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Recent Progress in Theoretical Studies on the Behavior of Ships in a Seaway

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Recent progress in theoretical studies on the behavior of ships in a seaway

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to calculate for example the acceleration and the position of the ship in the surrounding water including to some extent the degree of wetness.

Let us now consider what we may actually expect from theoretical studies on the behavior of a ship in a seaway. Rephrasing slightly Krylov's general statement our present aim is to establish the dependence of ship motions upon its form and weight distribution in the actual seaway or otherwise expressed, to furnish basic data for developing ships with optimum seagoing qualities.

As indicated above we are yet far from this goal. The choice of hull forms from the point of view of seagoing qualities is at present still more a matter of opinion than of actual knowledge.

This is understandable since the matter is extremely difficult - and the endeavors made at present do not correspond in any way to the importance and complex character of the problems at stake.

Nonetheless one can list a large number of purposes for which the theoretical investigations on the motions of ships in a seaway are useful or even indispensable. Without attempting completeness or even a logical order in our enumeration such studies can yield:

1) A general information on the most important and characteristic phaenomena of the behavior of a ship in a seaway. It is surprising how inadequate the knowledge of these phenomena

is even with experienced professional people.

2) Prediction of motions for a given ship in a given (simplified) seaway.

3) Contributions to the problem of safety by establishing limiting values of motions, accelerations, forces etc.

4) Explanation of special effects influencing the behavior; e.g. stability, directional stability, resistance.

5) Establishment of ideas and basic data for reducing motions (stabilization, damping devices).

6) Guidance as to how to plan and to perform model experiments and full scall research. This point seems to be essential in connection with the aims of our Congress. Considerable waste has occured in performing experimental work by lack of theoretical knowledge; therefore in planning similar work in the future more emphasis should be laid on the use of results obtained by analytical methods.

There are essentially two branches of mechanics on which our reasoning is based: hydrodynamics and the theory of oscillations of rigid bodies. We shall neglect elastic properties of the ship, since matters of strength areoutside of the scope of our lecture and these external forces which depend upon the elasticity of the ship structure will be dealt with Dr. Szebehely. It must be pointed out, however, that besides the hydrostatic and hydrodynamic forces which change roughly with the period of encounter of the ship other forces of an impact character do arise. These are important especially with high speed craft and even may set a limit to the permissible velocity of the latter before the power available is exhausted. Pertinent investigations have been performedt for seaplanes which can be adapted to the needs of naval architecture. [3] [38]

Further we shall not enter into the interesting study of the resistance experienced by the ship in seaway although it represents clearly a part of the behavior of the ship. The reason therefore is

1) problems of resistance are scheduled for a later meeting and
2) I am unableble at present to make definite suggestions as to how to proceed with pertinent investigations. There is no question, however, that in the near future theory will be able to deal with the thrilling subject moresuccessfully and extend the pioneer work due Havelock, [24] Brard [25] and others.

We mentioned before that the treatment of our subject rests essentially on two branches of mechanics. In earlier research more emphasis has been laid on the application of the theory of oscillations and the hydrodynamic part has been slightly neglected. This somewhat narrow attitude is now beeing corrected. Clearly, from a rigorous formal point of view there exists only one boundary problem. This aspect has been brought forward recently by several writers. Notwithstanding its extreme difficulty results the formulation as such is useful. results the formulation as such is useful. In the meanwhile concrete results must be reached by appropriate simplifications. A basic one is the introduction of of the ideal fluid concept. The general formulations of the boundary problem mentioned above does make sense only when the water is treated as an ideal liquid. Obviously, there exists problems of high pratical significance, for example the damping by bilge keels, where the viscous effects are decisive. More generally expressed, the investigation of damping phenomena may frequently require the consideration of viscosity. This applies especially to the motion of roll. By the introduction of discontinuous potentials a part of these problems can, however, be treated by the "mechanical model" of the ideal fluid.

Broadly speaking, it is rather striking how useful the ideal fluid concept proves to be when dealing with our subject. This means that excepting special cases mentioned above Froude's Model law can be applied in general with better confidence than in the field of resistance research.

Another basic simplification is the substitution of regular wave trains for the actual seaway. Although this assumption severely restricts the applicability of results to practice it represents an indispensable intermediate step. Clearly, serious attempts must be made and are beeing made to develop a more realistic scheme for the actual seaway, but there we are still at the beginning of a new branch of our subject. Proposals have been made earlier to correlate the regular seaway with the actual one by assuming some average wave length and height.

Simplifying further we come to the case of a ship oscillating in calm water. The study of free oscillations constitutes a classic part of ship theory which in itself is important from a theoretical and practical point of view. In addition, however, it becomes popular at present to deal with forced oscillations in calm water. The reason herefore will be explained later.

Scientific exploration lags far behind actual needs. In fact, most solutions so far obtained are crude approximations based on extremely simplified mechanical models. However, the situation is much improving recently by the development of appropriate general methods [43].

Different trends in the character of present research can be stated. Experimentalists are inclined to search for immediate answers to practical problems. Because of lack of basic knowledge this approach may fail. For example investigations on the influence of variations of the hull form on the behavior in a seaway frequently remain inconclusive because the effects lie within the rather broad limits of accuracy. Frequently by simplifying problems or exaggerating certain effects one obtains more useful results than by sticking to projects scheduled after immediate practical needs. Thus a drastic reduction of the number of degrees of freedom down to one may be advantageous provided later steps are taken to deal with more complex motions.

On the other hand there is a tendency at present to deal with the problem of the ship behavior in a broader sense than earlier While Krylov and his immediate successors restricted themselves to the study of oscillatory motions we observe at present a definite trend to develop general "mechanics" of a ship in a seaway 6, 7, 8, 5 . This means e.g. that problems of resistance, directional stability and steering etc. in a seaway become increasingly more popular. Obviously, ship mechanics in the present sense includes the knowledge of simpler "theories" presened by the motion of a ship in calm water.

A report on the progress in a field must start from some plane of reference, preferably an earlier survey on the subject. As such we choose the report presented by Dr. Vedeler to the Congress 4 and a paper by Mr. St.Denis and myself 5 .

Dr. Vedeler discussed an ample list of subjects grouped following the six degrees of freedom of a ship.

The scope of his synopsis to which we shall refer later is broader than that of reference [5] . Our aim was to give a rather comprehensive survey of the more elementary problems in our field. All equations of motions were linearized and coupling terms have been neglected. The Froude-Krylov hypothesis following which the pressure at the hull is that corresponding to the undisturbed wave structure has been supplemented in the known manner by the introduction of added masses and hydrodynamic damping forces. These latter were treated in a rather summary way; however, reference to more consistent investigations was made. As usual the seaway was assumed as regular.

From the point of view of our theme the time which has elapsed since the publication of the mentioned papers has been rather fertile. However, only one paper treats the general case of the ship moving under an arbitrary heading angle in a regular seaway 9 . As this subject is not too well known we begin with a short discussion of the earlier fundamental publications. Next we shall deal with investigations in calm water which recently have gained considerably in importance. Further we shall treat some cases of motions in a regular seaway and finally mention attempts to consider the actual, i.e. irregular seaway.

II Fundamental investigations on the oscillations of a ship in a regular seaway

So far there exist three comprehensive original investigations:

1) The classical momoir presented by Krylov,

2) a paper by Haskind 10

3) and one by F. John 11

1) Krylov's paper underlies almost all later studies on the subject. Therefore it may be useful to state once more what an analysis following Krylov's lines can yield and wherein it fails. It has been shown experimentally and by some observations on sea that Krylov's approach succeeds in describing the general character of oscillatory ship motions in a regular seaway especially when the ratio /L is not small. By introducing the hydrodynamic effects known as added masses and

damping a closer approximation to reality is arrived at. On the other hand, several errors are admitted.

1) The influence of hydrodynamic pressures on <u>exciting</u> forces and moments has been ignored, especially the reaction of the ship on the seaway has been neglected 12 .

2) The equations have been linearized.

3) First order coupling terms have been neglected

4) The damping has been treated in a summary way.

Because of 1) quantitative errors in calculating the exciting forces must be admitted which are more serious in the case of shorter waves (small /L) and at high speeds of advance.

Because of 1) and 2) maximum values of displacements especially of the angle of roll, cannot be determined with reasonable accuracy.

3) The elimination of coupling terms precludes the possibility to explain a number of interesting characteristic phenomena.

The question as to how far the basic assumption of a regular seaway is a reasonable one, is rather delicate. Within the limits of a linear theory synchronism or, more precisely, the state where the maximum amplification factor occurs is the most serious condition for a given <u>ship</u> and <u>wave</u> <u>configuration</u>, It seems advisable to retain the fiction of a regular seaway as a standard assumption for model experiments and calculations because the hypothesis presumably leads to a more severe estimate of the worst conditions than are actually met at sea. On the other hand it is obvious that the regular seaway concept does not lead to an exhaustive treatment of the seaworthiness problem; especially it does not yield information on the averag performance of a ship in an actual seaway.

In reference [5] we quoted frequently a paper by <u>Haskind</u> which in the meanwhile has been translated and thus has been made more accessible. Haskind asserts that he has solved the "Krylov problem by <u>hydrodynamical</u> methods. It is worth while to compare this claim with what has been actually accomplished.

Haskind formulates the hydrodynamic problem as follows: The displacement of the ship from its average position is considered as small; therefore the boundary conditions are complied with at the mean (undisturbed) position of the hull. This agrees methodically with the assumptions made in deriving the free surface boundary condition,

$$\frac{\partial \Phi}{\partial z} - \kappa \Phi = 0 \qquad (1)$$

when the ship is not advancing. The expression (1) becomes more complicated for a vessel moving with constant speed if the potential Φ is referred to axes rigidly connected with the body. The potential $\Phi'(x,y,z,t)$ studied by Haskind consists of two parts: the first one $\Phi(x,y,z,t)$ represents the potential of the disturbed motion due to the <u>oscillations</u> of the ship, including their influence on the regular seaway, the second part is the well known potential $\Phi^{*}(x,y,z,t)$ of the wave motion. By splitting off the time factor $e^{i\omega t}$ since only steady state forced oscillations are considered one obtains with

$$\Phi(x,y,z,t) = \varphi(x,y,z)e^{i\omega t} \quad etc.$$

$$\varphi'(x,y,z) = \varphi(x,y,z) + \varphi^{+}(x,y,z) \tag{2}$$

The boundary condition for $\varphi(x,y,z)$ on thebody S is

$$\frac{\partial\varphi}{\partial n} = v_n - \frac{\partial\varphi^{+}}{\partial n} \tag{3}$$

where v_n is the normal velocity of a givenpoint at the body. From the boundary values (3) and $\Delta\varphi = o$ the potential φ can be derived.

We put $\varphi = \varphi_2 + \varphi_0$ (4)

where φ_0 takes care of the reflexion phenomena caused by the ship in a seaway.

Essentially φ is calculated by substituting pulsating sources and sinks for the oscillatory motions of the body. Kochine [has shown that the distribution of singularities over the surface of the body can be found from an integral equation and he has proved that for small and large values of the parameter $\kappa = \omega^2/g$ a solution exists.

The linearisation of the problem leads to the result that the familar concepts of hydrodynamic inertia and damping forces are applicable; they are components of the total hydrodynamic forces, and depend upon added masses m_{ij} and damping coefficients N_{ij} respectively. Further, one obtains the usual expressions for the restoring terms and formulas for the exciting forces and moments Fe Me

$$F_e = -\rho g a e^{i\omega t} \iint_S (\varphi_0 + \varphi^+) \vec{n}\, dS \tag{5}$$

$$M_e = -\rho g a e^{i\omega t} \iint_S (\varphi_0 + \varphi^+) \vec{r} \times \vec{n}\, dS \tag{6}$$

which by the terms φ_0 consider the disturbing effect of the ship on the seaway.

The case of the ship at rest (zero speed of advance) is thoroughly treated as a useful introduction to the general case of the ship moving with finite speed of advance U. Added masses and damping factors become functions of the body shape, of the wave length λ (or the parameter $\kappa = \omega^2/g$), the course angle χ and of the speed of advance U. This means that the added mass concept must be still further generalized than in the case of a body oscillating in calm water at or near the surface.

Haskind applies his reasoning to a study of the heaving and pitching motion.

The vertical force Z and the pitching moment M consists of four "components":

$$Z = Z_o + Z_1 + Z_2 + Z_3 \tag{7}$$

with Z_o Mo due to the uniform speed of advance

Z_1 M_1 hydrodynamic terms caused by the oscillations of the ship,

Z_2 M_2 restoring (hydrostatic) generalized forces

Z_3 M_3 exciting forces.

To obtain explicit results the Michell (wedge like) ship is introduced, otherwise expressed, we substitute for the oscillating ship pulsating sources and sinks distributed over the longitudinal center plane. Although the Michell ship is a rather poor approximation for an actual hull when motions in a vertical plane are considered the results are interesting. Amongst other things they reveal the influence of the appoximations made.

We leave aside the constant forces Z_o M_o which we can interpret as caused by the uniform motion of the body in calm water and arrive at following expressions for the hydrodynamic terms:

$$Z_1 = -m_{33}\ddot{z} - m_{53}\ddot{\psi} - N_{33}\dot{z} - N_{53}\dot{\psi} = 0 \qquad (8)$$

$$M_1 = -m_{35}\ddot{z} - m_{55}\ddot{\psi} - N_{35}\dot{z} - N_{55}\dot{\psi} = 0 \qquad (9)$$

For the moving ship $m_{35} \neq m_{53}$ and

$$N_{35} \neq N_{53}$$

Simplifying further by assuming a ship symmetrical with respect to the midsection one obtains

$$m_{35} = -m_{53} \qquad N_{35} = -N_{53} \qquad (9a)$$

Introducing

$$Z_3 = \rho g a A_0 E e^{i\omega_e t} \qquad (10)$$

$$M_3 \doteq \rho g I_y \bar{\vartheta} \Psi e^{i\omega_e t} \qquad (11)$$

with ω_e the frequency of encounter, I_y the moment of inertia of the waterline, $\bar{\vartheta}$ the effective wave slope E and Ψ the dimensionless heaving and pitching functions, the equations of motion are written as

$$(m+m_{33})\ddot{z} + N_{33}\dot{z} + \rho g A_0 z + m_{53}\ddot{\psi} + N_{53}\dot{\psi} = \rho g a A_0 E e^{i\omega_0 t} \quad (12$$

$$(J_y+m_{55})\ddot{\psi} + N_{55}\dot{\psi} + \rho g I_y \psi - m_{53}\ddot{z} - N_{53}\dot{z} \doteq \rho g I_y \vartheta \Psi e^{i\omega_0 t} \quad (13$$

Thus even for a ship symmetrical with respect to the midship section there is a hydrodynamic <u>intertial</u> and <u>damping</u> coupling. These terms will be discussed later.

