ON N. F. KUDRIANCEV AND E. G. NIKIFOROV's ARTICLE " ABOUT THE CHOICE OF EFFECTIVE CONSTRUCTIONS OF THE MEASUREMENT INSTRUMENTS AND THEIR OPTIMAL PARAMETERS FOR THE MEASUREMENT OF SEA-CURRENTS IN THE UNDULATING WATER LAYER "

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SUMMARY

The author first summarizes and then analyses the 1964 paper of Mr. N.F. KUDRIANCEV and Mr. E.G. NIKIFOROV concerning the construction of current-meters for the measurement of sea-currents.

The conclusion reached by KUDRIANCEV and NIKIFOROV regarding the unfitness of the anemometric current-meters for measuring currents in undulating water is entirely supported by the author of the present article.

As far as current-meters of the reversible type are concerned, some inaccuracies have been proved concerning the way they present the field of velocities of undulating water. Consequently current-meters of this type as applied today are not likely to lead to objective results.

Finally the present author proposes some lines along which observations of sea-currents should be carried out to attain results approximately representing the actual conditions.

1. — INTRODUCTION

The above-mentioned article was published in *Okieanologia,* No. 3, 1964, a publication of the Soviet Academy of Sciences, Moscow, pages 479 to 487. The authors concentrate their attention at the beginning of the article on the great number of methods used for observations of sea-currents. What is, however, most interesting, and worthy of note, is that the authors observe that doubts arise each time among research workers when it comes to dealing with the observation data on sea-currents obtained from the upper surface zones during even quite moderate undulation. These doubts seem to be the reason why there are large deviations in the data concerning the current's direction, and why sometimes considerable velocities are left unexplained, and also the character of their changes in relation to the increase of depth. All this makes us speculate on both the correctness of the indications of the measurement devices and on the complexity of the current structure.

Since these problems arise from observations which usually take place in wind and are therefore exposed to the wind action which causes undulation, the authors have considered the conditions in which the measurement instruments work in the upper surface sea zone, and primarily the structure of the field of velocities of undulating water.

Undulating water leads to oscillation of the craft (a ship, floating station, etc.) carrying the measurement equipment, causing a deterioration in their working conditions and some substantial errors in the measurements of the velocity and the direction of the current.

However, since the existing measurement devices in principle record only the horizontal components of the velocities, it will be sufficient in this case, according to the authors, to consider only the horizontal projection of the velocity field structure. The horizontal plane of the vectors is shown in figure 1, where $\vec{v}_t$ expresses the vector of the current, $\vec{u}_0$ and $-\vec{u}_0$ the extreme positions of the horizontal components of the orbital velocities, whilst M denotes the corresponding extreme positions of the vector representing the geometrical sum $\vec{v}_t + \vec{u}_0$ and $\vec{v}_t - \vec{u}_0$.

During the wave period τ the horizontal component u_z of the orbital velocity is expressed, according to the authors, by :

$$u_z = \frac{\pi h}{\lambda} e^{-k'z} \cos \sigma t = u_0 \cos \sigma t$$

where $k' = \frac{2\pi}{\lambda}$, $\sigma = \frac{2\pi}{\tau}$, h is the amplitude of the wave, λ is the wave length and z the ordinate, reckoned from under the sea surface at rest.

The authors later determine the magnitude of vector M, as well as the angle between it and the direction of the wave propagation. In this way the current resultant M is a assumed to change continuously both its magnitude and its direction.

At this point the authors complete their analysis of the structure of the field of the velocities in an undulating water layer and proceed to anlayse the functioning of the speedometers in mechanical current-meters.

The authors divide the meters into two groups :

1. Reversible (of mill-like type), whose direction and speed of rotation depend on their position in relation to the current's direction;
2. Irreversible (of anemometric type), where the direction and the speed of rotation are not dependent on their position in relation to the direction of the current.

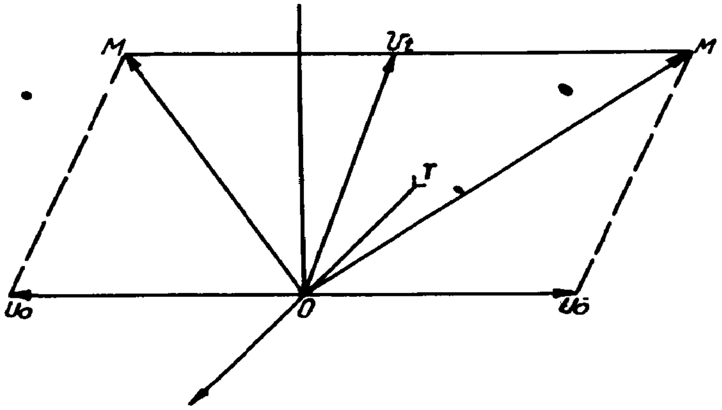


FIG. 1. — Horizontal plane of the field of undulating water velocities

The reversible meters record the resultants of the water displacement in a given direction during a defined interval of time independently of the law of alternations in flow velocity and of the direction of the current. The irreversible meters always record the velocity modulus whatever the law of velocity alternation may be.

The ideal device for the measurement of flow velocity, according to authors, will be one which in a stream subject to change in direction would adopt a position agreeing with the direction of the current vector and which during the time the measurement is performed would remain motionless in space, its speedometer recording the resultant flow of water in the direction of the vertical plane of symmetry of the device.

Concerning reversible current-meters, it has been assumed that these record only the velocity component of the current which is parallel to the symmetry plane of the device, itself parallel to the direction of the flow velocity. Projecting M in figure 1 on the current direction v_t at time t the projection will be $M_t = v_t + u_0 \cos \phi \cos \sigma t$, where ϕ is the angle between the direction of the current and the direction of the wave propagation. The resultant stream in the direction of the current vector, during period τ of the wave, will be expressed by :

$$\frac{1}{\tau} \int_0^\tau M_t \, dt = v_t$$

Thus the mean velocity of the stream for a wave period is equal to v_t. Hence it is evident that reversible meters satisfy the requirements of an ideal current-meter.

As regards the irreversible meters, the authors have made a number of mathematical transformations on the basis of which they come to the conclusion that current-meters with irreversible meters should not on any account be used for the measurements.

In their analysis of the irreversible meters the authors have assumed that the symmetry plane of the device takes a position precisely oriented in the direction of the current. In fact, however, under the influence of the orbital movement of water molecules, in reality the device commences *an oscillating motion in the horizontal plane* whenever the horizontal component of the rotation momentum is equal to zero.

Preserving this condition, the authors introduce an appropriate differential equation for the horizontal oscillation of the device's plane of symmetry. After making an analysis the authors come to the conclusion that in the conception of an ideal current-meter for an undulating water zone the condition $K/J = 0$ should be fulfilled, K being the resistance coefficient and J the moment of inertia of the device. It is difficult to obtain the ratio $K/J = 0$ accurately in actual practice as the device takes its position according to the stream by means of a rudder. To obtain the required ratio it would be necessary to design and construct a surface with a moment about the axis of rotation equal to zero, and such a device would not be able to record the changes in direction of the velocity vector of the stream.

Finally the authors summarize the basic requirements for current-meters in undulating water zones. The first requirement is that the speedometer should in all cases be reversible. In addition it is very important that there should be a lack of rapid oscillation of the device in the horizontal plane as this conditions the working of these meters. This requirement is met by creating suitable working conditions for the current-meter's direction indicators, and this can only be achieved by diminishing the ratio K/J, i.e. mainly by increasing the device's moment of inertia. The next requirement concerns the removal of the tendency of the device to oscillate in the vertical plane which occurs when the moment of the device's surface projection on the horizontal plane is equal to zero, or when the moments of inertia for the parts lying both before and beyond the suspension point have equal values.

Lastly attention should be given to the " specific gravity " determined by the quotient of the division of the device's weight in air by the weight of water it displaces. The specific gravity should be considerably greater than unity, for otherwise the acceleration of the device in alternating streams will exceed the acceleration of the streams themselves which leads to a strong increase in the oscillating movement in the vertical and the horizontal planes, as well as to a considerable deterioration in the functioning of the direction indicators (in particular the magnetic ones).

According to the authors, a device will satisfy the requirements of an ideal current-meter when it is insensitive both to the changes in direction of a stream in the horizontal plane and to the vertical displacement of the device. The current-meter must have the shape of a toroidal ring.

At the end of their article the authors underline the fact that the problems they have considered have not, as far as they know, yet been published anywhere. Furthermore, the lack of choice of appropriate and theoretically proved general characteristics may in the process of construction lead to (and in some cases has already led to) a series of basic drawbacks to the devices which considerably worsen their application and also the reliability of the data obtained by means of these devices. These facts should be taken into account when considering the numerous conclusions on current observations (e.g. the works of PANOV and OZMI-

DOROV) because the indications given by wrongly designed devices may not in reality correspond to the actual stream structure.

The authors arrive at the following conclusions :

1. Since the undulating water layer is exposed to wind forces and its thickness varies between some tens up to several hundred metres such factors as pulsation of the flow velocity and the oscillation in direction of the flow vector may affect the working of mechanical current-meters.

2. The first of these factors makes it necessary to employ current-meters of the reversible type, for otherwise the device will record not the current velocity but the modulus of the velocity of the stream.

3. The second factor mentioned leads to a strong short oscillation of the device in the horizontal plane and to large deviations in the indications of the direction recorder. This may be avoided by selecting the appropriate K/J ratio and the right weight for the device.

4. To obtain correct results in undulating water current measurements, the measuring devices employed for this purpose should be constructed to satisfy special requirements. The degree of satisfying these requirements must be taken into account when analysing the existing observations made with these instruments.

2. — MULTIPLICITY OF THE METHODS OF OBSERVING CURRENTS

An undoubted merit of the authors is that they pay attention to various ambiguities arising in the working out of their data on sea-currents. At the present time there are actually a great number of means for determining both the velocity and the direction of currents. Unfortunately, all the methods so far applied either show very great errors, or are likely to give quite false results. This has already been proved in 1959 [3] by a series of laboratory and field experiments performed at the Institute for Hydraulic Engineering at the Polish Academy of Sciences in Gdansk.

It seems that the authors have not heard about constructing an active drift anchor or an universal float [6]. Both of these are simple in design, differing, however from others now in use in that they indicate the direction of the sea-current desired by the observer, and thus they prove quite evidently that it is not reasonable to use any kind of float for the measurement of sea-currents. Only two of the many measurement methods seem to furnish objective results, and only provided that certain requirements which will be discussed in the following paragraph are satisfied.

