probability distributions of wind, waves and current. However, most model testing procedures separate these distinct inputs and assume that superposition of the responses to the individual inputs will give a realistic answer. How do we know that this is right?

O. BJÖRHEDEN - KaMeVa Marine Laboratory, Kristinehamn, Sweden.

ON THE OCCURRENCE OF LOW-FREQUENCY OSCILLATIONS

I have no comments but merely one question to the Committee. In his presentation Dr. van Oortmerssen emphasized the need for more data on wave grouping with reference to a possible risk of second order wave drift forces inducing resonance oscillations of moored offshore structures. I do not question this need in any way, on the contrary I believe it is very important to collect more information about waves. I would like to know, however, if there is any evidence known to the Committee of such low frequency oscillations occurring in reality, i.e. is there any clear proof in terms of full scale recordings or observations of their existence? Finally, I wish to thank the Committee for a very nice report.

A. M. FERGUSON - University of Glasgow, Glasgow, United Kingdom.

ON SCALING AND INTERFERENCE PROBLEMS IN MODEL TESTING

I would ask that the next Ocean Engineering Committee give advice on the scaling problems which arise when model testing a semisubmersible where some of the model elements are experiencing sub-critical and others are at super-critical Reynolds numbers. Secondly, there is a great lack of information on interference effects on lift and drag coefficients between surface-piercing cylinders either parallel to each other or at some angle. It would be useful if all the available data on this aspect of model testing were presented in the Proceedings of the ITTC.

II. REPLY BY THE OCEAN ENGINEERING COMMITTEE

Firstly the Committee must express its thanks to all the discussers who have raised a considerable number of interesting points and in some cases provided the Committee with invaluable additional information.

The question raised by the penetrative discussion written by *Dr. Standing* and presented by *Dr. Hogben* has puzzled the Committee, and we agree that we have a troublesome problem that must be cleared up by all possible means. We will attempt to make the calculation methods a little clearer, and also comment on the effect of Keulegan Carpenter (KC) number.

Firstly the grouping of the calculation methods in Figure 22 of the Proceedings (which corresponds to Figure 12 of the detailed paper) should be explained. The results from Group 2 as a whole are shown in Figures 19-21 (which correspond to Figures B-5-1 - B-5-3 of the detailed paper, ref 5.61 of the Committee Report).

Out of these we chose 6 programs which happened to give calculation results nearest to experiment. These correspond to the left part of the thickly shaded area in Figure 22 (shown as a sub-group of Group 2 in the detailed paper). Hereafter we refer to this sub-group, and the remainder of Group 2 as sub-groups A and B respectively.

We considered that the coefficients of the Morison formula in sub-group A were well chosen, simply because they gave calculation results near to experiment. The details of the methods of sub-group A, regarding the natural period of heave, are shown in Table 1. Roughly speaking, as shown in Figures 19-21, the results of sub-group A and the sub-group B, scatter around the experimental result and the value predicted by three-dimensional theory respectively, and the coefficients of the virtual mass are evidently more correct experimentally in sub-group A than in sub-group B. Thus the Committee concluded that "This implies the necessity of taking into account the viscous effect". However, as the discusser points out, since at this stage the experimental and analytical evidence are insufficient, the Committee agrees that we should have written "This could imply the necessity of taking into account the viscous effect". This amendment will be made in the publication in "Ocean Engineering".

Table 1 - Calculation Method of Sub-group A

Symbol	Calculation Method
H	Unknown to the Committee
J	The coefficient of the virtual mass is corrected so that the calculated natural period agrees with the one measured in a free oscillation test.
L1	The coefficient of the virtual mass defined by DnV is used. The interferences between the columns and the lower hulls are considered.
M	The coefficient of virtual mass is calculated numerically.
O	The coefficient of virtual mass defined by DnV is used.
P	The coefficient of the virtual mass is estimated from methodical experiments on various rectangular sections with rounded corners. The interferences between the columns and the lower hulls are considered.

Next the Committee would like to comment a little on the effect of Keulegan Carpenter (KC) number. As Dr. Standing points out, there seems to be a general trend that the experimental virtual mass of a rectangular cylinder with rounded corners is a little less than that predicted by the potential theory at low KC number. Tanaka et al (1980) reported an experimental investigation into the hydrodynamic forces of rectangular cylinders with rounded corners, where the experimental virtual mass was about 10% less than that predicted by the potential theory at a KC number around 1. Therefore, while the effect of KC number may not fully explain the differences between the exact potential theory and the experiment, we must investigate the viscous effects, not only on two-dimensional cylinders, but also on three-dimensional bodies as a possible cause for the differences.