Haskind illustrates by a numerical example the dependency of the damping coefficient upon the speed of advance U or more correctly upon the speed parameter $\tau_0 = U/c$ where c is the wave velocity. The results are shown as ratios

$$\frac{N_{33}(\tau_0)}{N_{33}(0)} \qquad \frac{N_{55}(\tau_0)}{N_{55}(0)}$$

i.e. as fractions of the damping at zero speed U = o.

No attempts have been made to investigate explicitly the influence of hydrodynamic phenomena (represented by the potential φ on the magnitude of the exciting forces. The structure of the expressions for Z_3 M_3 is based on hydrostatic reasoning"; no attempts have been made to introduce characteristic parameter which may indicate, for example, the influence of the ship form on reflexion.of his "complete"

Apparently Haskind has realized the shortcoming of his "complete" solution and has proposed an experimental supplement [3].

I have been unable so far to evaluate the expressions for the added masses and to check if they lead to a correct dependency upon a dimensionless frequency parameter $F_\omega = \omega\sqrt{\frac{B}{g}}$

Some doubt may be expressed if the substitution of singularities following lines use for the michell ship is adequate. However, in 13 quoted before consistent results have been communicated.

Further valuable information may be extracted from 12 by extended numerical computations. However, the claim cannot be justified that the hydrodynamic problem has found a final solution within the limits of the linearized theory.

No attempts have been made to attack the resistance problem even under the strained assumption of a constant speed of advance.

We conclude this survey by a quotation from Fourier following which a problem cannot be considered as solved before numerical solutions have been obtained. This idea deserves full attention in ship theory where because of the complex form of the ship hull and the intricate character of the free surface phenomena solutions lead to complicated expressions.

3. Although full credit has been given earlier to a paper by F. John 11 , we refer to it once more because of two reasons: 1) here in a lucid form the general boundary problem has been stated to which our investigations on the behavior of a ship in a seaway can be reduced and the formalism of linearisation has been expounded,

2) For waves in shallow water in the presence of flat floating bodies explicit results have been obtained. Shallow water means

-16-

that the wave length depth of water h and <u>flat</u> bodies comply with the condition that the radius of curvature Flat bodies represent an idealization of the ship form which is the opposite extreme of the"narrow" Michell ship. Under these assumptions the wave equation can be used for points under the free surface.

Following cases solved by John deserve our special interest:

1) Waves generated by a freely floating cylinder,
2) Waves generated by a forced vertical motion of an obstacle,
3) Wave disturbed by a rigid obstacle,
4) Motion of a floating body generated by incoming periodic waves.

Reference is made to the original but as example Fig.8 is reproduced which pictures the reflection coefficients of an incoming wave for a fixed and a freely floating cylinder. The immediate applicability to harbor work is obvious; when dealing with ships the assumptions should be remembered for which the results are valid.

A recent synopsis 9 will be treated later. The Krylov problem is being reconsidered under the original assumptions by Radosavljevic.

III Motions in calm Water

1. Free oscillations

From the point of view of the theory of oscillations this problem has been frequently treated. Departing from the elementary linearized equation of damped harmonic oscillations <u>rheolinear</u>

linearized equation of damped harmonic oscillations rheolinear and non linear equations have been discussed.

Much thought has been given to the experimental determination of the damping force which is expressed by the binomial

$$K_1 \dot{\varphi} + K_2 \dot{\varphi}^2 \tag{14}$$

when the "extinction law" is given by

$$\delta\varphi = a\varphi + b\varphi^2 \tag{15}$$

The resulting equation of motion can be handled without too much difficulty, but generally it is preferred to linearize the damping term. In this latter form the damping coefficient so obtained is commonly used in analysing forced motions also what is probably permissible in the neighborhood of the most important synchronism condition as long as the damping is small.

Moderate interest only was earlier devoted to the determination of added mass values; more efforts were concentrated on the treatment of non linear and rheolinear restoring forces. The solution of the resulting equations of motion is known; what is needed in general is an appropriate application of scienti-fic methods available. This does not exclude, that interesting and important results will be found. Our remark applies especially to rheolinear problems whose formal treatment can be reduced to Mathieu and Hill equations. Generally the formalism will prove to be usefull when dealing with more complicated problems. An interesting stability problem has been recently discussed [45] .

The study of free oscillations will always remain an important part of ship theory because it leads to the determination of the natural periods.

In courses on rational mechanics as well as on ship theory the chapter on free oscillations precedes the chapter on forced ones because the former is considered as easier. This is quite natural as long as motions of solid bodies are treated. Things look slightly different from a hydrodynamic point of view. The added mass and damping coefficients can be <u>calculated</u> much easier for a hull performing forced oscillations in calm water than oscillating freely. This appears to be pausible already from the simple fact that in the former case the frequencies are prescribed. Further, the study of forced oscillations leads to much more general and interesting results because the hydrodynamic force varies appreciably or even decisively with a dimensionsless frequency parameter $F_\omega = \omega \sqrt{\frac{B}{g}}$

To my knowledge beside [11] only two papers dealing with the <u>hydrodynamics</u> of free oscillations have been published:

1) by L. Sretensky: "On the damped oscillations of the center of gravity of floating bodies" [16] . It treats the two dimensional free oscillations of a "thin" (wedge like) body. Difficult and tedious computations lead to an interesting extinction curve. Fig.2 From it we gather that the period concept can no more be sustained rigorously what is not surprising as even the damped harmonic oscillation is no period motion. There are

There are some experimental indications which support the shape of the calculated extinction curve at higher values of the time paprameter.

2) <u>Haskind</u> [17] has generalized the problem by

   a) treating the three dimensional case

   b) admitting a constant speed of advance

   c) and considering the coupled motions of simultaneous pitching and heaving.

Explicit formulas have been given for the Michell ship but no numerical evaluations have been made so far. Some results concerning the coupled motions will be discussed later.

2. Forced oscillations in calm water

Theoretical and experimental investigations of forced motions with one degree of freedom in calm water acquires fundamental importance. They enable us to determine in the simplest manner <u>added masses</u> values and <u>damping coefficients</u>. Results so obtained are applicable to the study of motions with two or more degrees of freedom and even to the analysis of phenomena met in an actual seaway.

We mentioned already the hypothesis following which damping coefficients and added mass values derived from free and forced oscillation tests concide practically provided the frequency parameter $F_\omega = \omega\sqrt{\frac{B}{g}}$ is the dame and damping values are not large. It should not be too difficult to establish the limits of its validity experimentally and analytically.

More serious and important is the question if added mass values and damping coefficients obtained from a calm water state are applicable without further corrections to seaway conditions.

From the structure of Haskind's integrals 10 it can be followed that in principle a dependency upon the seaway characteristics does exist. Obviously, numerical evaluations should be made in the next future. However, at the present state of knowledge one should not be too meticulous. From a practical point of view small errors in the magnitude of damping coefficients and moderate errors in added mass values are of no great moment. Much lower accuracy is required than that needed in resistance research.

From Ursell's 18 and Haskind's 10 work it can be followed that by substituting source-sink systems for a body considerable errors in the determination of the hydrodynamic oscillatory forces (added masses and damping) can be committed. Recently our knowledge in this field has been appreciably extended by O. Grim 19 . + Like Ursell, Grim restricts himself to the twodimensional case of forced motions of a body with zero speed of advance and thus tackles a less ambitious problem than Haskind. Nevertheless, his publication deserves our full interest because of the originality and efficiency of the method used and the importnat results reached. Beside, his theoretical work is supported by beautiful experiments.

+The paper published in the JSTG represents a condensation from the original thesis.

About two years ago the present writer published a survey on free surface effects 20 . It is gratifying to acknowledge that several blank spots in our knowledge there indicated have been filled out by Grim's investigation.

Grim constructs the velocity potential from:

1) the potential valid for the motion of a body in the unbounded fluid,
2) a term which in a known manner allows to comply with the boundary condition on the free surface,
3) a term which enables us to satisfy approximately the normal velocity condition on the boundary of the oscillating body. It represents the potential due to a pressure system applied over that fictive part of the free surface which is occupied by the oscillating body.

By increasing the number of arbitrary parameter in the pressure function the degree of approximation can be improved, par example, the normal velocity condition satisfied for a larger number of points on the boundary. However, it appears that very few terms yield already satifactory results. In this way reliable values of the damping force and added masses can be obtained for an ample class of sections studied by F. Lewis 21 . The method is valid for the vertical, horizontal and rolling oscillations.

The introduction of a "force dipol" concept is especially useful. Its meaning follows from Fig.: 3 by increasing the force and reducing in such a way that remains finite a singularity system is obtained which is suitable for the representation of a flow in the neighborhood of a body. To my knowledge such dipols and higher order force singularities have been introduced by Nemenyi into the theory of elasticity but so far have not been used in hydrodynamics.

Especially powerful is the application of the least square method proposed by the author to comply with the boundary condition on the body. It yields error estimates which possess a simple physical meaning.

Results obtained by Grim for the circular cylinder are in close agreement with Ursell's findings quoted before [18] and other ones communicated in a recent paper [22] which have been reached by a totally different approach.

Within the limitations enumerated before Grim's results lend itself immediately to the solution of practical problems. Let us first consider the heaving motion. Using the numerous graphs published by the author one is enabled to calculate the damping coefficients and added mass values, for almost all section forms met in practice.

Figures ...4...5...... reproduced form the JSTG/1953 show characteristic results. As independent variable appears the frequency parameter $\xi = \frac{\omega^2 a}{g}$ where a is a characteristic length (radius of a circle, half beam, eventually draft). Obviously, an agreement should be reached as to the standard form (linear or quadratic) of the frequency parameter.

The "wave damping" is determined by the dimensionsless wave amplitude $\bar{A}$ (the amplitude of the wave at infinity referred to a characteristic amplitude of the forced body motion).

Having in mind that the damping is proportional to the square of $\bar{A}$ it is evident from the diagrams that the damping force is rather sensitive to changes in the section form.
Grim has applied his results obtained for the heaving to the study of the pitching motion by introducing a strip method. The error committed by using the twodimensional approach in a threedimensional case is in many cases tolerable. To check the calculations Grim performed model experiments in calm water; pitching was excited by suitably arranged rotating weights. The agreement between results of computation and measurement was good. The interesting coupling effect stated will be discussed further beneath.

Earlier the largest interest was concentrated on the motion of roll. The situation has recently changed, at least as far as the hydrodynamics of the subject are concerned, since the hydrodynamic phenomena connected with the heaving motion lend themselves to an easier theoretical investigation. However, attention is again calles to a paper by Ursell [22]. Here the author cameto rather striking conclusions with respect to the properties of wave damping for various sections. To my knowledge Ursell's suggestion to cheek experimentally some of his findings so far has not been carried out.

The results obtained by Grim for added masses and damping forces in the case of the side motion and the roll are as fundamental as in the case of heaving. Introducing the necessary changes into the structure of the velocity potential his method is immediatelyapplicable to the solution of these difficult problems. Explicit data have been obtained for circular and elliptical sections see fig..6..7... Interesting coupling effects will be mentioned later.

It is now well known that the emergy dissipated by wavemaking is responsible for the over whelming part of the damping effect in heaving and pitching, at least for the ship at zero speed of advance. Nonetheless the consideration of effects due to viscosity may be required, especially in the case of roll. Because of the scarcity of recent publications on this subject we restrict ourselves to an <u>observation</u> on the viscous damping of ships when underway. [23]

Techel points out that the damping force due to friction can be expressed in the usual manner by $N\dot{\varphi}$ provided the speed of advance U is large as compared with the speed caused by rotation.

3. Coupled motions in calm water

Following Vedeler [4] the problem of coupling deserves a special paper.

We shall try to supplement the list of coupling effects enumerated by him. Free and forced oscillations are treated simultaneously.

1. The hydrostatic coupling of heave and pitch is mentioned in any reasonable book on ship theory. Denoting the horizontal distance between the center of buoyancy and flotation by e, by ν_z and ν_ψ the uncoupled frequencies, by i_y the radius of gyration of the load water line one obtains the characteristic equation

$$h^4 + (\nu_z^2 + \nu_\psi^2) h^2 + \nu_z^2 \nu_\psi^2 (1 - \varepsilon) = 0 \tag{16}$$

where
$$\varepsilon = \frac{e^2}{i_y^2}$$

Because of the extreme smallness of ε in most cases the resulting frequences ν_z^+ ν_ψ^+ are very close to ν_z ν_ψ .

The resulting motions are of the type

$$C_1 \cos(\nu_z^+ t + \zeta_1) + C_2 \cos(\nu_\psi^+ t + \zeta_2) \tag{17}$$

generally in shipbuilding practice one avoids to discuss such "complicated" expressions.

2) Much more interesting are other coupling effects. Pursuing [4] we begin with the so called "gyrostatic" effects. Choosing as axes of reference the principal axes of the body and retaining non linear terms, one obtains for the rotation of the body in a vacuum Euler's equations.

Neglecting the presence of the free surface the influence of the surrounding ideal liquid can be considered following lines developed by Kelvin und Kirchhoff [14].

The idea of this approach is to avoid the calculation of forces from the hydrodynamic pressure distribution by using the added masses concept. However, in more complicated cases the latter are not known and one has to resort to the determination of the pressure distribution as the fundamental phenomenon.

The added mass terms are included into the left sides of the equations of motion. Several writers starting from a slightly different point of view prefer to collect all hydrodynamic terms on the right side. This is, obviously, a purely formal matter.

It is understood that the investigation performed beneath yields only a formal scheme which, nonetheless, may contribute to clarify the problem.