3. — THE FIELD OF VELOCITIES OF AN UNDULATING WATER LAYER

Analysing the work of current-meters, the authors rightly pay attention to the field of velocities of an undulating water layer. Unfortunately they make the mistake of considering the field of velocities only in the horizontal projection. When, however, we take into account the vertical cross section of the field of velocities obtained by placing the plane parallel to the wave propagation some orbital velocities of different magnitude in time will occur, acting at a point upon the axis of the z ordinates below the calm water level. In figure 2 point A has been marked on the axis of the z ordinates below the water level at rest. At this point, at the time it passes through the wave trough, a water molecule A_1 will have orbital

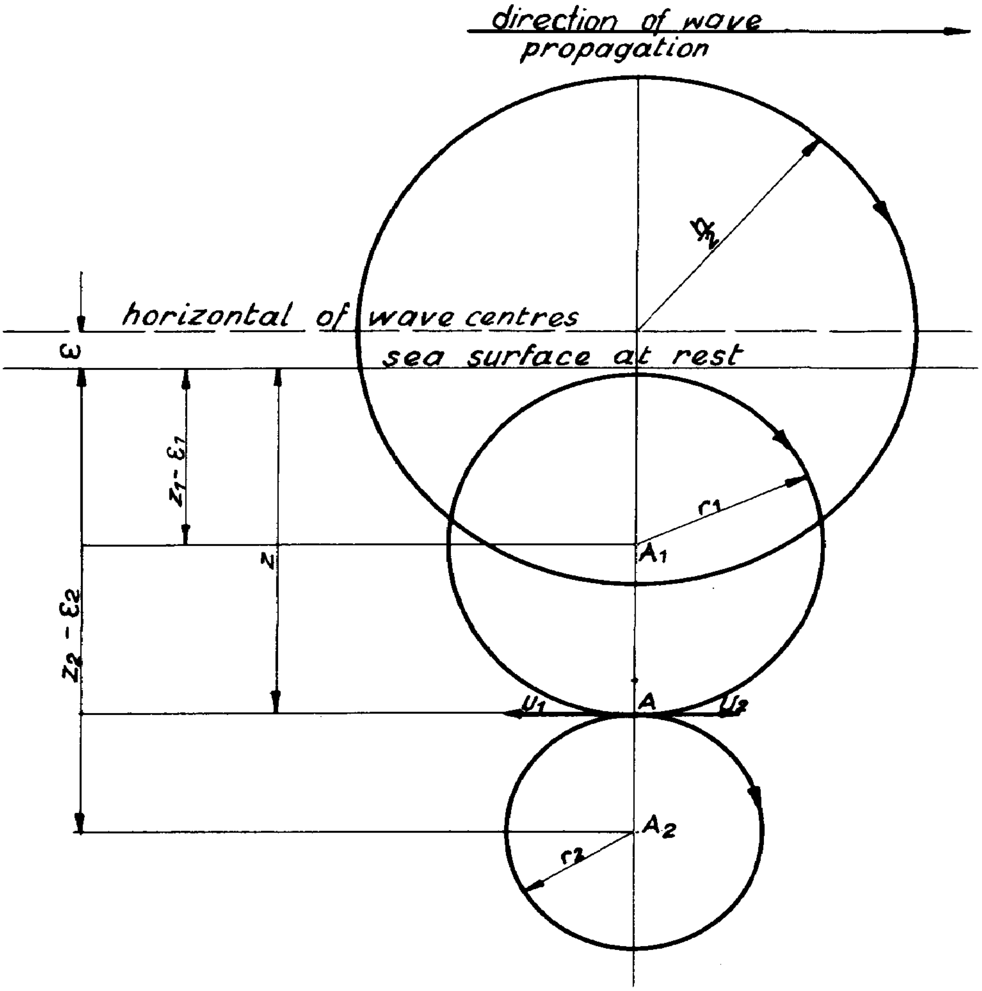


FIG. 2. — Vertical cross section of the field of undulating water velocities

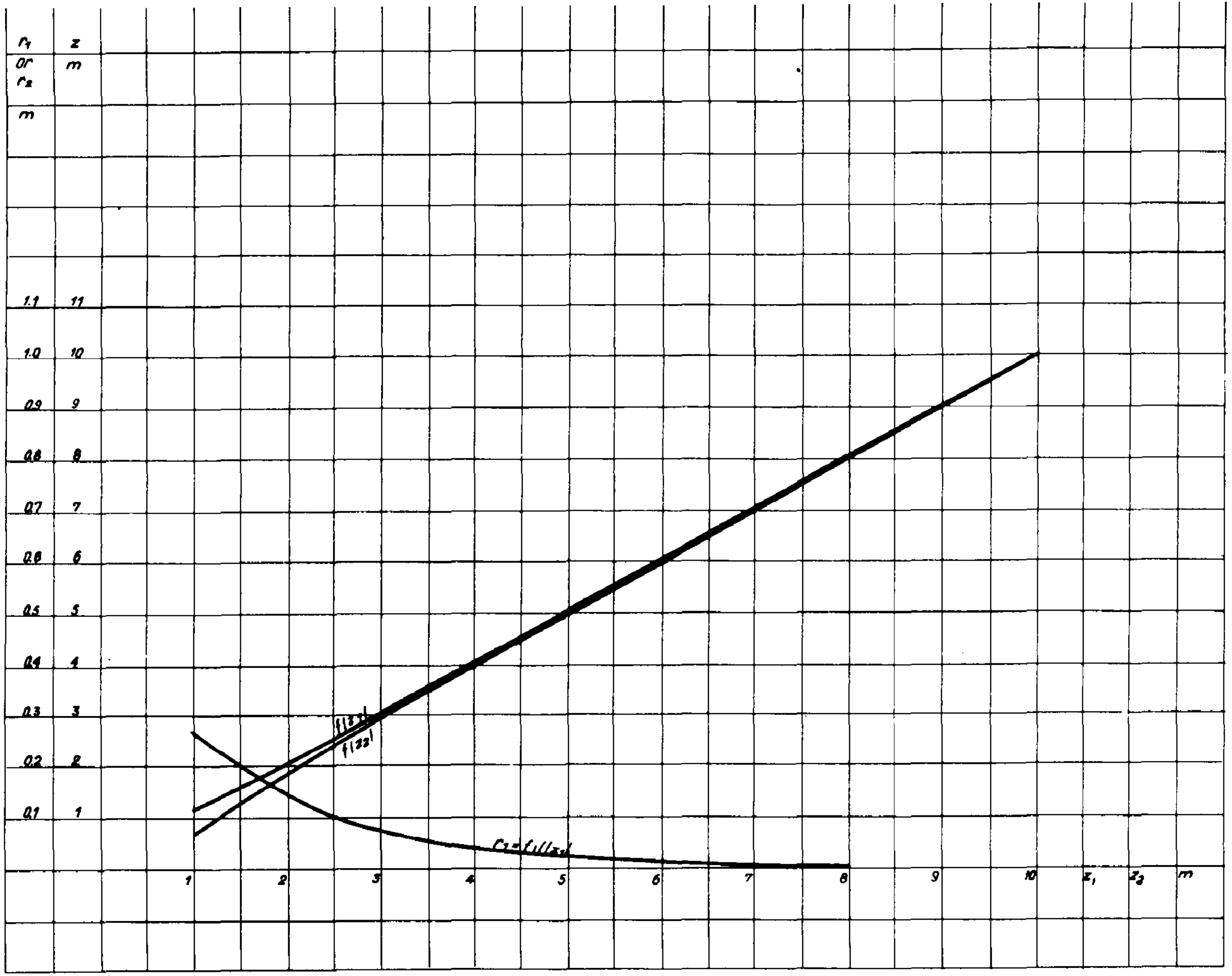
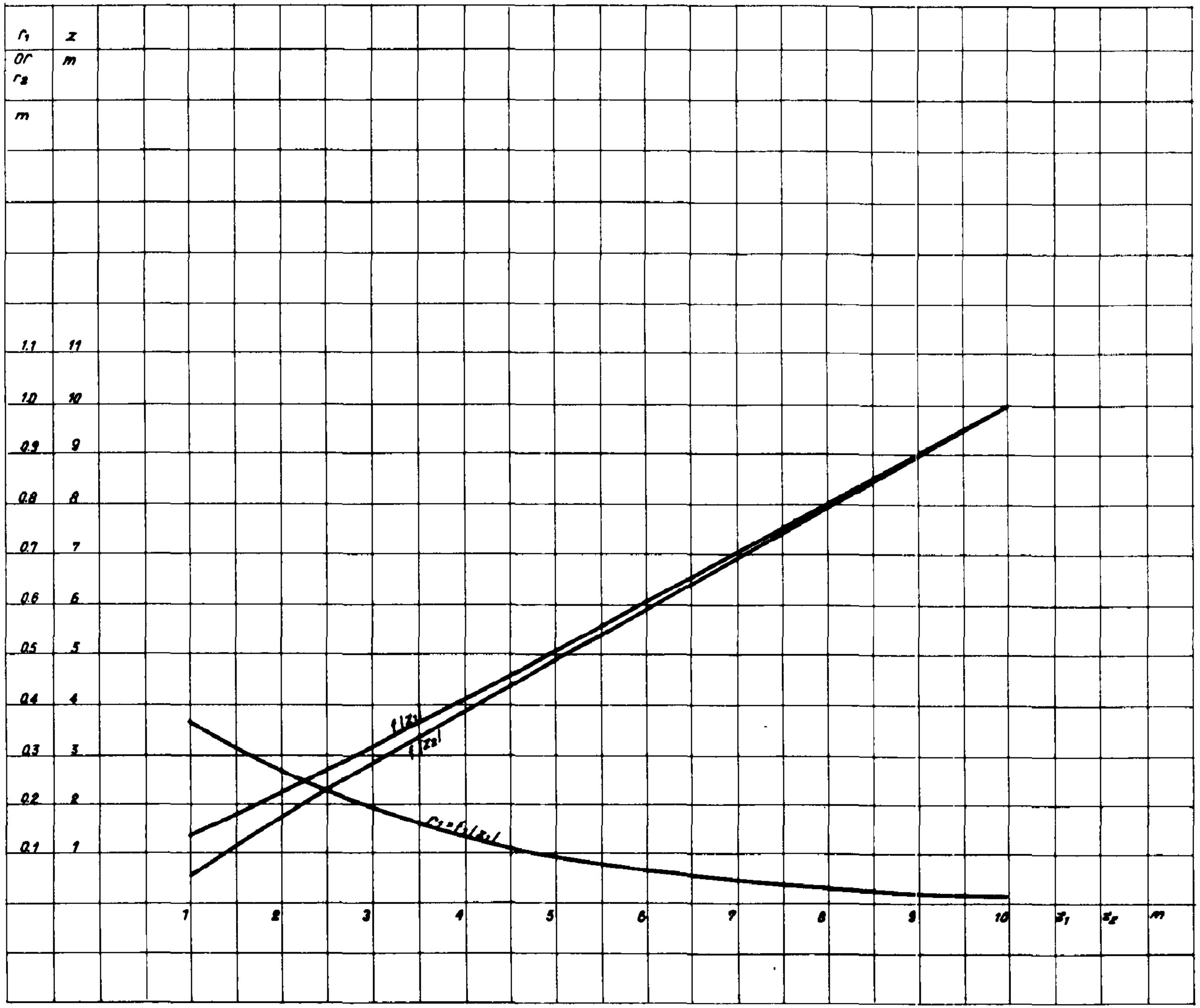