However, we agree with the discusser that the Committee should continue the investigation to clarify the reasons for the differences. This point is included in our Recommendations.

The Committee thanks *Prof. Clauss* for his contribution on the use of "Gaussian Wave Packets". This and other techniques that might be termed "transient wave tests" are very useful for defining the linear responses of a structure because of the speed with which results may be obtained.

The Committee was, however, uncertain whether there were any particular properties of the "Gaussian wave packet" which made the technique more useful than other transient wave methods. The Committee also feel that it is important to emphasize that transient wave techniques of this type should only be used for derivation of transfer functions when one is already sure that the response is linear.

The Committee also thanks *Dr. Tanibayashi* for his comments on the Report and for high-lighting the work on "Design Irregular Waves" by Toki.

It was not the intention of the Committee to suggest that the fitting of probability distributions, and extrapolation to low probability events, was a reliable procedure. On the contrary, we are concerned that such extrapolations can give very misleading extreme value predictions where strongly non-linear effects are present. The Committee noted that it was important to gather sufficient model data and perform careful tests on the data (such as those suggested by Ochi), to determine whether the extreme value predictions are meaningful.

The design irregular wave method clearly produces several wave tests that can be used as a criterion, or standard of comparison, for the extreme response of a ship or offshore structure. However, the Committee is still concerned about the method by which the results of such tests can be extended into predictions of extreme values for the life of the vessel or structure. One has to estimate the probability of meeting such conditions in reality, and set these alongside the rest of the population of possible extreme circumstances before any measure of extreme response probability can be arrived at.

Toki's method appears to assume that the most severe test for the structure will be a combination of an extreme wave height and slope. However, for many types of compliant structure this may not be the case. More severe motions/accelerations/forces may occur in lesser waveheights and slopes occurring at particular frequencies, or in certain groups or packets. The prime function of the model test should be to identify these worst cases, and the Committee is concerned that the design irregular wave method requires that the experiment must first prejudge the nature of the worst case.

The Committee is grateful to *Dr. Sand* for his very helpful comments and suggestions. Dr. Sand's main point concerns deterministic versus stochastic wave generation methods. This is a topic that has already been discussed several times in various sessions of the Conference. We find ourselves in substantial agreement with Dr. Sand's comments and in particular feel that deterministic wave generation is a very valuable technique for helping us understand the mechanisms behind the generation and propagation of multi-directional waves.

Both *Dr. Wicher's* and *Dr. Takagi's* discussion on motion damping are progress reports reflecting further findings beyond the Committee's Report. One of the tasks of the present Committee is to review testing techniques and theoretical methods developed for systems with low-frequency responses. For the prediction of the low frequency response inherent in moored floating structures a good knowledge of the damping mechanism is essential. It has been noted that such systems may exhibit dynamic excursions 10 to 20 times that of the static offset due to mean drift force alone. Dr. Wichers and Dr. Takagi have independently obtained the same finding with regard to damping of low frequency surge in waves. Their work indicates that the added damping in waves, referred to as "wave damping", is the same mechanism as a ship's added resistance in waves. Hence the damping coefficient b_{1xx} (page 565 Figure 25) may be obtained as a partial derivative of the added wave resistance with respect to drift velocity, and may be obtained by experiment or by calculation. Dr. Takagi further noted that for damping of low frequency sway, linear viscous damping plays as important a part as that of the waves. The Committee thanks them for their timely contribution.

However, due to the delicate nature of the wave damping coefficient (being proportional to wave height squared) it is hard to obtain accurate estimates by extinction tests or by forced oscillation tests in waves, and the result is often accompanied by a significant amount of scatter. Computation by 2D or 3D diffraction potential theory for low speeds is still to be developed. As noted in Recommendation 6, we would like to encourage further attention to be directed to this problem.