Using Lamb's notations [14] the general equations of motion of a body in an ideal liquid are of the type: 14 for forces

$$\frac{d}{dt}\frac{\partial T}{\partial u} = r\frac{\partial T}{\partial v} - q\frac{\partial T}{\partial w} + X \tag{18}$$

and for moments

$$\frac{d}{dt}\frac{\partial T}{\partial p} = w\frac{\partial T}{\partial v} - v\frac{\partial T}{\partial w} + r\frac{\partial T}{\partial q} - q\frac{\partial T}{\partial r} + L \tag{19}$$

Here X and L are the extraneous forces, the Kinetic energy T is the sum of the Kinetic energies of the body T_1 and of the surrounding fluid T_0. The generalized forces exerted on the moving solid by the surrounding fluid are of the type

$$X_0 = -\frac{d}{dt}\frac{\partial T_0}{\partial u} + r\frac{\partial T_0}{\partial v} - q\frac{\partial T_0}{\partial w} \tag{20}$$

and

$$L_0 = -\frac{d}{dt}\frac{\partial T_0}{\partial p} + w\frac{\partial T_0}{\partial v} - v\frac{\partial T_0}{\partial w} + r\frac{\partial T_0}{\partial q} - q\frac{\partial T_0}{\partial r} \tag{21}$$

The expressions for T_1 and still mor for T_o are extremely tedious in the case of a body without properties of symmetry. While essentially motions of a body possessing no more than two panes of symmetry should be studied we restrict ourselves here to the simple case of a solid with three planes of symmetry.+)

Then we obtain departing slightly from Lamb's notation

$$2\,T_1 = m(u^2 + v^2 + w^2) + J_x p^2 + J_y q^2 + J_z r^2 \qquad (22)$$

and

$$2\,T_o = m_{11}u^2 + m_{22}v^2 + m_{33}w^2 + m_{44}p^2 + m_{55}q^2 + m_{66}r^2 \qquad (23)$$

The fluid reactions are of the type

$$X_o = -\,m_{11}\dot{u} - m_{33}qw + m_{22}rv \qquad (24)$$

$$L_o = -\,m_{44}\dot{p} + (m_{55} - m_{66})qr + (m_{22} - m_{33})vw \qquad (25)$$

and the equations of motions become neglegting damping terms

$$(m + m_{11})\dot{u} + m_{33}qw - m_{22}rv - X_1 = 0 \qquad (26a)$$

$$(m + m_{22})\dot{v} + m_{11}ru - m_{33}pw - Y_1 = 0 \qquad (26b)$$

$$(m + m_{33})\dot{w} + m_{22}pv - m_{11}qu - Z_1 = 0 \qquad (26c)$$

$$(J_x + m_{44})\dot{p} + (J'_z - J'_y)qr - (m_{22} - m_{33})vw - L_1 = 0 \qquad (27$$

$$(J_y + m_{55})\dot{q} + (J'_x - J'_z)ru - (m_{33} - m_{11})wu - M_1 = 0 \qquad (27b)$$

$$(J_z + m_{66})\dot{r} + (J'_y - J'_x)uq - (m_{11} - m_{22})uv - N_1 = 0 \qquad (27c)$$

here we have denoted:

1) by $X_1 \ldots\ L_1 \ldots$ the extraneous forces which in the case of the ship oscillatiog in calm water are primarily hydrostatic forces

+) It is further assumed that the axes of symmetry are the principal axes of the body.

2) by $J'_z = J_z + m_{66}$ $J'_x = J_x + m_{44}$ $J'_y = J_y + m_{55}$ the virtual moments of inertia.

The introduction of non linear terms, obviously, involves a severe complication of the mathematical problem. That is one reason why very little has been done in this field.

The first step in treating these equations should therefore consist in estimates of the order of magnitude of the "gyrostatic" terms. Par example J'_x is very small compared with J'_z and J'_y, and m_{11} is small compared with m_{22}, m_{33}. When dealing with "normal" ships the influence of the free surface effect on added mass values must be considered. This can be done using the results of recent investigations mentioned before. Hence in the near future we shall be enabled to tackle the present problems of coupling with more confidence than before.

In cases with weaker properties of symmetry the same formalism (20) (21) can be applied although. The quantitative evaluation of the additional terms arising requires considerable work. Clearly, the Kirchhoff-Kelvin theory can yield one part of the coupling effects only; important linear coupling terms arise because of other physical effects.

3) Such are <u>hydrodynamic</u> coupling effects due to damping. For free heaving and pitching oscillations there exists the solution found by Haskind [15]. We quote only the simplest case

valid for a Michell ship symmetrical with respect to the midship section

$$(m+m_{33})\ddot{z} - cU\dot{\psi} + \int_0^t K_{33}(t-\tau)\frac{dz}{d\tau}d\tau + \int_0^t K_{35}(t-\tau)\frac{d\psi}{d\tau}d\tau + \rho g A_0 z = 0 \quad (28)$$

$$(J_y + m_{55})\ddot{\psi} + cU\dot{z} + \cdots = 0 \quad (29)$$

with c a coefficient.

Here K_{33} K_{35} .... are intricate integrals which take care of the time history and lead to complicated motions of the character shown in fig. 9. From our present point of view we are interested in the coupling terms - cu $\dot{\psi}$ and + cu $\dot{z}$. Notice the opposite signs and the fact that they do not disappear for the symmetrical ship except when the speed of advance u = o.

4. Beside their theoretical value Grim's investigations should be considered as exemplary from the point of view of engineering science because the author combines in a consequent manner the analytical and experimental approach. This method of research led e.g. to the determination of following coupling effect. We mentioned already Grim's experiments on pitching in calm water. In addition to the pitching the simplified symmetrical model of the Wigley type [44] performed. a heaving motion which varied approximately proportional to the speed of advance being zero for zero velocity. This checks in principle with Haskind's analysis eq. (28) (29) valid for calm water motions; the same result could be derived from eq (12) (13)

representing forced conditions.

5. Grim has pointed out that the horizontal transvers motion and the motion of roll in general are coupled and therefore should be treated simultaneously.

Denoting by Y_1 and M_x extraneous forces the following two equations of motion are obtained:

$$m_y' \ddot{y} + N_{22}\dot{y} + m\overline{OG}\ddot{\varphi} + \frac{m_{44}}{h_{\varphi i}}\ddot{\varphi} + \frac{N_{44}}{h_{\varphi N}}\dot{\varphi} = Y_1 \qquad (30)$$

$$J_x' \ddot{\varphi} + N_{44}\dot{\varphi} + mg\,\overline{GM}\varphi + m\overline{OG}\ddot{y} + m_{22}h_{yi}\ddot{y} + N_{22}h_{yN}\dot{y} = M_x \qquad (31)$$

Here the notations have been introduced:

$\overline{OG}$ distance of the center of gravity G from the point of reference 0

h levers of horizontal hydrodynamic forces, particularly h_{yi} h_{yN} levers of the inertia and damping force due to transverse motion,

$h_{\varphi i}$ $h_{\varphi N}$ due to rotation

Assuming that Y_1 and M_x vary harmonically with time the equations have been discussed for the elliptic cross section. In the case of the circular section the equations (30) (31) can be considerably simplified. The theoretical work has been supplemented by experiments.

6. Grim [27] has shown that coupling can exist between roll, pitch and yaw. The theoretical proof refers to free oscillations in calm water; it is based on Lagrange's equation of motion. From the investigation follows that the yawing motion in

in calm water is determined by the pitch and roll. Further it is shown that the roll can be influenced by the pitching motion. Formally this is obtained from the properties of the Mathieu equation.

Exciting pitching motions of a model by an inertia oscillator heavy rolling was demonstrated when the period of pitch was half t the natural period of roll. However, Grim indicates that the coupl coupling is weak since a slight change in the frequency relations because the roll to disappear.

IV Motions in Seaway.

1. Exciting forces

1.1 Theoretical considerations

1) Havelock 26 and the present writer have calculated exciting forces due to hydrodynamic efforts experienced by wholly submerged very elongated bodies moving uniformly on a straight horizontal path in a regular seaway.

The essence of the rather coarse approach by the present writer is the following: First, forces and moments resulting from apparent buoyancy (Krylov hypothesis) were determined. Provided the depth of immersion f of the body is not small the most interesting results depend on the sectional area curve; there is no need to restrict ourselves to bodies of revolution. The general case of the motion under an arbitrary heading angle with respect to waves can to a considerable extent be based on the simpler case when the ship is advancing in a bow or stem sea.

Hydrodynamic force effects are estimated using an approximate method due to W.Tollmien 28 . It applies to forces experienced by a body moving with a constant speed of advance in a slightly non uniform steady flow. Presumably, the application of this interesting method is superseded to some extent by the more general approach due to Cummins 43 . We omit therefore a discussion of the underlying assumptions and state the result, That the vertical force Z can be calculated from the apparent buoyancy force multiplied by the factor

$$1 + \varkappa_{33} + (\varkappa_{33} - \varkappa_{11}) \frac{u}{c} \qquad (32)$$

provided the ratio λ/L wave length is large. The result agrees with the findings of a more rigorous elaborate investigation on the motion of a spheroid due to Sir Thomas Havelock [26] . Here the disturbance of the wave train by the spheroid is calculated in an exact manner. The computations lead to the evaluation of all components of the force an moment experienced by the spheroid in a seaway. With the kind permission of the INA we reproduce two graphs showing the striking dependency of the effects u upon the Froude number. However, the resistance X does not vary with the speed.

The six generalized force coefficients are definde following the pattern

$$C_x = \frac{\overline{X}}{\Delta \vartheta} \qquad C_{yy} = \frac{\overline{M_{yy}}}{\Delta L \vartheta} \qquad (33)$$

with $\bar{\vartheta} = \frac{2\pi a}{\lambda} e^{-\frac{2\pi f}{\lambda}}$ the maximum effective wave slope at the depths f of the axis:

So far the present writer feels unable to suggest as to how quantitative estimates for surface craft can be derived from the results so far obtained. However, beside their immediate significiance these results may be usefull in planning experiments with model of surface ships.

2) Extensive research work on the motions of bodies in a seaway has been performed at the University of California, Institute of Engineering research, Berkeley Cal.

Restricting ourselves primarily to the theoretical side of these investigations we mention a paper by Fuchs and Mac Camy 30 Oscillations of a floating rectangular block advancing with a constant speed normally to the wave crests in water of finite depth are studied assuming:

1) sinusoidal waves (classical first order theory)
2) Stokes waves (second order theory)

Calculating the buoyancy and moment from the undisturbed wave pressures rather tedious expressions are obtained in the second case for the heaving and pitching motions. In order to find the position of the body to the second order the surging motion has to be determined to the first order. Thus a new interesting oc- coupling effect has been established. Comparisons were made of motion amplitudes calculated under various assumptions. (shape of waves, damping) with experimental data. The results are in- conclusive. It is doubtful if it is worth while to introduce corrections for nonlinear wave effects as long as the distortion of the seaway by the moving body is being neglected. This criti- cism applies to the analysis of concrete results of measurements only; it is not intended to belittle the value of the investiga- tion.

3) By courtesy of Dr.John Wehausen I had the opportunity to study two recent papers by M. Haskind. 31 32 .

We shall restrict ourselves to some superficial remarks on the investigation "Oscillations of a floating contour onthe surface of a fluid with consideration of gravity" 31 .

Here the following problem is treated: given a cylinder with a symmetrical contour L floating in a regular seaway. The hydrodynamic effects are to be determined. General formulas are given for the amplitude of waves due to the oscillating body at plus and minus infinity and for the forces Z, Y (horizontal side force) and the rolling moment M_x. These results are applied to the well known class of Lewis contours 21 .

No conclusions can be derived at present since the actual evaluation of the formulas will require a considerable amount of work. The problem attacked by Haskind represents the most general linearized twodimensional problem in our field. Because of its fundamental importance from a practical and a scientific point of view a considerable investment of thought and labour in reaching explicit results is fully justified.

1.2 Experimental approach, model investigations

Haskind did not calculate explicitly the distortion of regular waves caused by the ship and the influence on the exciting forces resulting therefrom. Together with Riemann 13 he supplemented his theoretical research by an experimental method which yields a hydrodynamic correction for these forces. For this purpose harmonic oscillations of a model with one degree of freedom, say heaving, are excited in calm water by an oscillator and added masses and damping factors derived. Further, the heaving motion z of the same model is excited by regular waves. Thus the graph

$$Z = \bar{z} \quad e^{i(\omega t - \delta)} \tag{30}$$

is obtained. Inserting [30] into the equation of motion

$$m'_z \ddot{z} + N_{33} \dot{z} + \rho g A_0 z = \rho g \alpha A_0 E e^{i(\omega t - \varepsilon)} \tag{31}$$

we find a complex relations from which by equating the real and the imaginary parts the exciting force coefficient E and the phase angle δ can be calculated. An example of the phase lag which following the Froude-Krylov hypothesis equals zero is shown in figure ...8... and the corresponding force coefficient E is compared with the"Krylov" value E_t in figure..9.. These two diagrams are to my knowledge the only pertinent data so far published.

The application of the method to other motions is obvious and the extension to coupled motions possible, at least in principle.

1.3 Report on "Ocean Vulcan" Sea Trials

The extended investigations performed by the Admiralty Ship-welding Committee on several vessels, expecially the "Ocean Vulcan" and "Clan Alpine" deal primarily with matters of strength and so far remain outside of the scope of our present survey, except that part of the work which treats forces acting on the ship at sea.

We are especially interested in the attempts to derive these forces from ample pressure measurements which exceed by far similar work done earlier. Unfortunately, the detailed analysis is not yet available therefore we must restrict ourselves to few examples published in Report 8 [29] . A plot of the variation of pressure with respect to the still water conditions is shown of pressure with respect to the still water condition is shown in fig. 10.

We note the decrease from the peak at the still water load line towards the bottom.

The authors tried also to establish the basic equations of heave and pitch in a more adequate manner by using the relations:

"force causing heaving acceleration = out of balance vertical force due to dynamic buoyancy - damping force due to heaving velocity",

and a similar for the pitching moment.

This slightly unusual restatement means that the hydrostatic and hydrodynamic exciting forces and the restoring forces are lumped together as out of balance force. Obviously, a more complete treatment requires the consideration of various coupled forces; thus the general formulation is not fortunate.

For actual computing work the Froude-Krylov hypothesis of the undisturbed pressure distribution is used. Added masses and damping are estimated in a rather coarse manner.
Instead of the linearized expressions for the restoring and exciting forces the out of balance forces are introduced. These are obtained by subtracting the still water values from the values read off special charts representing the total buoyancy and trimming moment as functions of a particularity defined draft and the trim angle. For each longitudinal position of the wave

profile with respect to the ship a seperate chart is needed. The equations of motions are solved by a step method.

The authors theoretical approach does not yield in the form proposed an improvement as far as hydrodynamics are concerned. It drops, however, linear restrictions with respect to the hydrostatic forces (including the Smith effect). It may prove to be useful if the tedious calculations can be performed by computing machines and if sufficiently accurate experimental values of the pressure distribution can be substiteted for the "theoretical ones".

§4 A case of gyrostatic coupling

To my knowledge gyrostatic coupling was treated first by Suyehiro 40 . He deals with the behavior of a floating body amongst long regular waves: dependent upon the period of the latter the body has the tendency to set itself parallel or normal to the wave crests. Suyehiro treats the motions of rolling, pitching and heaving simultaneously; the equations are linearized exept for a "gyrostatic" term in the relation for yawing. The exciting term in the equation of yaw has been neglected, which may be permissible when the speed of advance is zero. Otherwise the problem must be reconsidered by more elaborate methods. The problem studied by Suyehiro presents a transition to the next chapter.

2. Ship mechanics.

1. Directional stability in seaway.

We pointed out already that recently there is a tendency of treat the behavier of a ship in a seaway under the broader aspect of ship mechanics.