FIG. 3. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2 as a function of z_1 or z_2, for a wave of $\lambda = 10$ m, $\tau = 2.53$ s and $h = 1$ m


r_1 or r_2
m
z
m
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
11
10
9
8
7
6
5
4
3
2
1
$f(z_1)$
$f(z_2)$
$r_1 = f_1(z_1)$
1
2
3
4
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6
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z_1
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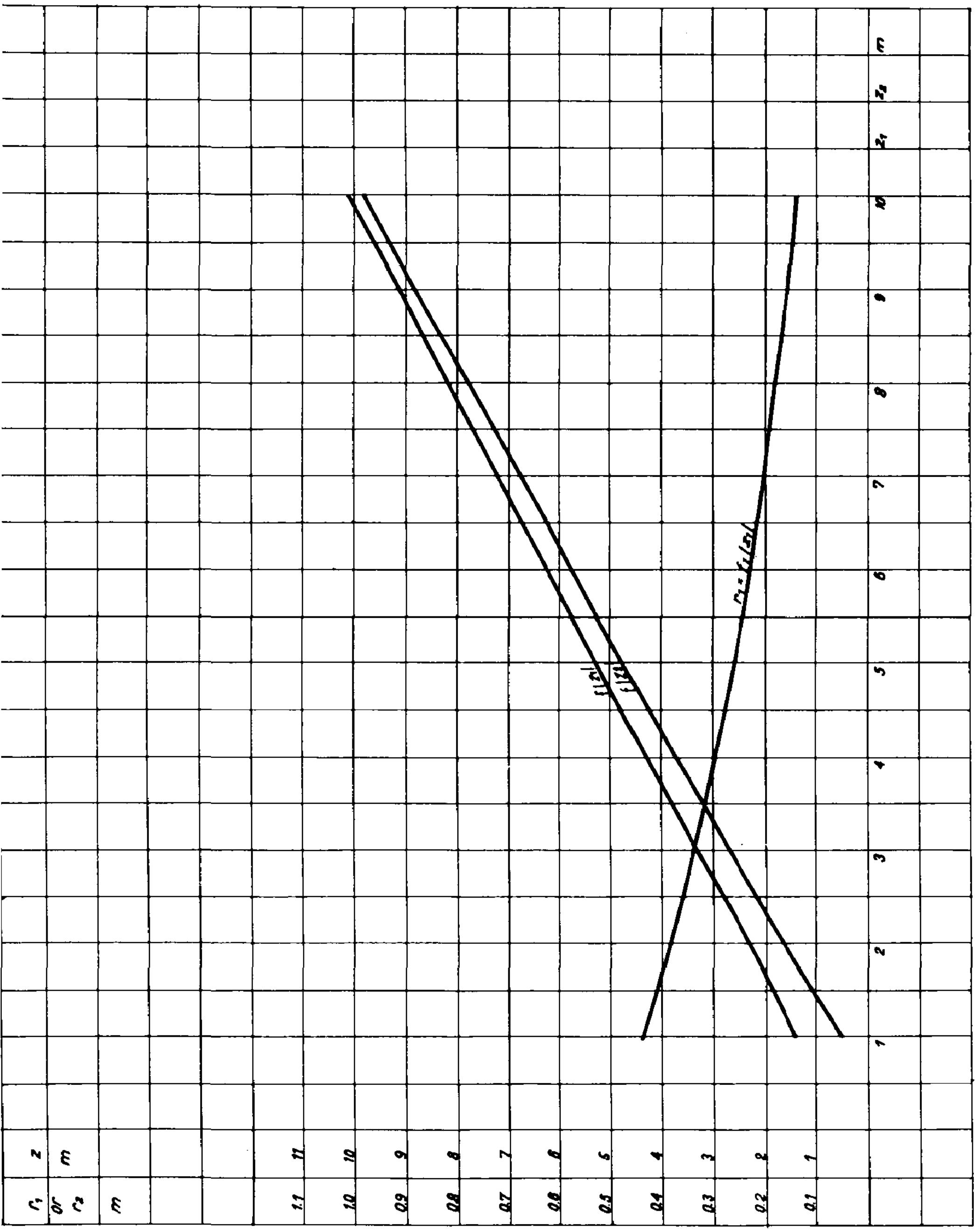


FIG. 5. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2 as a function of z_1 or z_2, for a wave of $\lambda = 50$ m, $\tau = 5.66$ s and $h = 1$ m