In *Prof. Clauss'* second contribution he has addressed the very important problem of damage stability of semi-submersibles. While intact semi-submersibles may be considered to be very stable, structural damage, flooding, human errors or failure in operating systems may have a dramatic effect on the stability, as has been shown by recent tragic accidents. Failure of anchor chains or malfunction of dynamic positioning systems can also be very dangerous in this respect. This may be elucidated by an example. Consider a semi-submersible working in bad weather in the dynamic positioning mode, and ballasted on one side to counteract the heeling moment due to wind, waves and thrusters. If this platform were to lose heading control, say due to some system failure, it might turn around so that the ballast moment and the wind and wave moments became additive. Such an event could easily lead to capsizing of the platform.

Because of the importance of damage

stability, and because there is lack of data and understanding of the topic, the Committee thanks Prof. Clauss for presenting his recent results on the behaviour of a semi-submersible in a damaged condition. The results clearly demonstrate the complex behaviour of the platform with increasing flooded volume. The Committee eagerly awaits further results on the topic, and hopes that further investigations will be made, perhaps giving particular attention to the effect of non-linearities in the behaviour of the platform in an inclined position.

Wind loads are extremely important for the behaviour of semi-submersibles and therefore the Committee is also very grateful to *Mr. Miroshnic* and *Dr. Treshchevsky* for presenting valuable data, which also underlines the importance of lift forces. In this connection, the Committee would also like to draw attention to the effect of the free water surface on the wind loads. In a recent study performed by the Texas A & M University on behalf of the MS3 panel of SNAME, the important effect of the relative position of the wave crest and the platform on the wind induced overturning moment was clearly demonstrated. The results of this study are to be published at the 1984 Annual Meeting of SNAME.

The varying nature of the wind speed complicates the problem further, and so the Committee would like to encourage further research work in this particular area to be directed towards the dynamic loads and responses that are so important for the safety of floating platforms.

Dr. Nakajima has given an impressive contribution in his note on the effect of dynamic tension of mooring lines for deep water systems, including the effects of elastic stretch of these mooring lines on such systems. The Committee appreciates his contribution. It reinforces the caution made in the Committee's Report on page 550, i.e. "It becomes important therefore that environment and system simulation in model tests should be as true to real life as possible".

In view of Dr. Nakajima's note, the Committee is of the opinion that, if the dynamic mooring line loads are as described, then it is possible that the stiffness of the system and the low frequency response of the system may also be affected. Therefore, further investigation into this aspect is awaited with interest.

The Committee would like to thank *Dr. Huse* for his comments. In reply, we firstly feel that the subject of model testing was addressed in the Report; but we agree that the subject of scale effects is of paramount importance. The investigation of scale effects demands a pool of full scale data with which to correlate the model tests, and the Committee would once again like to make a plea for more full scale measurement data to be made available to the research community.

The Committee feels that model testing and numerical simulations are complementary activities that must progress together. In the last report of the 16th ITTC Committee the subject of hybrid models - models that contain both physical and numerical components -

was mentioned but perhaps a future Committee should give this subject further attention.

Mr. Björheden raises the question on whether offshore structures and vessels experience low frequency motions in reality. The Committee has no doubt that such motions occur. One can see them in the behaviour of all types of compliant structure or moored vessel. The phenomenon is also apparent in the behaviour of dynamically positioned vessels.

The Committee recognises only too well the complexities of the ocean environment as eloquently described by *Prof. Maeda*. Some model tests are of course conducted in combined winds, waves and currents but there are usually important doubts about the realism of such physical simulations. As Prof. Maeda points out, much model testing is carried out with only one of the environmental inputs present, and superposition assumed for the design process. The possible dangers in this process are recognised by the Committee, but with the present state of the art this is often the best that can be done. This question, along with many others, would be more tractable if there were large bodies of full scale data with which model tests and superposition calculations could be compared. Wind/wave/structure interaction research going on at present in some establishments may also go some way to identifying superposition errors.

Finally the Committee thanks *Dr. Ferguson* for his comments. We agree that forces on small diameter cylinders are an important problem area, but we are not sure about the significance of the terms "sub-critical" and super-critical" Reynolds number in these highly turbulent wave flows. There is evidence to suggest that the scale effects in wave flows are not as strong as would be supposed from 2D steady flow tests.

The Committee has to agree that lift/drag data on cylinders in close proximity, and on inclined cylinders, is also an area requiring much further data and the next Committee will undoubtably encourage and monitor such work and inform the Conference.

Reference

Tanaka, N. et al.: "Experimental Study on Hydrodynamic Viscous Force Acting on Oscillating Bluff Body", Journal of the Kansai Society of Naval Architects Japan, No. 179, 1980 (in Japanese).