The need for such a generalisation was suggested by the study of the yawing motion which is basicly connected with the properties of directional stability and steering of the ship.

The first step in this direction was made by Davidson [6]. The present writer attacked the problem pf the directional stability in regular waves in a more general way [8]. Because of the extreme complexity of the task this attempt does not go much beyond a formulation of the fundamentals involved. One inherent difficulty is the variability of the ship speed over one period pf encounter. Neglecting it oneaobtains stability criteria which beside the well known stillwater derivatives depend upon the wave characteristics, the heading angle and the speed of advance. The magnitude of various impottant parameters is not yet known, but in the light of recent progress in our field it appears possible that by combined analytical and experimental methods quantitative data can be obtained. However, it appears advisable to set aside a gnneral investigation till a better understanding of the resistance problem has been reached.

Starting from [6] the special case of a ship advancing in a following sea has been treated rather thoroughly by Grim [7]. Important results have been found which qualitatively at least agree with observed phenomena at sea. The paper does not lend itself to a short review; however, the main conclusion is interesting following which a stable motion of the ship in a long following sea appears to be almost impossible. There is a high probability that the control by the rudder will be lost and the ship will turn quickly into a position parallel to the wave crests. During the circling motion an appreciable list connected with it may endanger the transverse stability of the ship. This leads us to the problem of:

2. Transverse stability in a seaway

In his classical memoir [1] Krylov expressed the intention to look into this question.

Krylov has not fulfilled his promise and within the following 55 years very little has been done to promote the solution of this important problem.

To my knowledge, French writers [3] were the first to calculate the metacentric height of a ship in a regular seaway from quasi static considerations. Results of this relementary approach are shown in fig.11... The idea was resumed by Kempf [34] and his collaborators [35]; recently Grim [27] calculated Reed's diagram under similar assumptions. The problem becomes now rather urgent in connection with attempts to "standardize" the

the transverse stability (better to fix lower limits of it). Clearly, these attempts remain arbitrary as long as so little is known about the actual magnitude of the decisive parameters in a seaway. Using the fact that the metacentric height changes periodically in regular waves Grim [29] was able to clarify an important phenomenon, which so far evaded explanation. It has been observed that a model running normally to a train of regular waves undergoes heavy rolling when the natural period of roll is twice that of the period of encounter. The formal treatment leads to a Mathieu equation. The solution was checked by a double set of experiments:

1) in calm water pitching motions were excited by revolving weights which simultaneously varied the position of the center of gravity of the model,.

2) by tests in regular waves.

This analysis shed additional light on the controversial matter why ships in a following sea frequently experience large amplitudes of roll.

3. Motions in a confused sea

We mentioned the problematic character of the concept "regular seaway" on which most of our theoretical and experimental work is based.

Already Krylov [1] gave serious thoughts to this question and proposed an approximative treatment of irregular seaway patterns by assuming plausible slight variations in the wave periods.

He explained the erratic behavior of a ship due to the superposition of forced and free oscillations ("Wave by wave method"). Tacitly the hope was nourished that the forced oscillations of a ship were responsible for the main part of the phenomena observed and that a closer agreement between theory and reality could be reached if free oscillations were properly considered.

Several times experiments were made with artificially produced irregular train of waves. As motions of models under such conditions never reached as high amplitudes as in regular waves of comparable length close to the synchronism condition the usefulness of the regular seaway concept as severest assumption imaginable was corroborated. This does not preclude that in a state far from synchronism irregular waves may produce larger ship amplitudes as regular ones. From a purely practical viewpoint attempts have been made to correlate actual sea conditions with regular trains of waves. [41,42]. Essentially all such attempts must remain illusory before a better knowledge of the actual seaway has been reached. The old "classification" of a seaway, obviously, does not meet the most modest requirements. A proposal made by the Deutsche Seewarte [36] though noteworthy still does not yield a reliable foundation.

In the last decade attempts have been made to improve the intolerable situation. Reference is made to a report by Fuchs and Mac Camy [37] which represents the continuation of an earlier work by Fuchs. [38]. It deals with the heaving and pitching of ships (or models) in irregular bow and stern waves and is based on the Fourier integral method. Time histories of heaving and pitching can be expressed as an integral of the recorded wav wave motion and a kernel. Good agreement is reached between predicted and recorded data. Omitting the discussion of the complex mathmatical work we mention a particularly interesting deduction. It refers to the "wave by wave-method". The report gives same indications that such a procedure may be plausible when the waves are "smooth" but fails when the seaway is quite irregular.

As the result of collaboration between oceanography and naval architecture a paper was presented by M.St.Denis and W.Piersson 9 . The part dealing with waves contains a thorough survey of methodes which lead to a representation of an irregular seaway. The statistical approach proposed yields quite new aspects. A clever sientist once remarked that for the average human being theory begins where understanding ends. Because of the surprising character of the mathematics involved - even powerful professional mathematicans are unable to grasp it - there is a certain danger that human nature will revolt against the new "theory".

However the new approach can already claim a success: Experiments (Fig.21) prove the authors' thesis: in spite of the identity of the frequency of encounter for all simultaneous motions of a vessel the number of zero crossings and maximum amplitudes over a fixed timeinterval may vary appreciably with the motion.

Further, contrary to thoughts prevailing earlier the author's work lead to the interesting conception following which the response of a ship in a confused sea is a steady state process rather than a contineous succession of transients.

The authors emphasize one serious limitation of their study - it refers to amplitudes only and leaves phase relations outside of its scope.

The statistical approach may supplement effectively hydrodynamic research following "orthodox" lines but by no means will replace it. That part of reference 9 shich deals with the equations of ship motions furnishes a strong support of my case, that classical hydrodynamics have not been superseded. In calculating added masses and damping forces no reference has been made to free surface effects"; further, hydrodynamic coupling effects have not been even mentioned. For the determination of exciting forces the use of surface integrals instead of volume integrals proposed by Krylov does not present an advantage. However, it is meritorious to emphasize the importance of the Smith effects which has been under estimated by Krylov.

Summarizing we state that

Conclusion

Summarizing we state that recent theoretical work in our field has developed in a satisfactory way. Powerful methods have been proposed, important special probelms have been successfully treated, and there exists a promising tendency to enlarge the scope of our discipline by subsuming the theory of oscillations to general mechanics of the ship. One can further assume that the study of resistance and propulsion in a seaway will benefit tin the near future.from the general progress made in our field.

We expect an immediate stimulating effect of the theoretical work on model research and later on full scale investigations. Instead of relying on "practical" routine model tests only which frequently are "run" under inadequately defined conditions emphasis should be laid on experiments intended to give answers to clearcut questions. Because of the difficulty of the subject the combined theoretical and experimental approach deserves full attention. Although we cannot yet share Krylov's optimism quoted at the beginning there is sufficient evidence that concentrated efforts will furnish in a not too distant future useful information on the seagoing qualities of ships.

Obviously, our synopsis presents a lot of weak spots which are partly due to shortcomings of the present writer and partly to the task requiring a progress report over a definite time. It is probable that valuable work has been overlooked; some interesting topics have not been mentioned. The present writer expresses the hope that further contributions by members of our congress will fill out the gaps left by him.

Notations

A - area
A_o - area of load water line
$\bar{A}$ - dimensionsless amplitude
B - breath, beam
C - constant; Lewis inertia coefficient
D - constant
E - dimensionsless heaving force function
F - Froude number
F_ω - frequency parameter
G - center of gravity
H - beam - depth ratio
I - moment of inertia of the waterline
J - mass moment of inertia
K - constant
K_{33} K_{55} .... integrals
L - ship length) $L = M_x$
M - moment in general) $M = M_y$
N - damping coefficient) $N = N_z$
O - point of reference
P - force
S - surface
T - Kinetic Energy
U - speed of advance
X)
Y) force components
Z)

a - ampli

a - wave amplitude, constant

b - constant

c - spedd of wave

f - depth of immersion

g - gravity acceleration

h - lever

i = $\sqrt{-1}$

i) indices as subscripts
j)

k - wave number $\frac{2\pi}{\lambda} = \frac{\omega^2}{g}$, with subscripts - inertia coefficients

m - mass

m' - virtual mass

m - with subscripts: generalized added masses (added masses, added moments of inertia, mass coupling factors)

n - normal

p) pressure
q) angular velocity components
r)

t - time

u)
v) linear velocity components
w)

x)
y) coordinates
z)

α - waterline area coefficient
β - section area coefficient
δ - increment, phase angle
ζ - phase angle
[illegible] - wave slope
$\varkappa$ - with subscripts - inertia coefficients
λ - wave length
ν - frequency
ξ - Grims frequency parameter
ϱ - density
τ - time variable
$\tau_o \tau = \frac{U}{c}$
φ - angle of roll, velocity potential
χ - course (heading) angle
ω - frequency
ψ - angle of pitch
[illegible] - angle of yaw
Δ - weight displacement: Laplace operatot; increment
Φ - velocity potential
Ψ - pitching moment function

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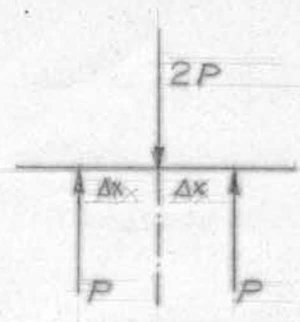
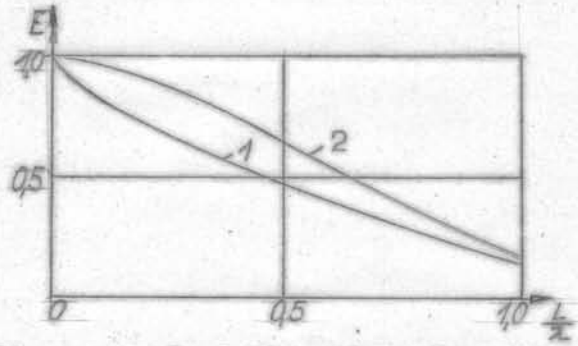
Fig. 3



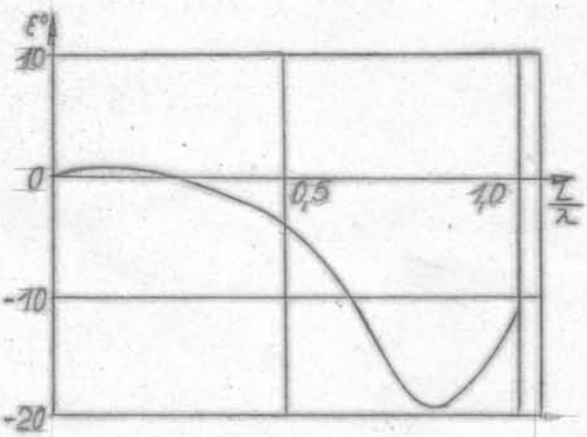
"Force dipol"

Fig.8



Dimensionless heaving function E.
2- calculated following Krylov
1- experimental curve

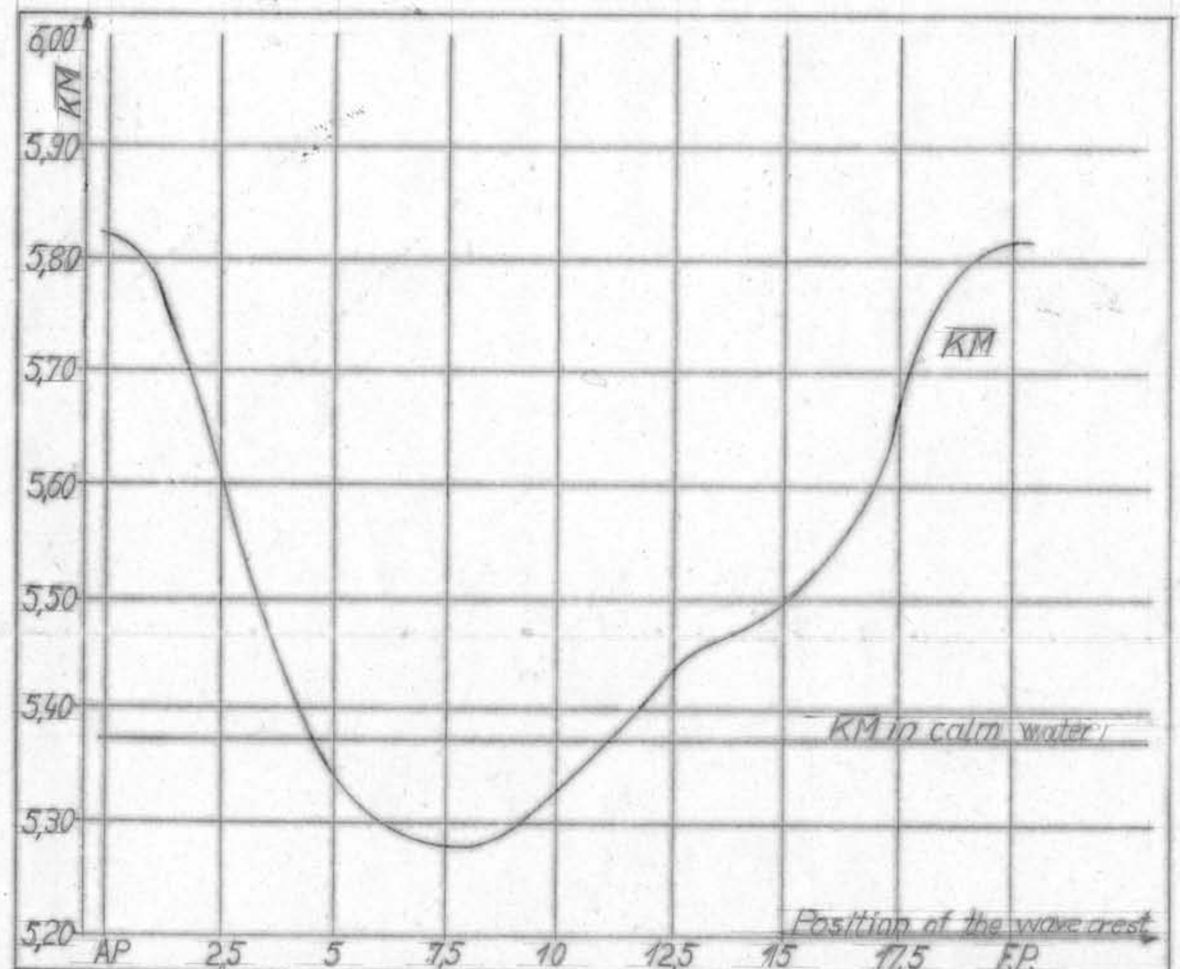
Fig. 9



Phase angle ε between the exciting force and the wave.
Erratum: Please, cinsert page 36 line 5 ε instead of ε5!