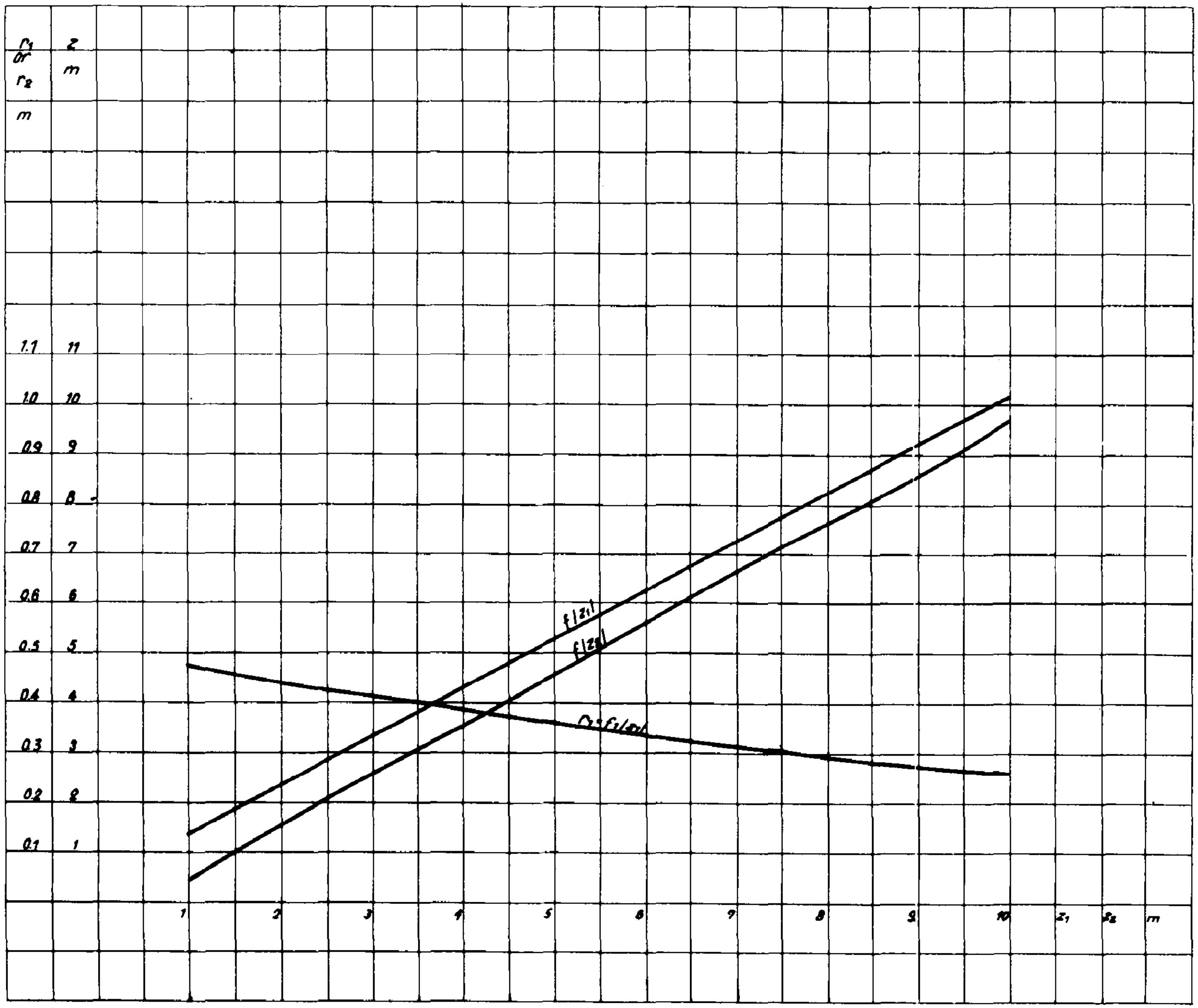


FIG. 6. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2

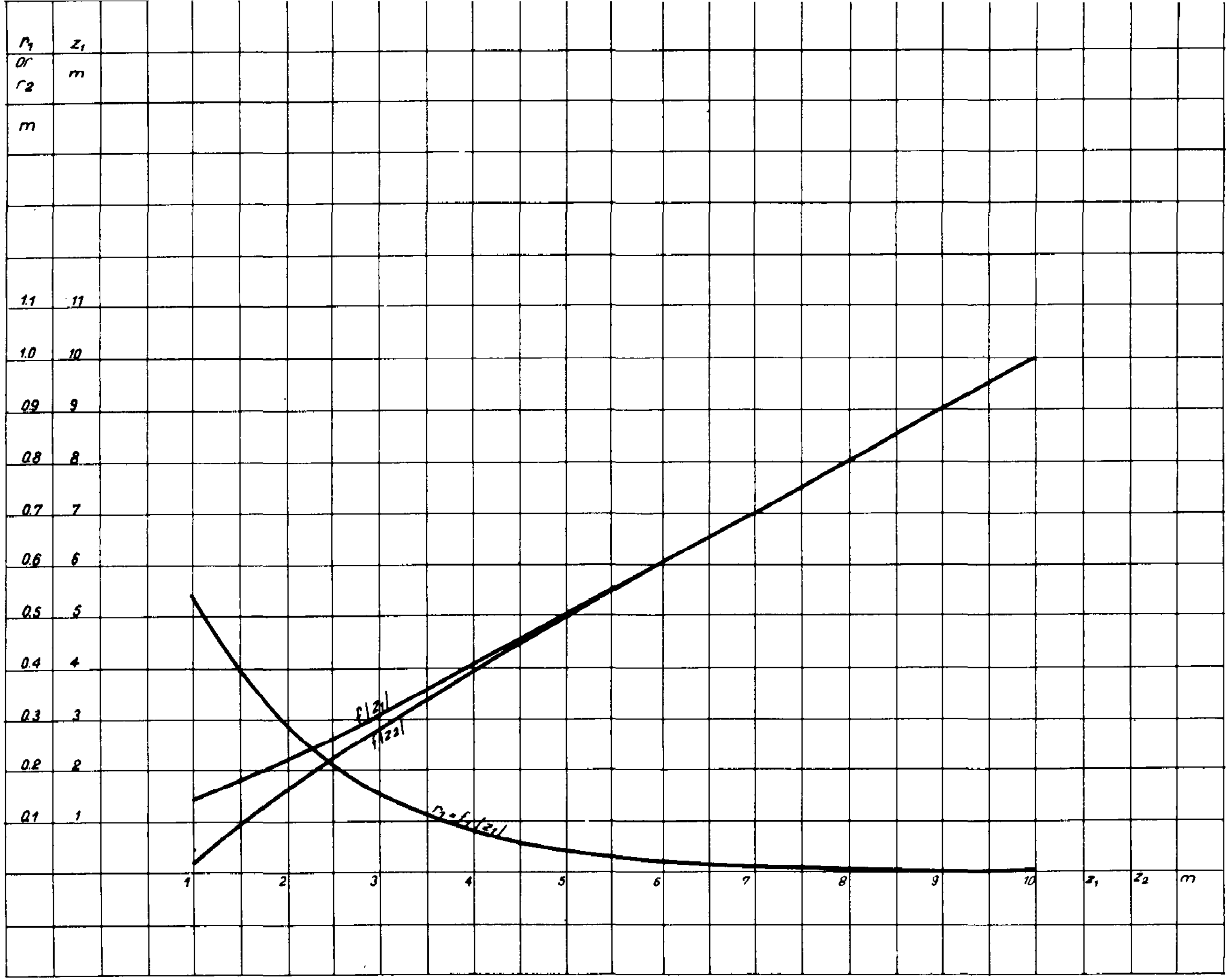


FIG. 7. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2 as a function of z_1 or z_2, for a wave of $\lambda = 10$ m, $\tau = 2.53$ s and $h = 2$ m

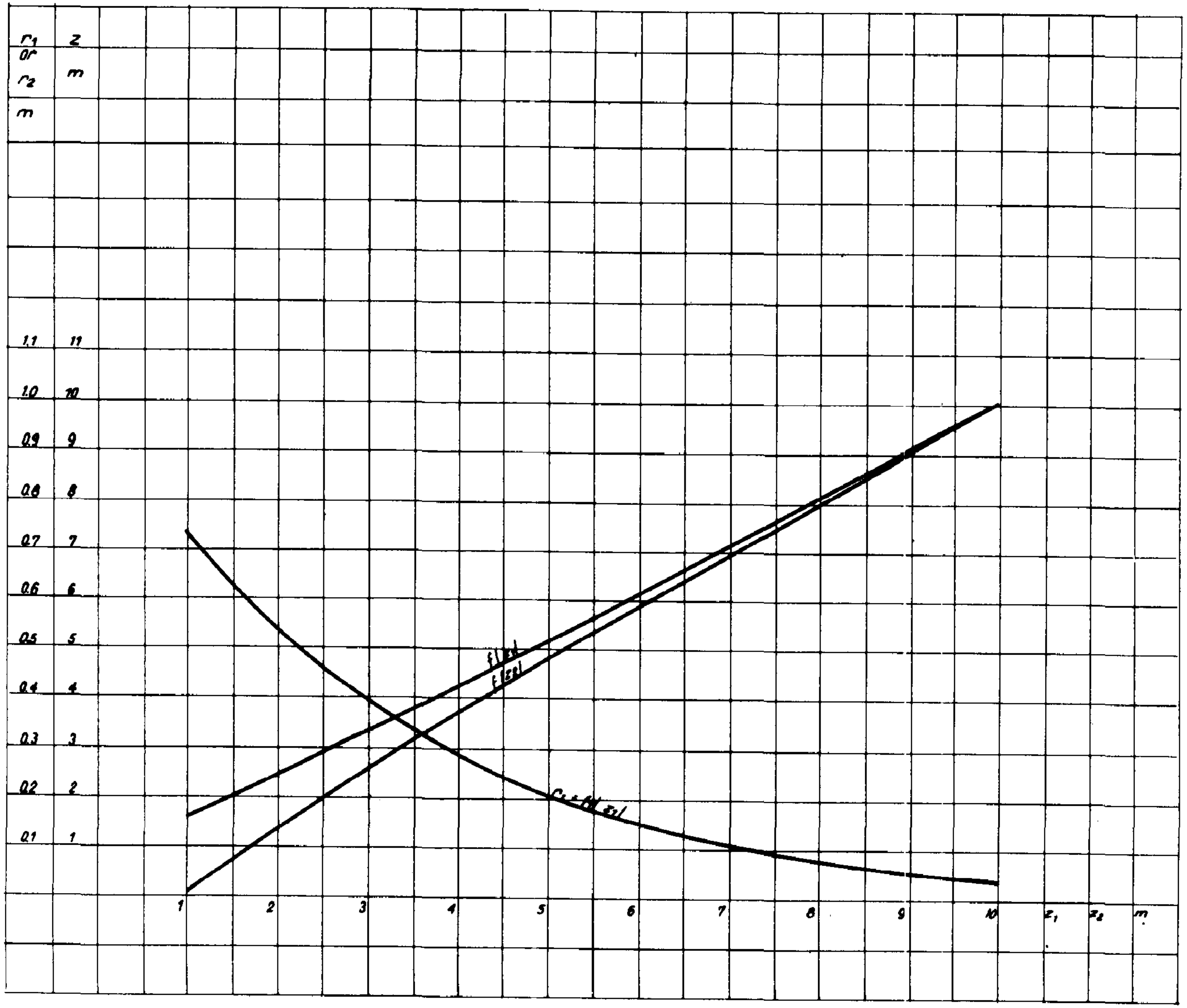


FIG. 8. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2

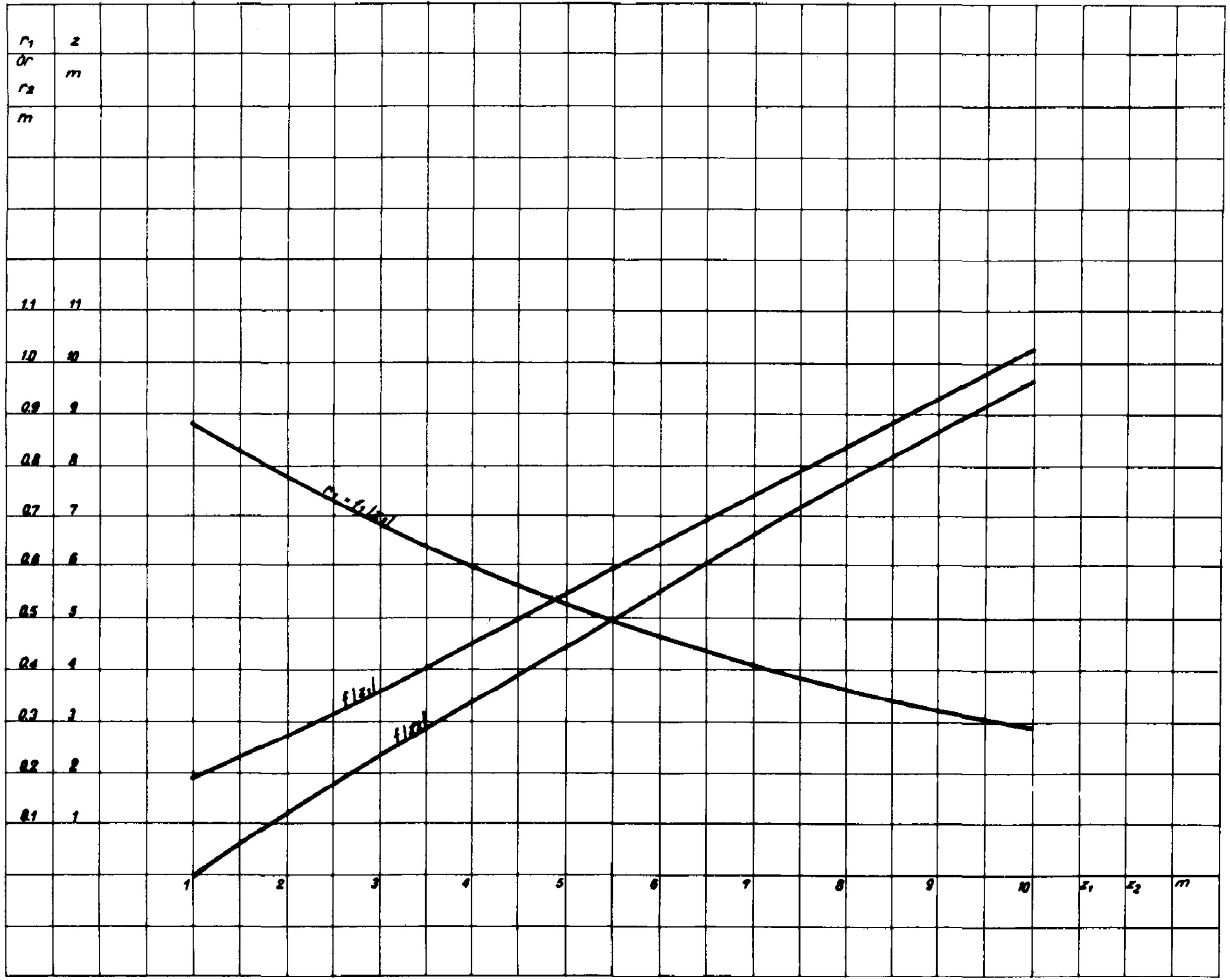


FIG. 9. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2 as a function of z_1 or z_2, for a wave of $\lambda = 50$ m, $\tau = 5.66$ s and $h = 2$ m

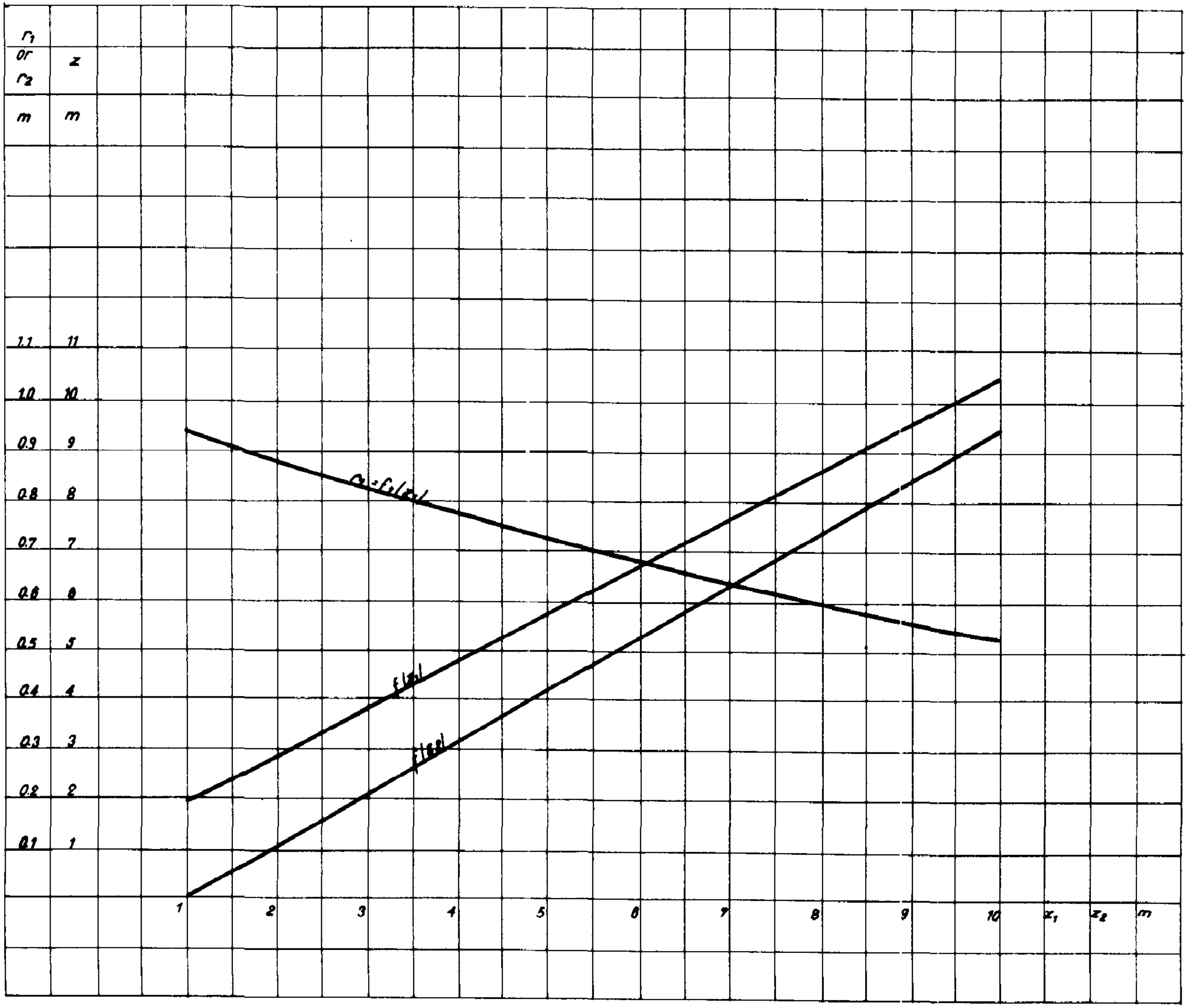


FIG. 10. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2.

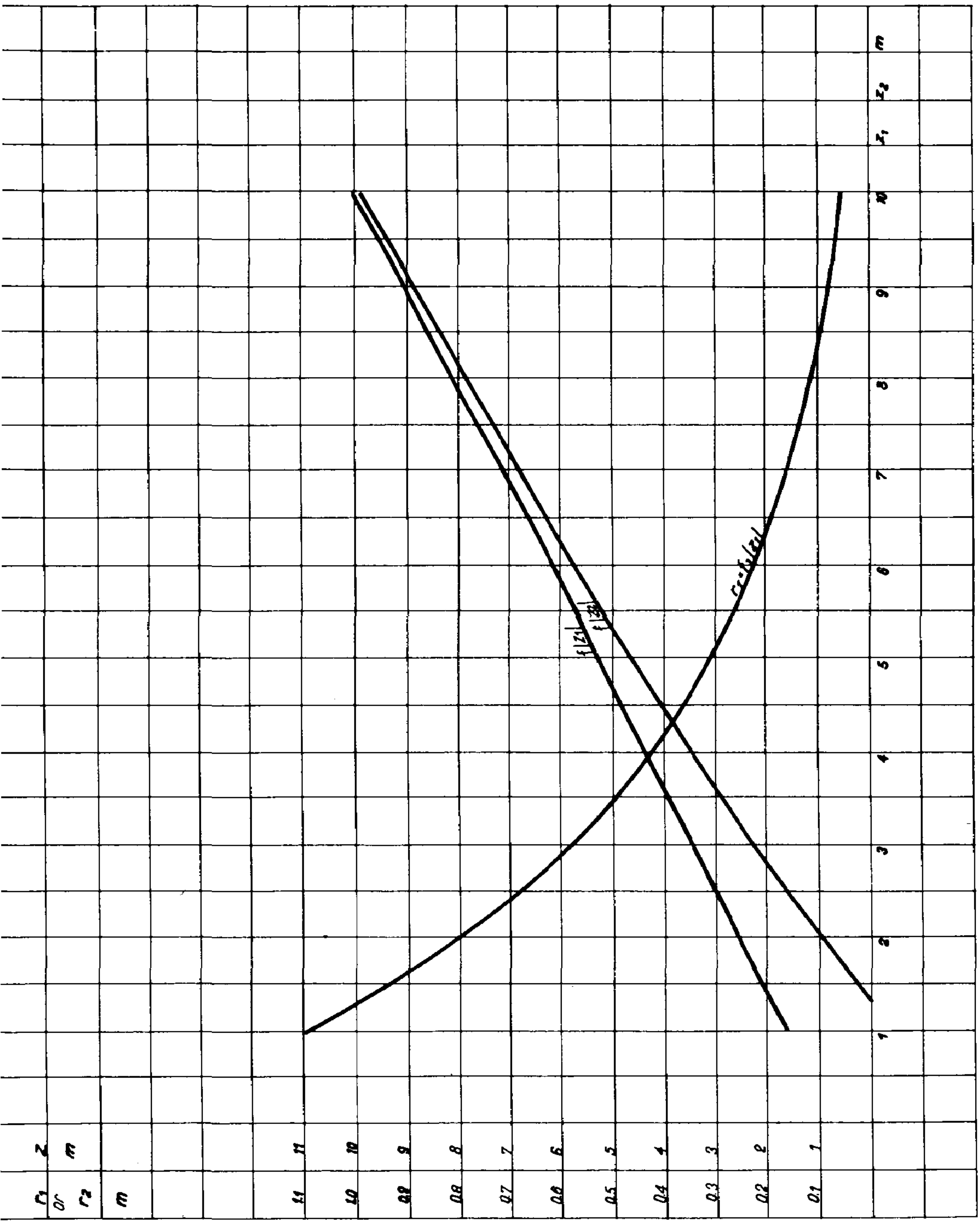


FIG. 11. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2 as a function of z_1 or z_2, for a wave of $\lambda = 20$ m, $\tau = 3.58$ s and $h = 3$ m