Figures 5, 7, and 10 have been omitted in this preliminary edition.

Fig. 11
Variation of the distance $\overline{KM}$ as a function of the position of the wave crest along the ship following a simplified calculation by J. Dieudonné.



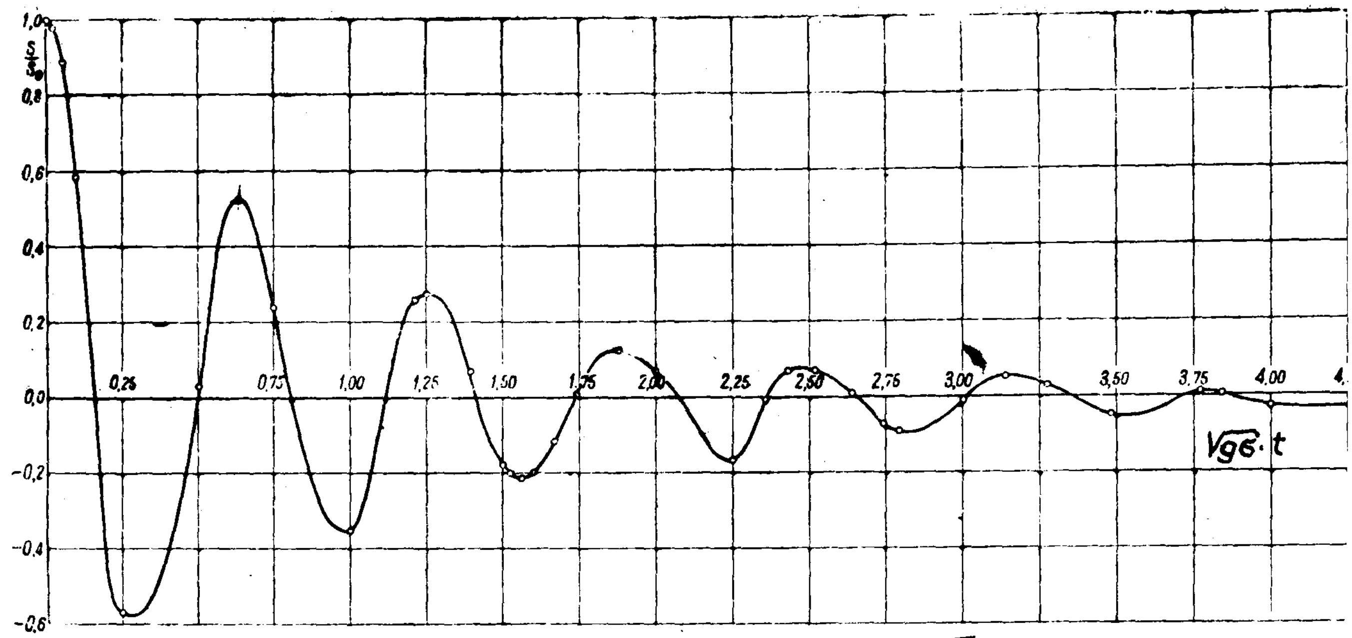
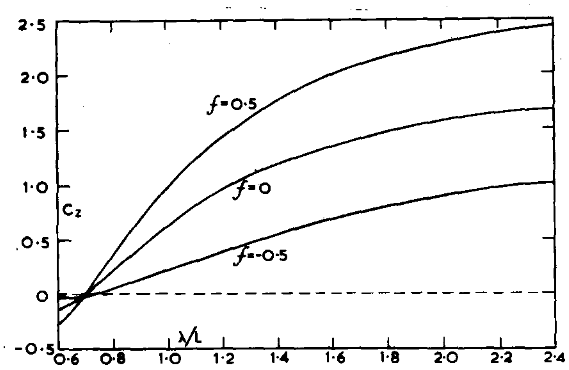
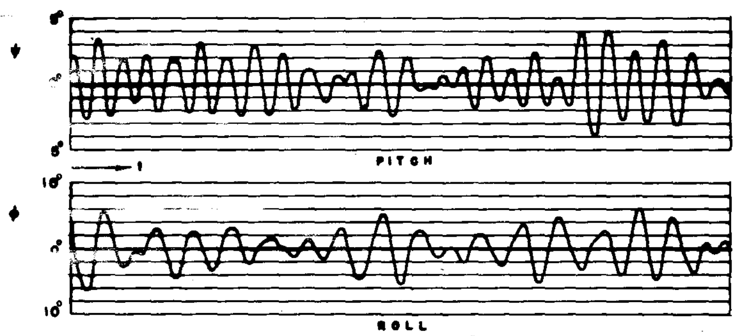


Fig. 2



—HEAVING FORCE COEFFICIENT FOR VARYING λ/L; *f* POSITIVE AGAINST WAVES, NEGATIVE WITH WAVES

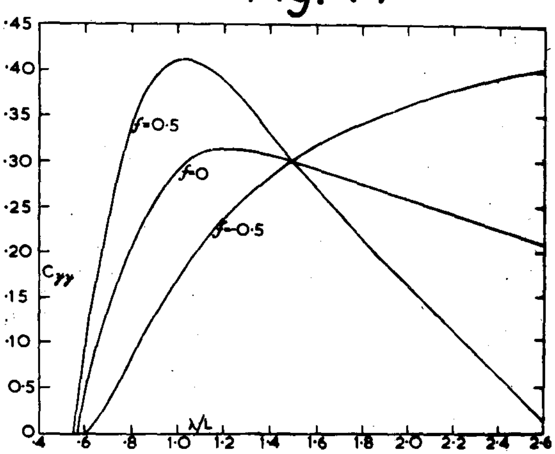
Fig. 13



—SIMULTANEOUS RECORD OF ROLL AND PITCH FOR A SHIP UNDERWAY IN A SEAWAY

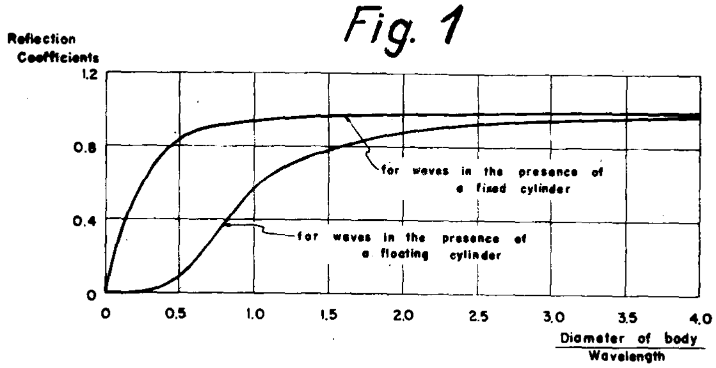
Fig. 12

Fig. 14



—PITCHING MOMENT COEFFICIENT FOR VARYING λ/L; *f* POSITIVE AGAINST WAVES, NEGATIVE WITH WAVES

Fig. 1



$$\text{Reflection coefficient} = \frac{\text{Amplitude of reflected wave}}{\text{Amplitude of incoming wave}}$$

A comparison of the coefficient of reflection of an incoming wave for a fixed cylinder and a freely floating cylinder.

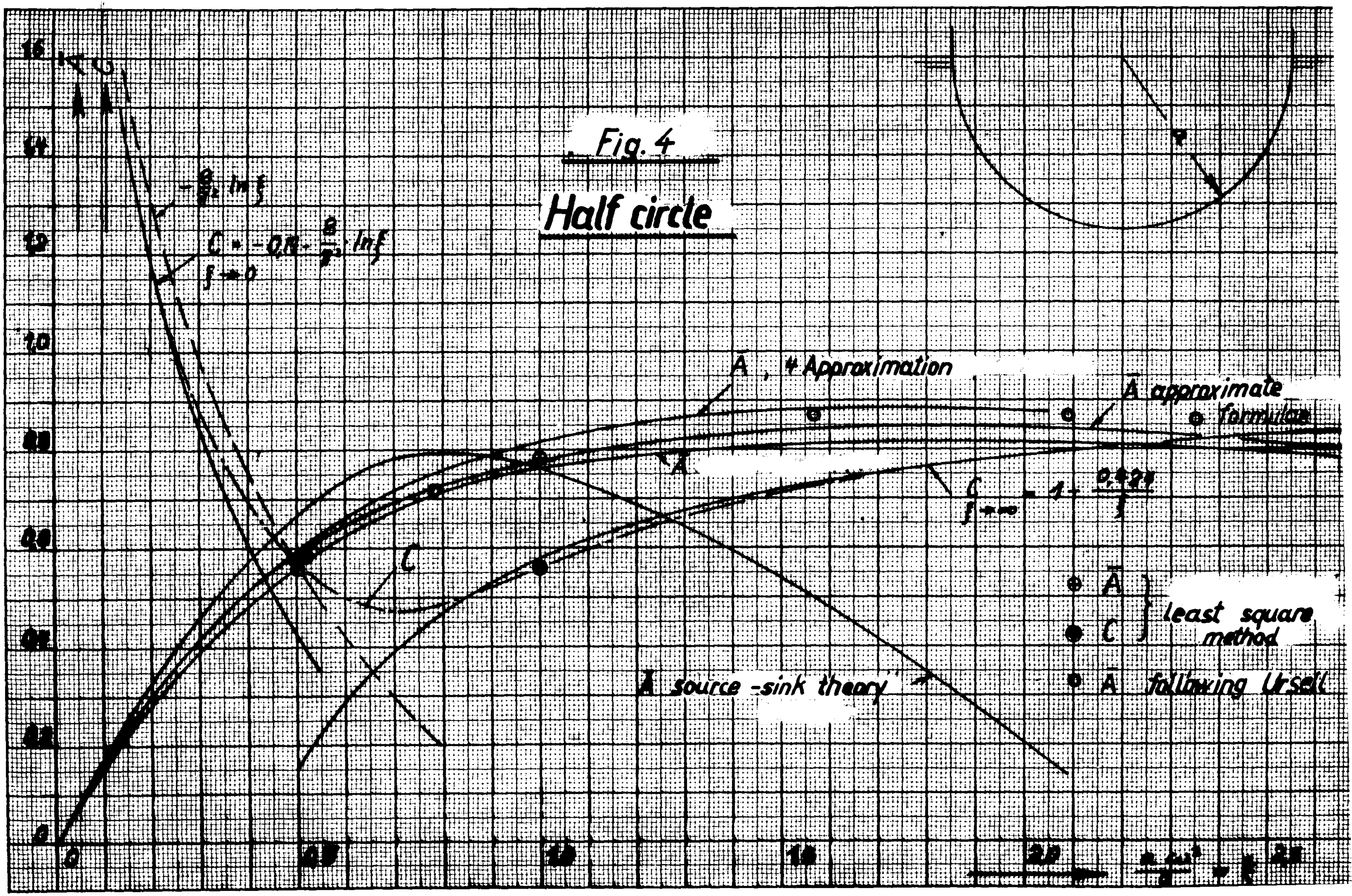


Fig. 4
Half circle
$-\frac{8}{\pi^2}\ln\xi$
$C_{\xi\to 0} = -0.11 - \frac{8}{\pi^2}\ln\xi$
$\bar{A}$, 4 Approximation
$\bar{A}$ approximate formulae
$\bar{A}$
C
$C_{\xi\to\infty} = 1 - \frac{0.424}{\xi}$
$\bar{A}$ source -sink theory
$\bar{A}$
C
least square method
A following Ursell
0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