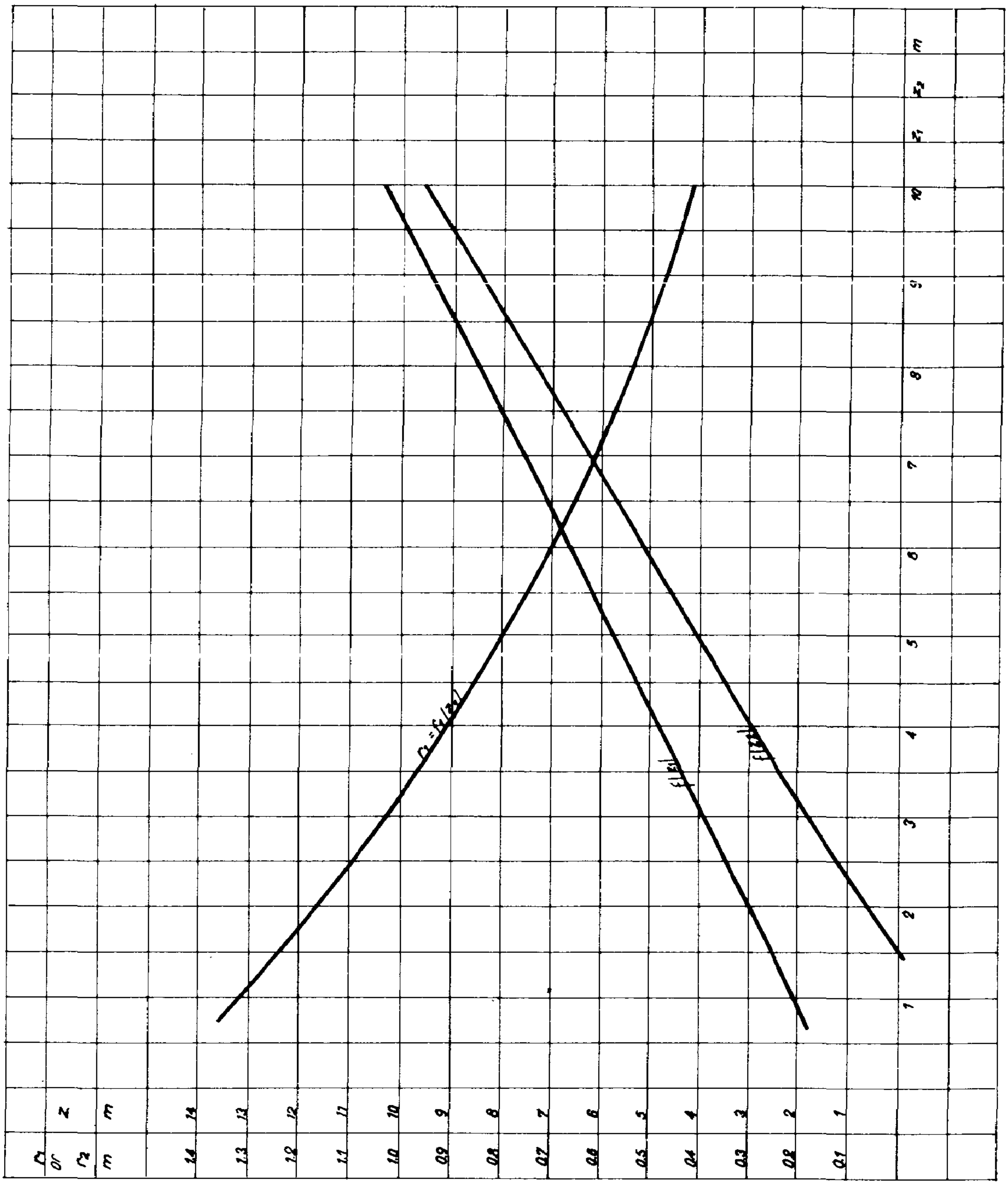


FIG. 12. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2

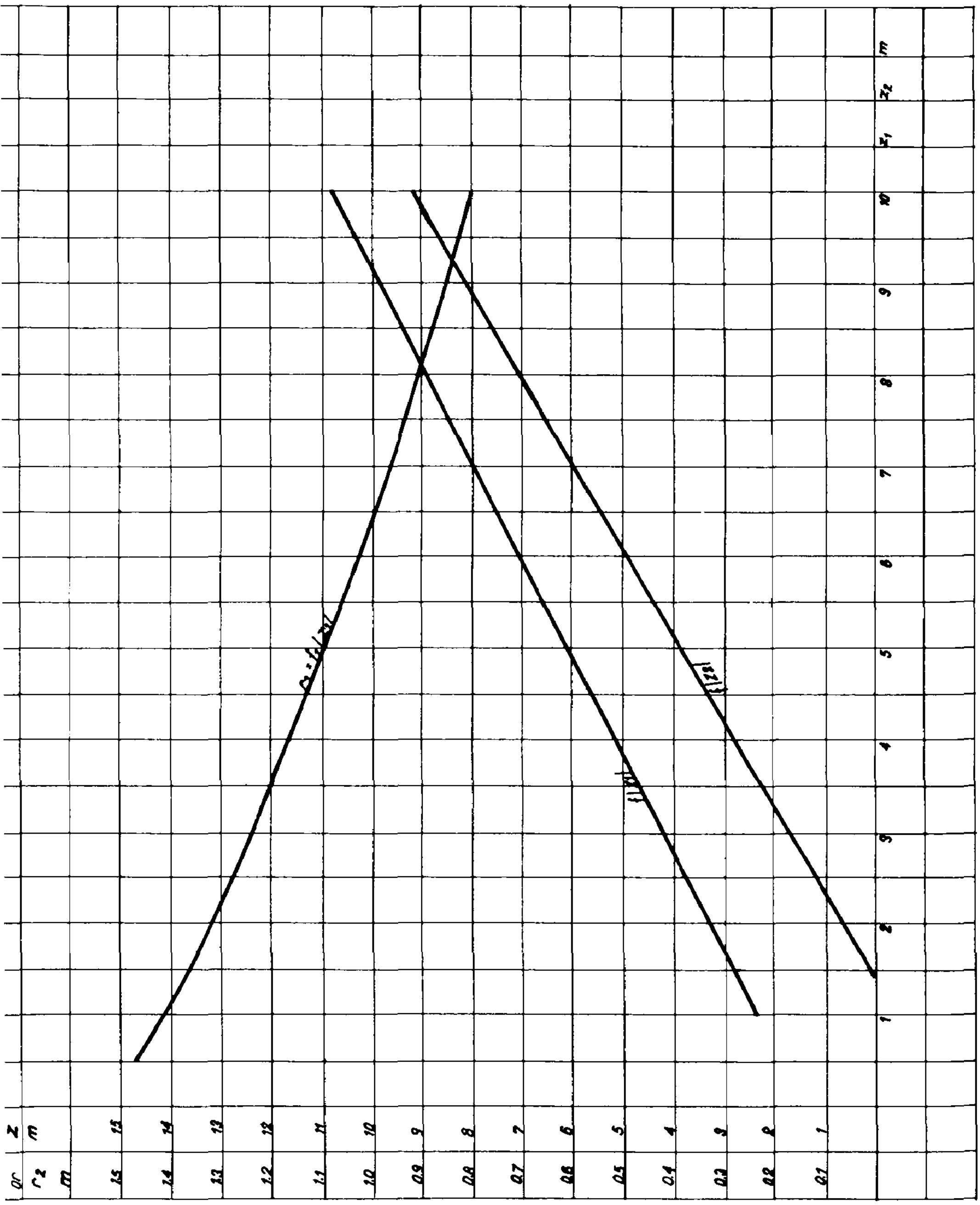


FIG. 13. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2 as a function of z_1 or z_2, for a wave of $\lambda = 100$ m, $\tau = 8.00$ s and $h = 3$ m

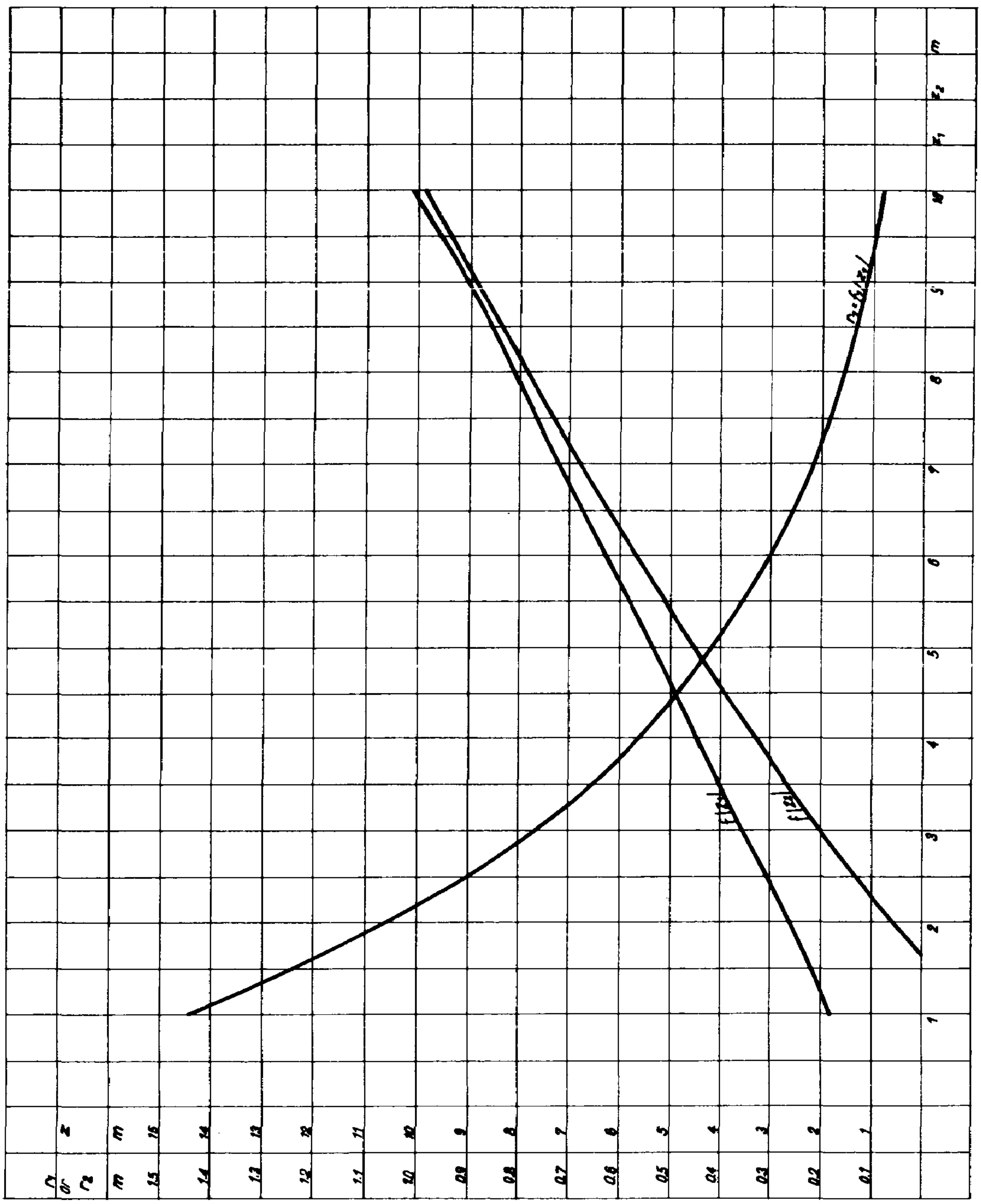


Fig. 14. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2 as a function of z_1 or z_2, for a wave of $\lambda = 20$ m, $\tau = 3.58$ s and $h = 4$ m