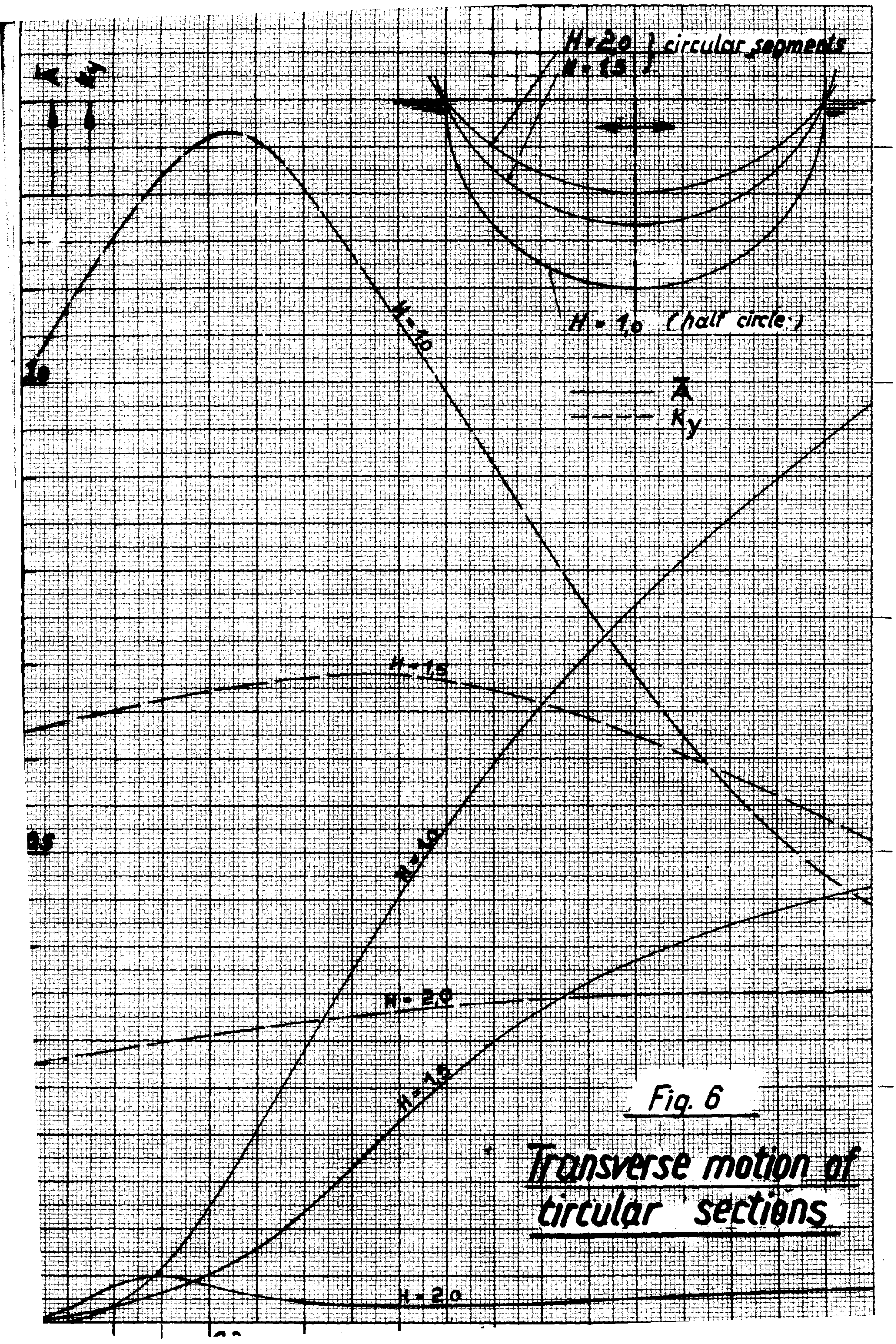
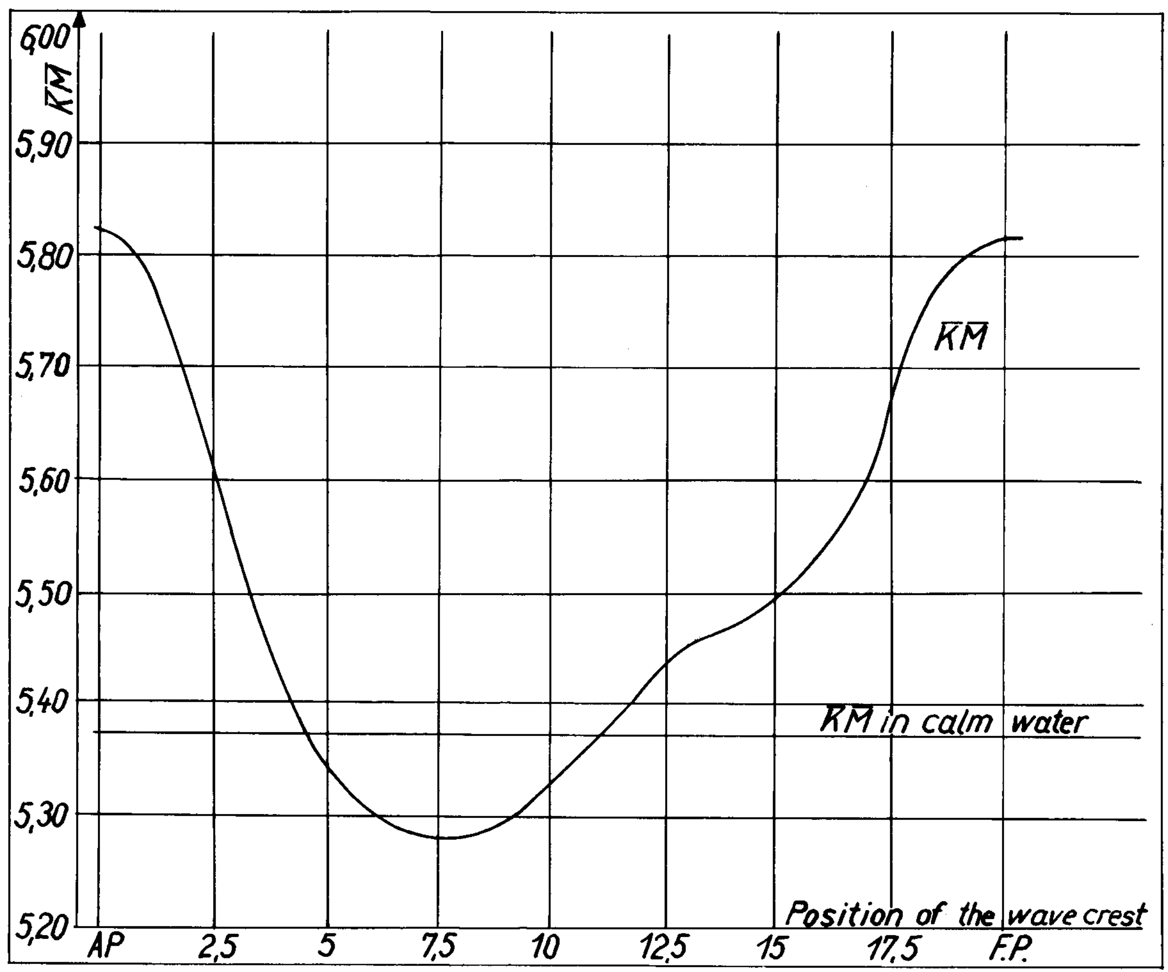


Fig. 6

Transverse motion of circular sections

Fig. 11

Variation of the distance $\overline{KM}$ as a function of the position of the wave crest along the ship following a simplified calculation by J. Dieudonné.



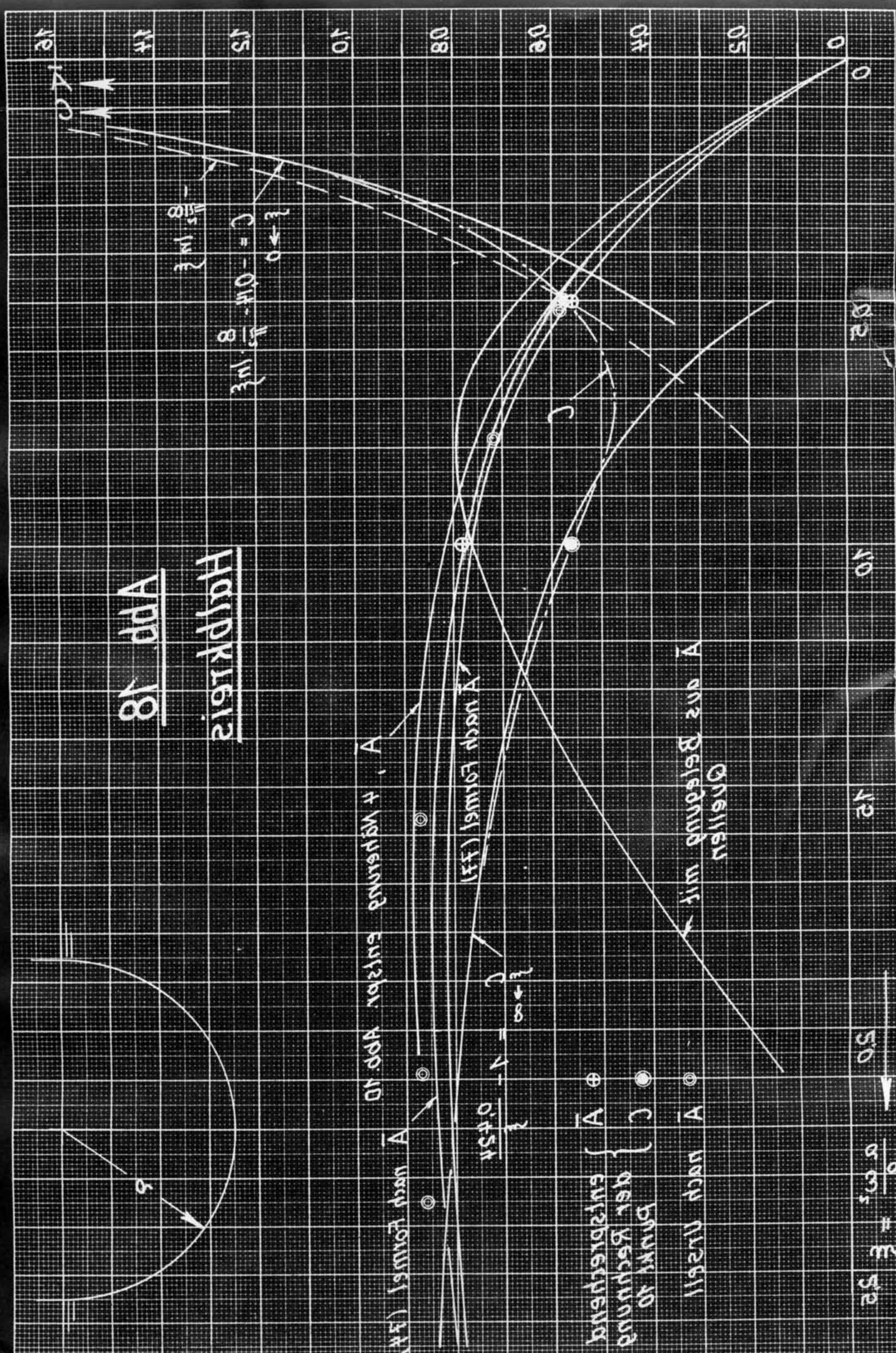


Abb 18
Halbkreis
Ā nach Formel (44)
Ā + Näherung entspr. Abb 10
Ā nach Formel (44)
Ā aus Belegung mit Quellen
entsprechend der Rechnung Punkt 10
Ā nach Ursell

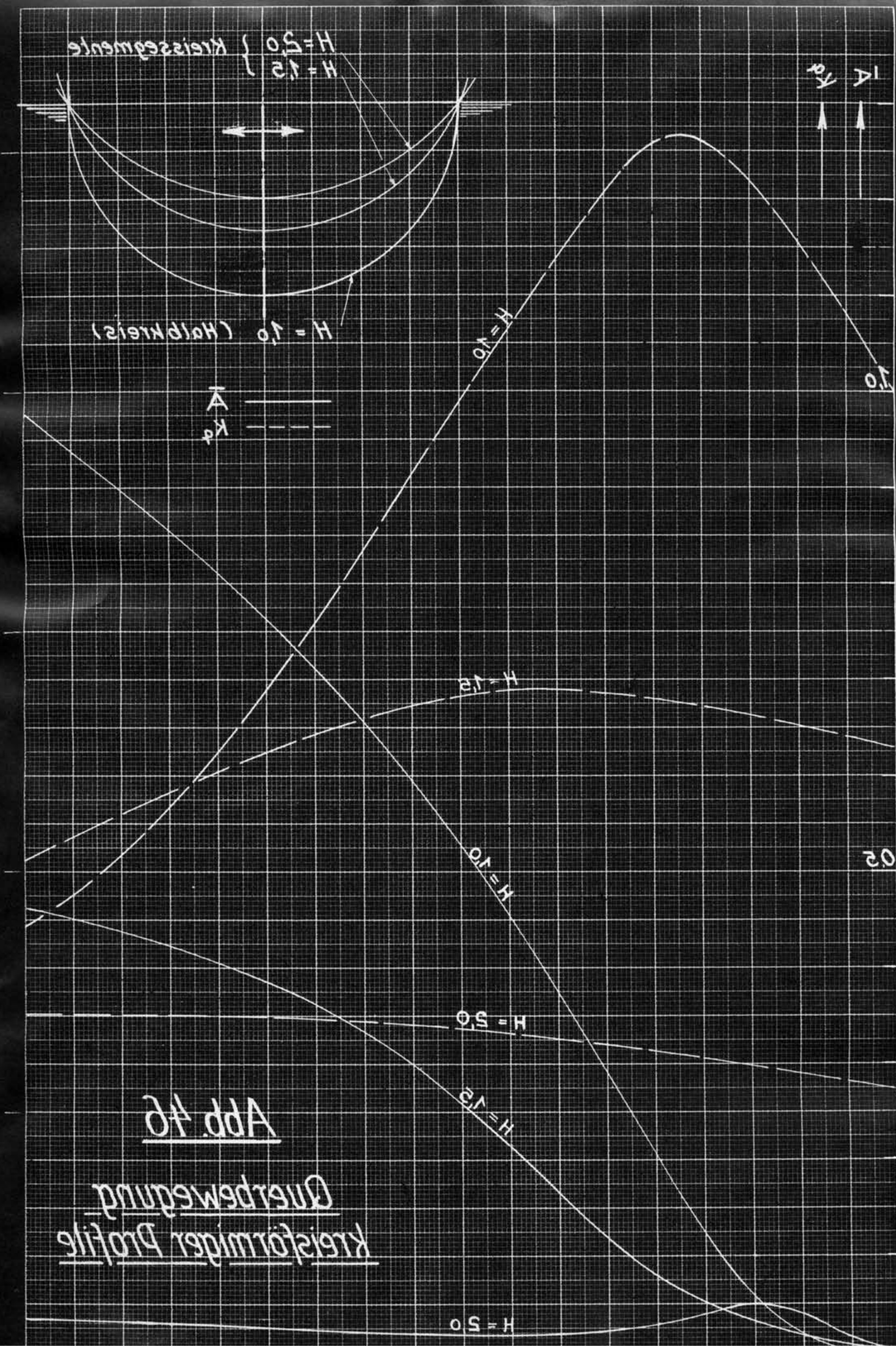


Abb. 46
Querbewegung
Kreisförmiger Profile

54 6.

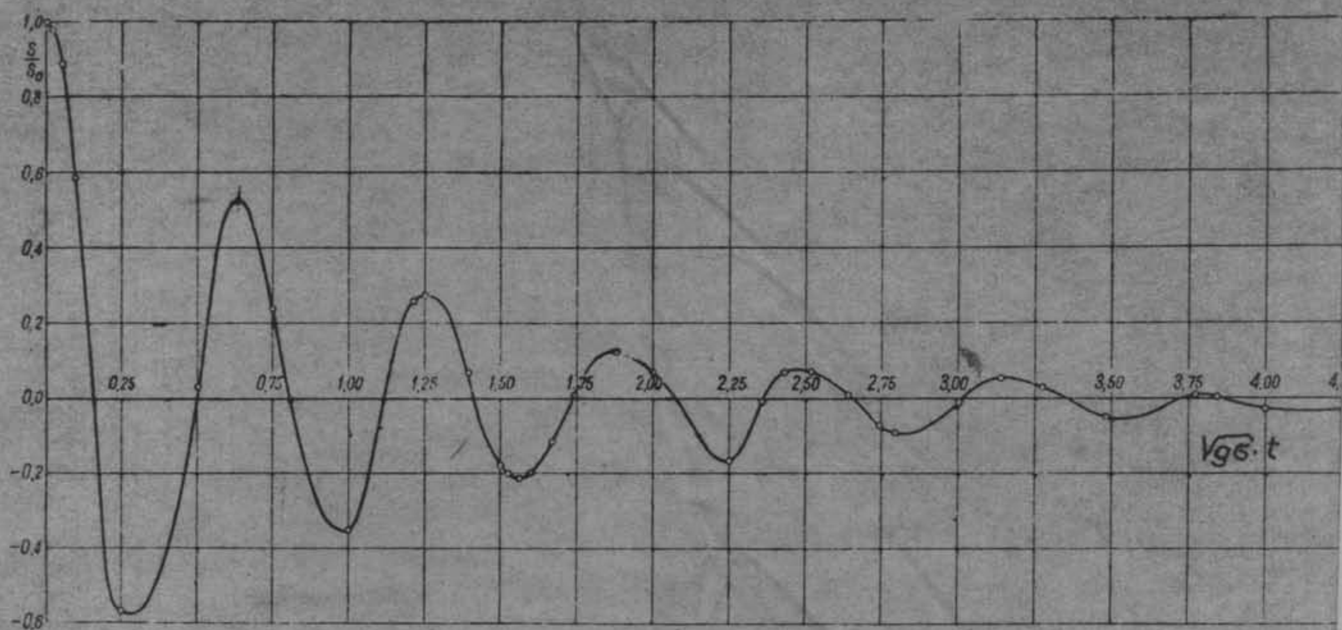
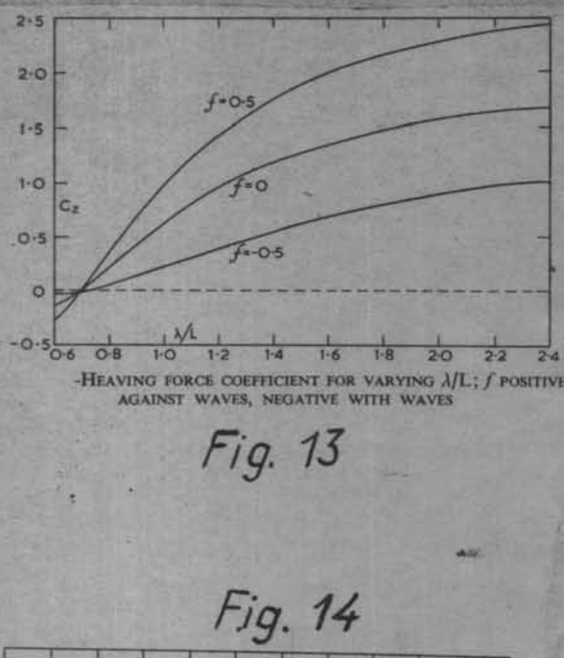
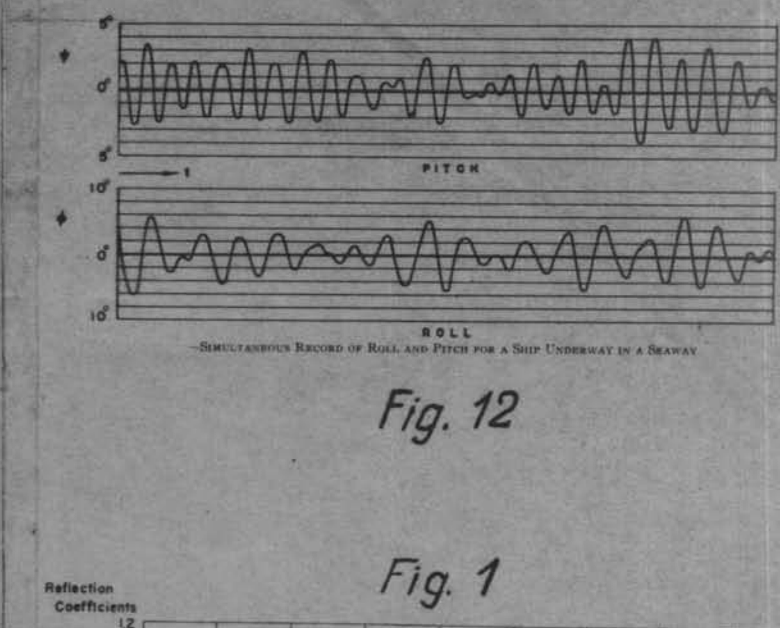


Fig. 2



-HEAVING FORCE COEFFICIENT FOR VARYING λ/L; f POSITIVE AGAINST WAVES, NEGATIVE WITH WAVES

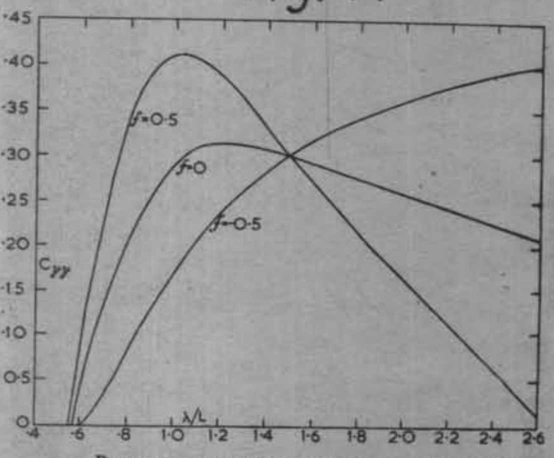
Fig. 13



-SIMULTANEOUS RECORD OF ROLL AND PITCH FOR A SHIP UNDERWAY IN A SEAWAY

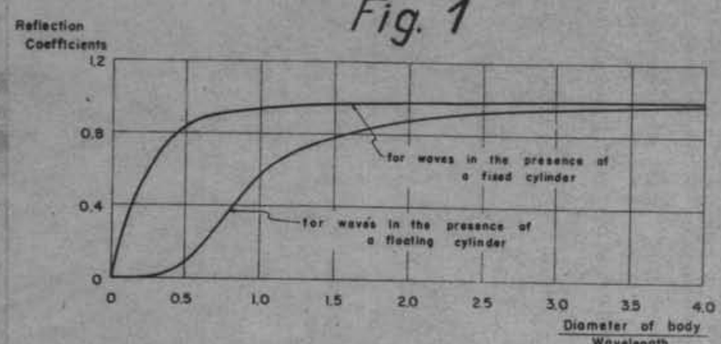
Fig. 12

Fig. 14



—PITCHING MOMENT COEFFICIENT FOR VARYING λ/L; f POSITIVE AGAINST WAVES, NEGATIVE WITH WAVES

Fig. 1



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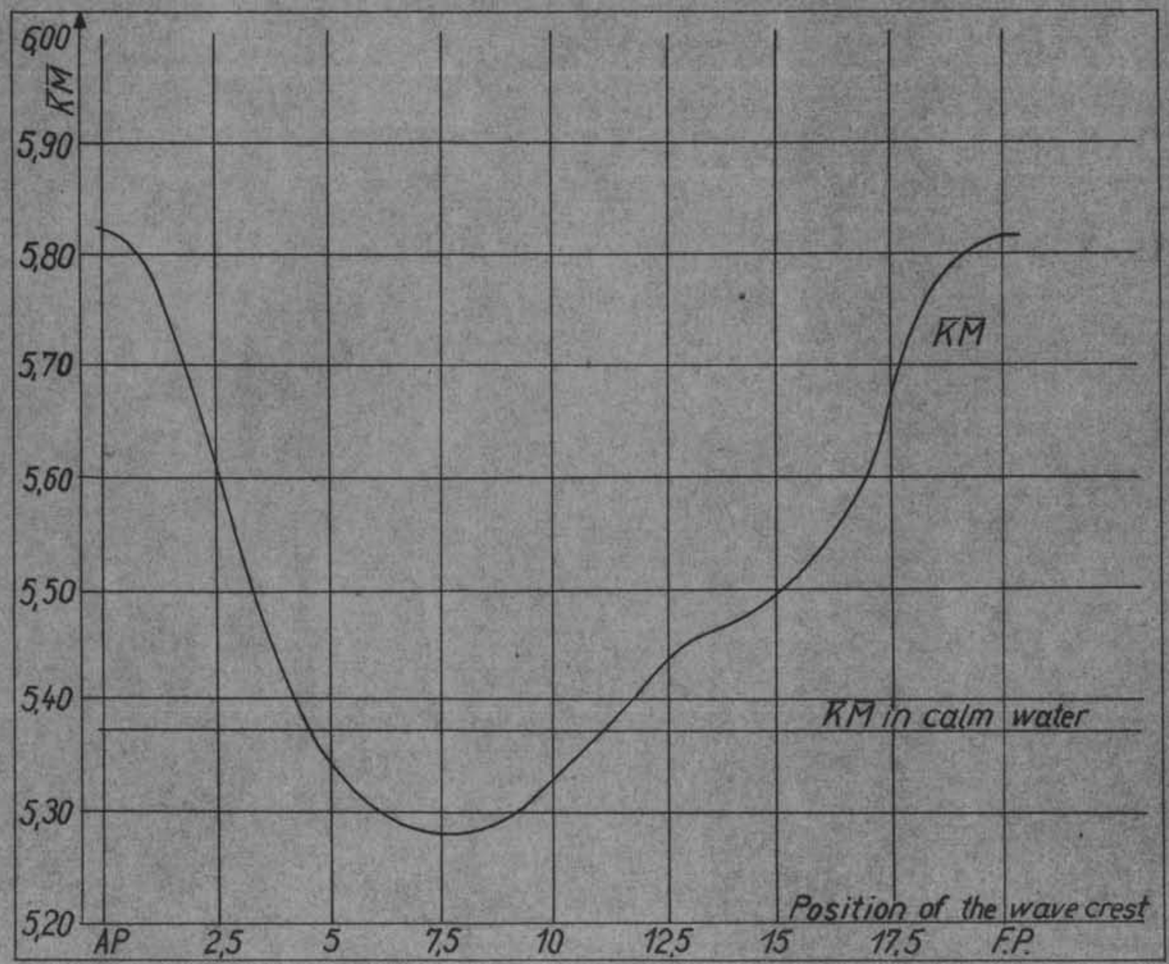
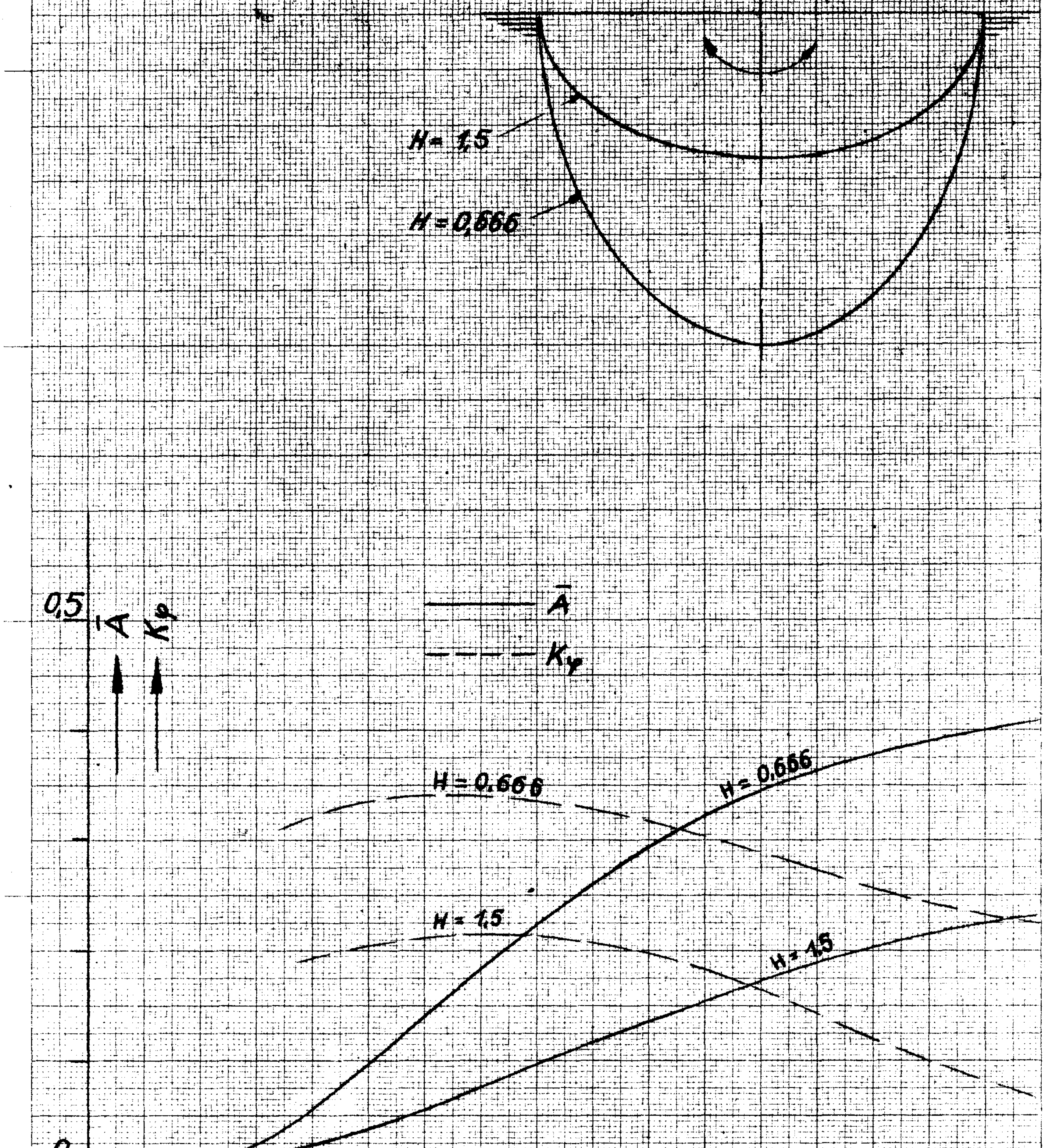
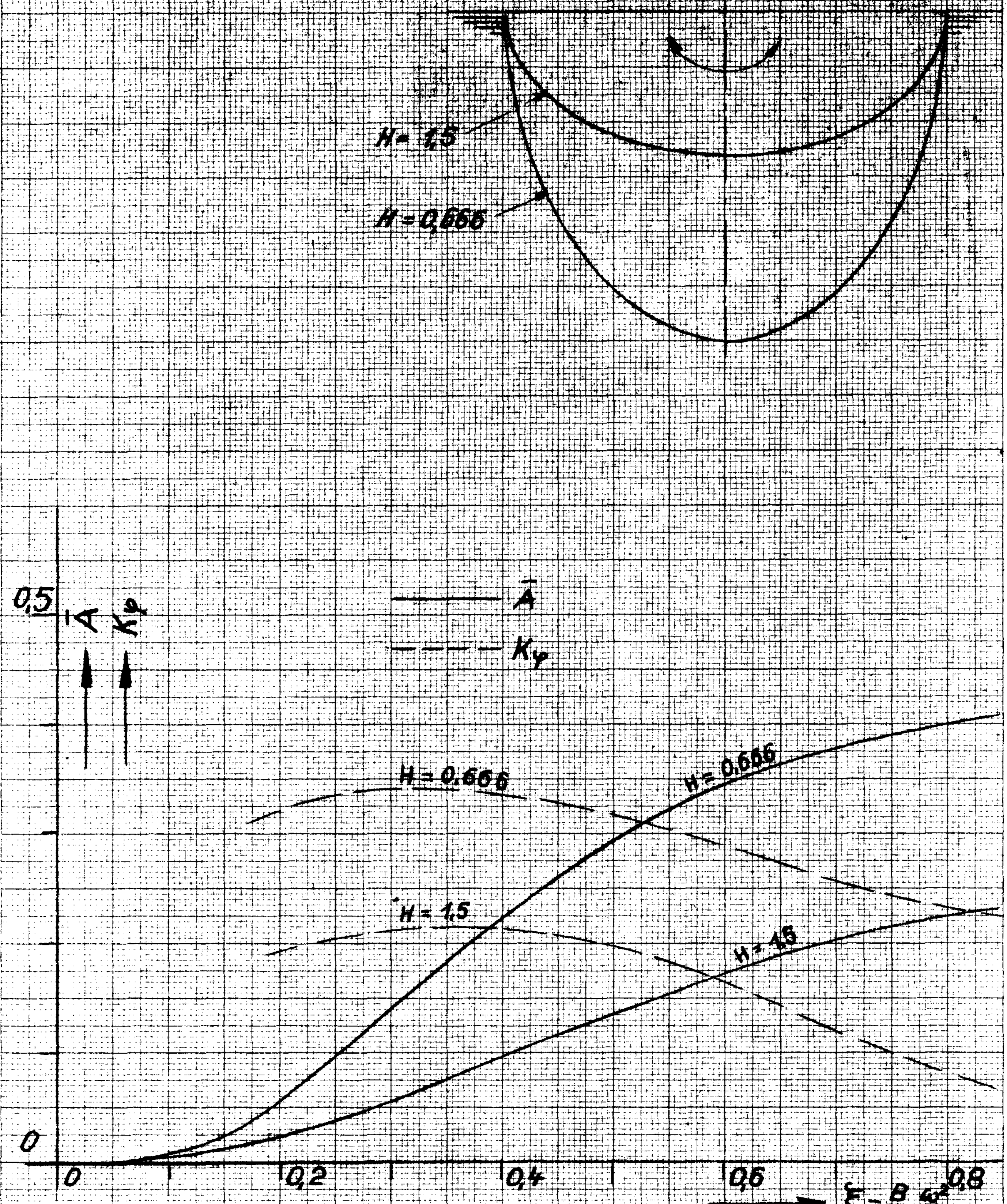