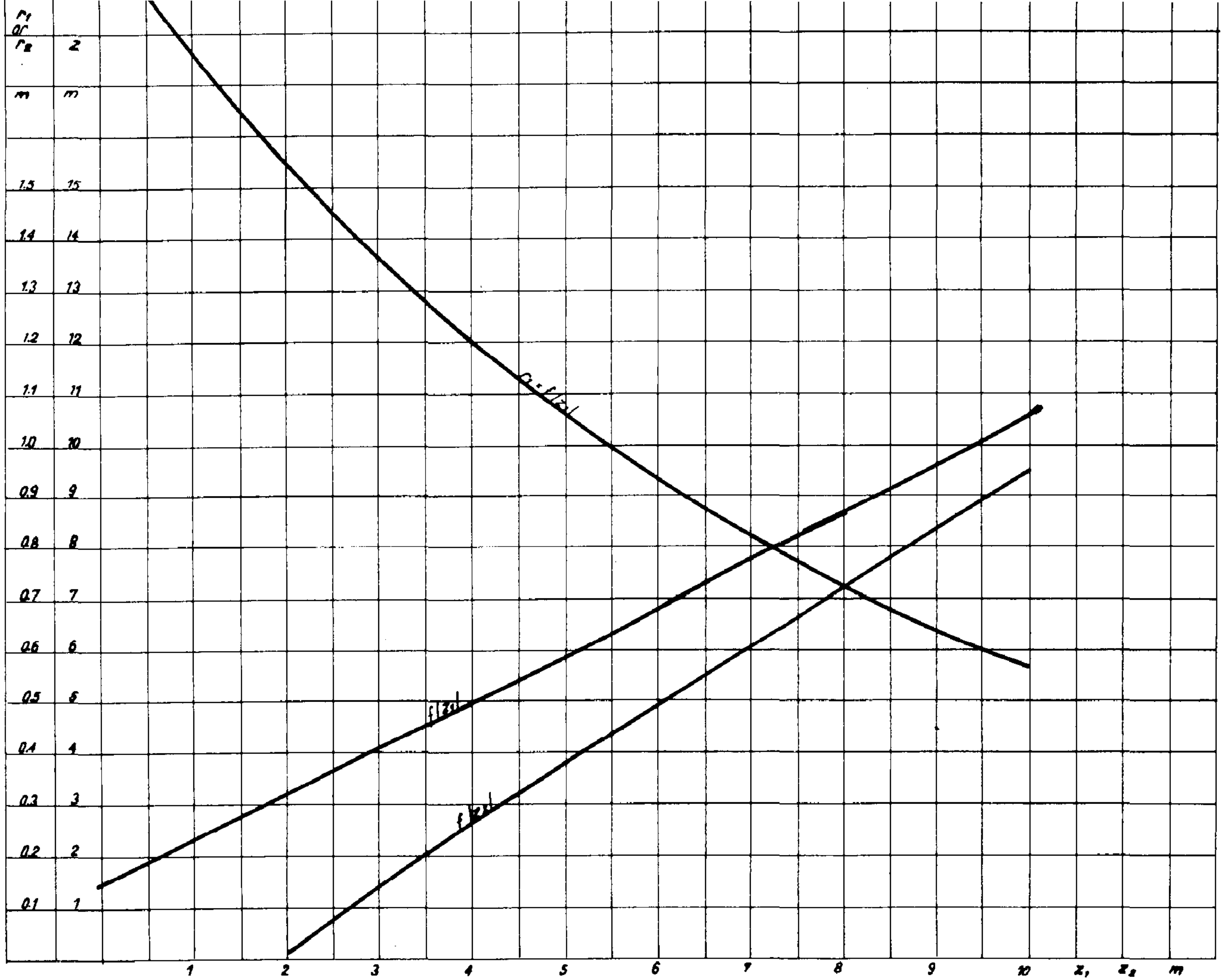
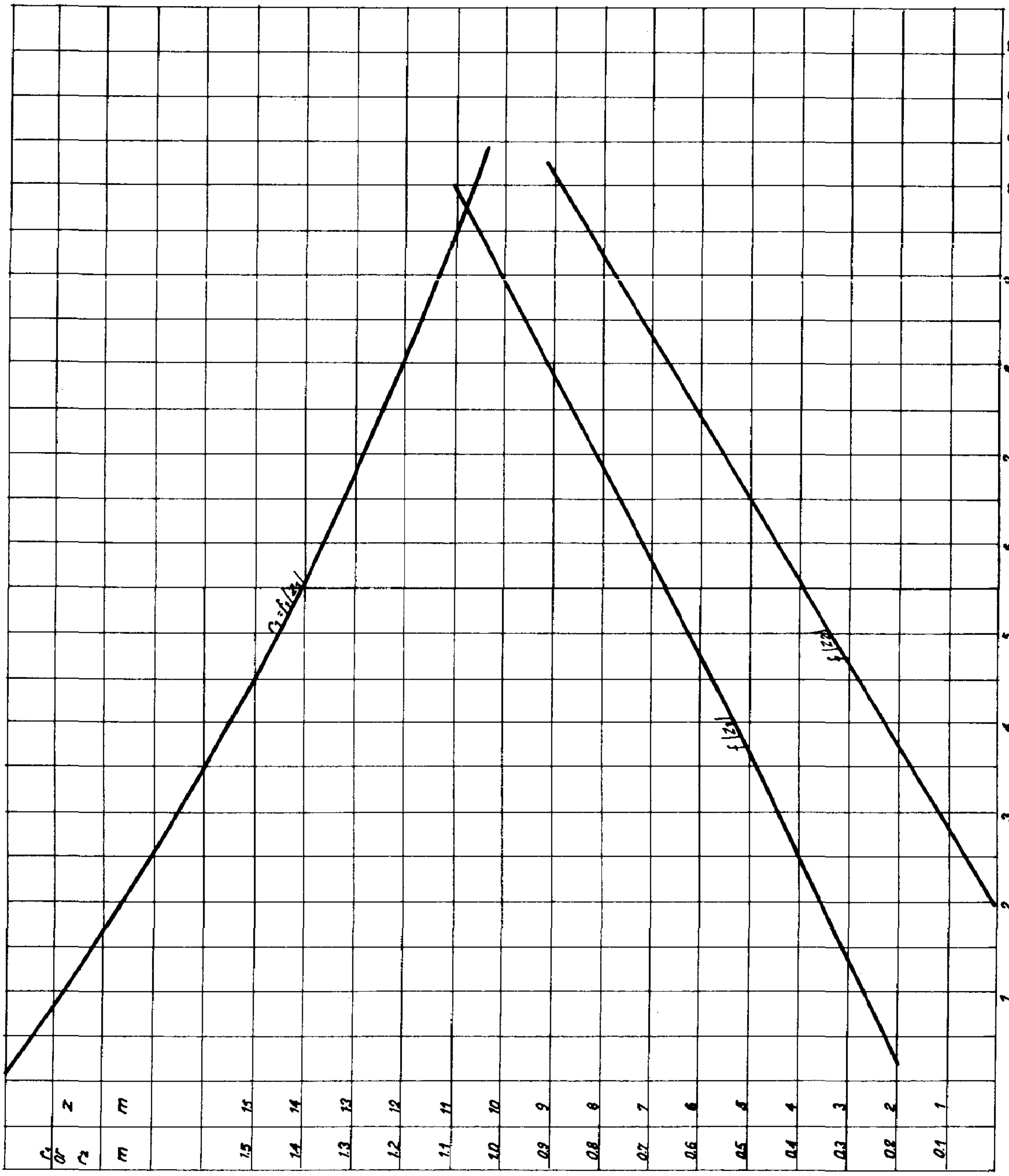


FIG. 15. — Graph of z as a function of z_1 or z_2, and of r_1 and r_2 as a function of z_1 or z_2, for a wave of $\lambda = 50$ m, $\tau = 5.66$ s and $h = 4$ m



$C_3 = f_2(Z_1)$
f(Z1)
f(Z2)
m
Z_2
Z_1
10
9
8
7
6
5
4
3
2
1
C_1 or C_2
Z
m
1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

velocity u_1. Its centre of rotation will be located on the axis of coordinates at a distance $z_1 - \varepsilon_1$ below the rest level. Its radius of rotation is

$$r_1 = \frac{h}{2} e^{\frac{-2\pi z_1}{\lambda}}$$

where z_1 is the height of the level of water molecule A_1 at rest, $\varepsilon_1 = \frac{\pi h_1^2}{2\lambda}$ is the height of suspension of the undulating centre above the level z_1, and $h_1 = h\, e^{\frac{-2\pi z_1}{\lambda}}$ the amplitude of the wave above the level z_1 at rest.

However at the time the wave crests pass through point A a water molecule A_2 will move across with orbital velocity v_2, the ordinate of its axis of rotation being $z_2 - \varepsilon_2$ below the sea level at rest.

The following relationships arise from figure 2 :

$$z = z_1 + r_1 - \varepsilon_1 \qquad \text{and} \qquad z = z_2 - r_2 - \varepsilon_2.$$

Substituting r by corresponding values we obtain the following expressions :

$$z = z_1 + \frac{h}{2} e^{\frac{-2\pi z_1}{\lambda}} - \frac{\pi h^2}{2} e^{\frac{-4\pi z_1}{\lambda}} = f(z_1)$$

and

$$z = z_2 - \frac{h}{2} e^{\frac{-2\pi z_2}{\lambda}} - \frac{\pi h^2}{2} e^{\frac{-4\pi z_2}{\lambda}} = f(z_2)$$

In order to find values z_1 and z_2 for a given z special lines have been marked on figures 3 to 16 for waves with the following characteristics. Length : 10, 20, 50 and 100 metres; amplitude : 1, 2, 3 and 4 metres. On the basis of these graphs it is possible to find all the corresponding values of z_1 and z_2 on the axis of abcissae for any discretional value z upon the axis of the ordinates. In the same figures there have also been plotted diagrams of the functions $r_1 = f_1(z_1)$ and $r_2 = f_1(z_2)$ which are necessary for estimating the values of radii r_1 and r_2 upon the axis of the ordinates for the values z_1 or z_2 found on the axis of the abcissae. Curves $r_1 = f_1(z_1)$ and $r_2 = f_1(z_2)$ are of course given by :

$$r = \frac{h}{2} e^{\frac{-2\pi z}{\lambda}}$$

TABLE 1

Values of z_1 and z_2, r_1 and r_2 and for orbital velocities u_1 and u_2 for waves with the following parameters :