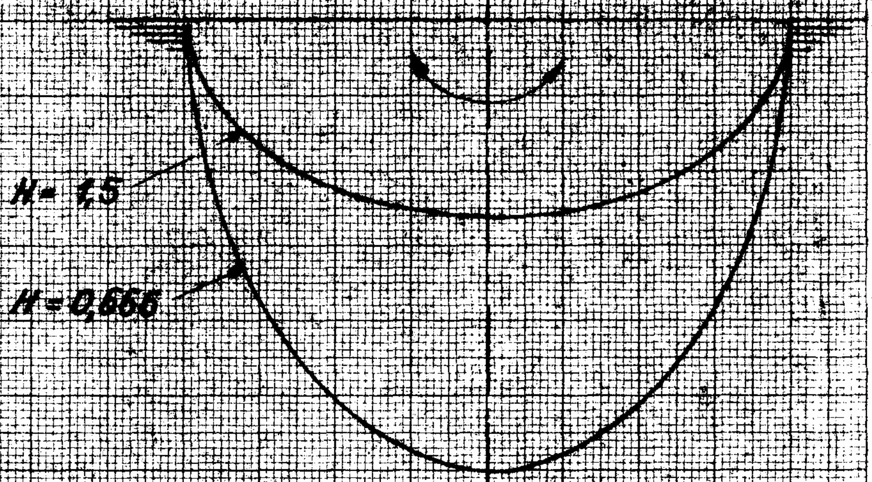


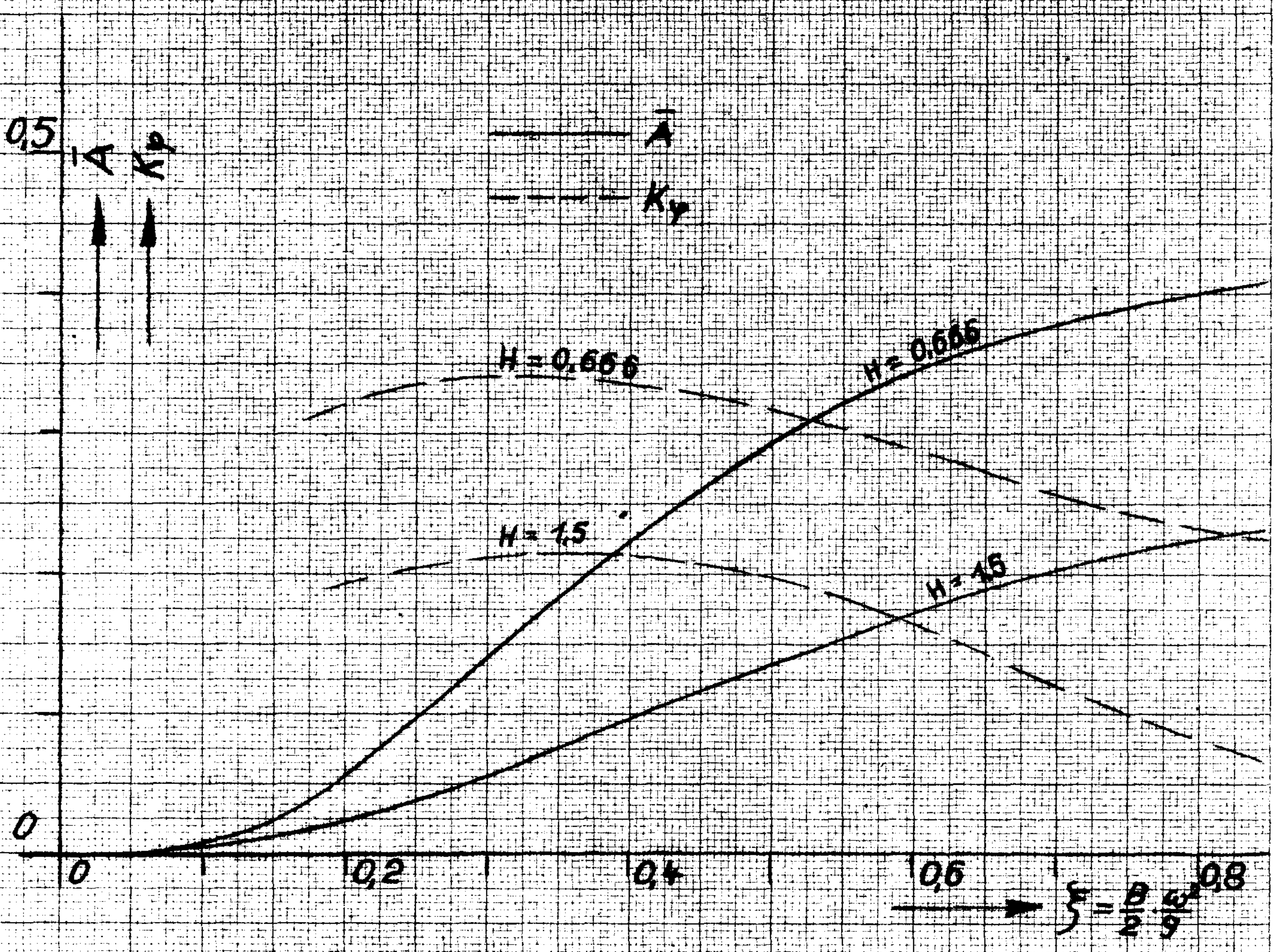
Rotation of elliptic profiles

A 4 210 x 297 mm fig 7



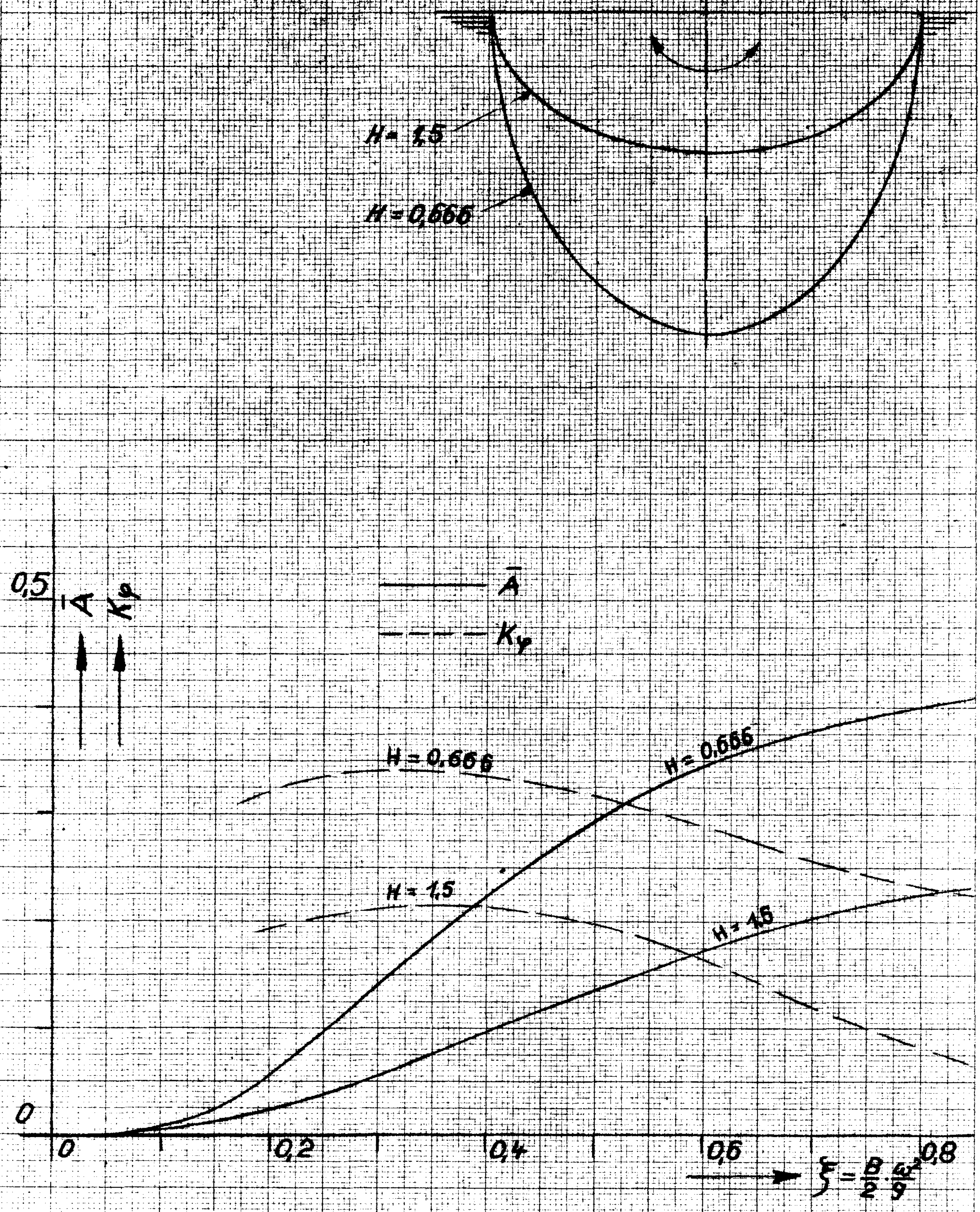
Rotation of elliptic profiles





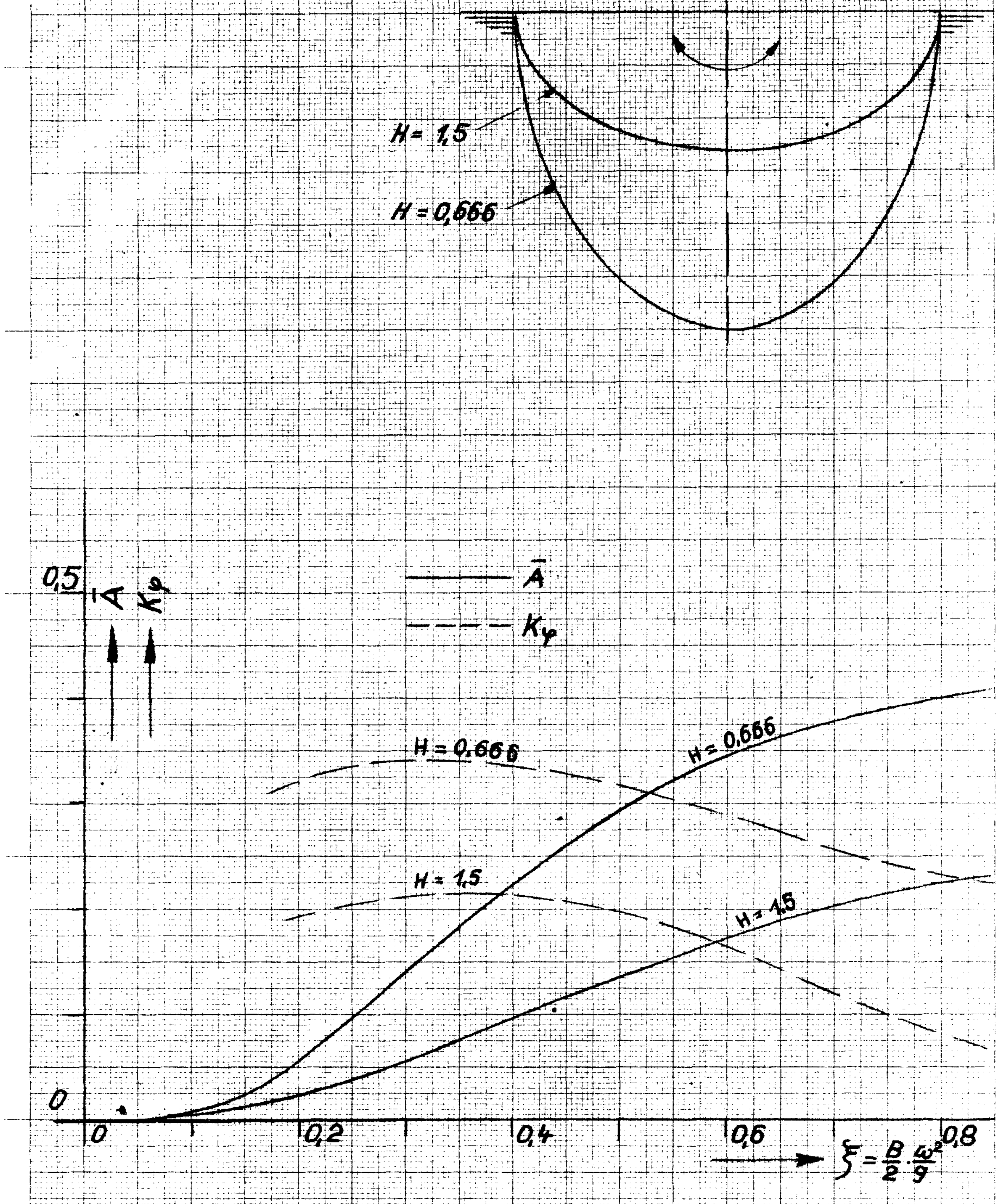
Rotation of elliptic profiles

Fig 1



Rotation of elliptic profiles

 Fig 7



Rotation of elliptic profiles

 Fig 7