$\lambda = 10$ m $\qquad \tau = 2{,}53$ s $\qquad h = 1$ m

z m	z_1 m	z_2 m	r_1 m	r_2 m	u_1 m/s	u_2 m/s	$u_1 - u_2$ m/s	$u_1 - u_2$ in knots
1	2	3	4	5	6	7	8	9
2	1.85	2,10	0.16	0,13	0,40	0,32	0,08	0,16
3	2.90	3,05	0.08	0.07	0.20	0.17	0.03	0.06
4	3,95	4.05	0.040	0.038	0.10	0.09	0.01	0.02

z m	z_1 m	z_2 m	r_1 m	r_2 m	u_1 m/s	u_2 m/s	$u_1 - u_2$ m/s	$u_1 - u_2$ in knots
1	2	3	4	5	6	7	8	9
		$\lambda = 10$ m		$\tau = 2.53$ s		$h = 2$ m		
2	1.70	2.30	0.34	0.24	0.84	0.59	0.25	0.50
3	2.80	3.20	0.17	0.13	0.42	0.32	0.10	0.20
4	3.85	4.10	0.09	0.08	0.22	0.20	0.02	0.04
5	4.90	5.05	0.05	0.042	0.12	0.10	0.02	0.04
		$\lambda = 20$ m		$\tau = 3.58$ s		$h = 1$ m		
2	1.70	2.25	0.29	0.24	0.51	0.42	0.09	0.18
3	2.75	3.20	0.21	0.18	0.37	0.31	0.06	0.12
4	3.85	4.15	0.14	0.13	0.25	0.23	0.02	0.04
5	4.90	5.10	0.10	0.09	0.18	0.16	0.02	0.04
6	5.90	6.10	0.075	0.065	0.13	0.11	0.02	0.04
		$\lambda = 20$ m		$\tau = 3.58$ s		$h = 2$ m		
2	1.55	2.50	0.61	0.46	1.07	0.80	0.27	0.54
3	2.60	3.35	0.44	0.35	0.77	0.61	0.16	0.32
4	3.70	4.25	0.31	0.26	0.54	0.45	0.09	0.18
5	4.80	5.20	0.22	0.19	0.38	0.33	0.05	0.10
6	5.85	6.15	0.15	0.14	0.26	0.24	0.02	0.04
7	6.90	7.10	0.11	0.10	0.19	0.18	0.01	0.02
		$\lambda = 20$ m		$\tau = 3.58$ s		$h = 3$ m		
2	1.35	2.75	0.98	0.62	1.71	1.08	0.63	1.26
3	2.45	3.60	0.68	0.47	1.19	0.82	0.37	0.74
4	3.55	4.50	0.48	0.36	0.84	0.63	0.21	0.42
5	4.65	5.35	0.34	0.28	0.59	0.49	0.10	0.20
6	5.75	6.25	0.24	0.21	0.42	0.37	0.05	0.10
7	6.85	7.15	0.17	0.15	0.30	0.26	0.04	0.08
8	7.90	8.10	0.12	0.11	0.21	0.19	0.02	0.04
9	8.90	9.10	0.085	0.08	0.15	0.14	0.01	0.02
		$\lambda = 20$ m		$\tau = 3.58$ s		$h = 4$ m		
2	1.20	3.00	1.36	0.77	2.38	1.35	1.03	2.06
3	2.40	3.75	0.93	0.61	1.63	1.07	0.56	1.12
4	3.45	4.55	0.66	0.48	1.15	0.84	0.31	0.62
5	4.60	5.40	0.47	0.37	0.82	0.65	0.17	0.34
6	5.65	6.30	0.34	0.28	0.59	0.49	0.10	0.20
7	6.70	7.20	0.24	0.20	0.42	0.35	0.07	0.14
8	7.80	8.15	0.17	0.15	0.30	0.26	0.04	0.08
9	8.90	9.10	0.12	0.11	0.21	0.19	0.02	0.04
		$\lambda = 50$ m		$\tau = 5.66$ s		$h = 1$ m		
2	1.60	2.35	0.40	0.37	0.44	0.41	0.03	0.06
3	2.65	3.30	0.35	0.32	0.39	0.36	0.03	0.06
4	3.70	4.25	0.31	0.29	0.34	0.32	0.02	0.04
5	4.70	5.25	0.27	0.26	0.30	0.29	0.01	0.02
6	5.75	6.20	0.24	0.23	0.27	0.26	0.01	0.02
7	6.80	7.20	0.21	0.20	0.23	0.22	0.01	0.02
8	7.80	8.20	0.19	0.18	0.21	0.20	0.01	0.02
9	8.85	9.15	0.16	0.155	0.18	0.17	0.01	0.02

z m	z_1 m	z_2 m	r_1 m	r_2 m	u_1 m/s	u_2 m/s	$u_1 - u_2$ m/s	$u_1 - u_2$ in knots
1	2	3	4	5	6	7	8	9
		$\lambda = 50$ m		$\tau = 5.66$ s		$h = 2$ m		
2	1.20	2.75	0.86	0.70	0.95	0.78	0.17	0.34
3	2.30	3.65	0.74	0.62	0.82	0.69	0.13	0.26
4	3.35	4.60	0.65	0.55	0.72	0.61	0.11	0.22
5	4.45	5.50	0.57	0.49	0.63	0.54	0.09	0.18
6	5.50	6.45	0.49	0.44	0.54	0.49	0.05	0.10
7	6.60	7.35	0.43	0.39	0.48	0.43	0.05	0.10
8	7.65	8.30	0.38	0.35	0.42	0.39	0.03	0.06
9	8.70	9.30	0.33	0.31	0.37	0.34	0.03	0.06
		$\lambda = 50$ m		$\tau = 5.66$ s		$h = 3$ m		
2	0.85	3.15	1.33	1.00	1.48	1.11	0.37	0.64
3	2.00	4.00	1.17	0.90	1.30	1.00	0.30	0.60
4	3.10	4.90	1.01	0.81	1.12	0.90	0.22	0.44
5	4.20	5.80	0.88	0.72	0.98	0.80	0.18	0.36
6	5.25	6.75	0.77	0.63	0.85	0.70	0.15	0.30
7	6.40	7.60	0.67	0.57	0.74	0.63	0.11	0.22
8	7.45	8.55	0.58	0.50	0.64	0.55	0.09	0.18
9	8.56	9.50	0.51	0.45	0.57	0.50	0.07	0.14
		$\lambda = 50$ m		$\tau = 5.66$ s		$h = 4$ m		
2	0.55	3.50	1.86	1.28	2.06	1.42	0.64	1.28
3	1.75	4.55	1.60	1.15	1.78	1.28	0.50	1.00
4	2.85	5.20	1.38	1.03	1.53	1.14	0.39	0.78
5	4.00	6.10	1.20	0.92	1.33	1.02	0.31	0.62
6	5.15	6.90	1.04	0.83	1.15	0.92	0.23	0.46
7	6.20	7.80	0.91	0.74	1.01	0.82	0.19	0.38
8	7.25	8.70	0.79	0.66	0.88	0.73	0.15	0.30
9	8.30	9.60	0.70	0.60	0.78	0.67	0.11	0.22
		$\lambda = 100$ m		$\tau = 8.00$ s		$h = 1$ m		
2	1.55	2.45	0.45	0.43	0.36	0.34	0.02	0.04
3	2.60	3.40	0.425	0.405	0.34	0.32	0.02	0.04
4	3.60	4.40	0.40	0.38	0.32	0.30	0.02	0.04
5	4.65	5.35	0.375	0.355	0.30	0.28	0.02	0.04
6	5.65	6.30	0.35	0.33	0.28	0.26	0.02	0.04
7	6.65	7.30	0.325	0.31	0.26	0.25	0.01	0.02
8	7.70	8.30	0.305	0.295	0.24	0.23	0.01	0.02
9	8.70	9.30	0.29	0.28	0.23	0.22	0.01	0.02
		$\lambda = 100$ m		$\tau = 8.00$ s		$h = 2$ m		
2	1.05	2.90	0.93	0.83	0.74	0.66	0.08	0.16
3	2.10	3.85	0.87	0.78	0.69	0.62	0.07	0.14
4	3.20	4.75	0.81	0.74	0.65	0.59	0.06	0.12
5	4.25	5.70	0.76	0.69	0.60	0.55	0.05	0.10
6	5.30	6.65	0.71	0.65	0.57	0.52	0.05	0.10
7	6.30	7.65	0.67	0.61	0.53	0.49	0.04	0.08
8	7.35	8.60	0.63	0.58	0.50	0.46	0.04	0.08
9	8.40	9.55	0.59	0.55	0.47	0.44	0.03	0.06

z m	z_1 m	z_2 m	r_1 m	r_2 m	u_1 m/s	u_2 m/s	$u_1 - u_2$ m/s	$u_1 - u_2$ in knots
1	2	3	4	5	6	7	8	9
	$\lambda = 100$ m			$\tau = 8.00$ s		$h = 3$ m		
2	0.60	3.30	1.45	1.21	1.16	0.97	0.19	0.38
3	1.70	4.20	1.34	1.15	1.07	0.92	0.15	0.30
4	2.80	5.15	1.25	1.08	1.00	0.86	0.14	0.28
5	3.85	6.10	1.18	1.02	0.94	0.82	0.12	0.24
6	4.95	7.00	1.10	0.96	0.88	0.77	0.11	0.22
7	6.00	7.95	1.03	0.91	0.82	0.73	0.09	0.18
8	7.05	8.90	0.96	0.86	0.77	0.69	0.08	0.16
9	8.10	9.85	0.90	0.81	0.72	0.65	0.07	0.14
	$\lambda = 100$ m			$\tau = 8.00$ s		$h = 4$ m		
2	0.20	3.70	1.98	1.58	1.58	1.26	0.32	0.64
3	1.30	4.65	1.84	1.49	1.47	1.19	0.28	0.56
4	2.45	5.55	1.71	1.41	1.37	1.13	0.24	0.48
5	3.60	6.45	1.59	1.33	1.27	1.06	0.21	0.42
6	4.70	7.35	1.48	1.26	1.18	1.01	0.17	0.34
7	5.75	8.30	1.39	1.18	1.11	0.94	0.17	0.34
8	6.80	9.20	1.30	1.12	1.04	0.89	0.15	0.30
9	7.85	10.10	1.22	1.06	0.97	0.85	0.12	0.24

Using the above-mentioned diagrams the orbital velocities u_1 and u_2 have then been computed. The results for deep sea conditions are illustrated in table 1.

Thus, taking into consideration the vertical cross section of the field of the waves' orbital velocities it is clear that formula 1, given by the authors, is not entirely correct. The same is true of formula 2, as well as of figure 1 where :

$$u_1 = \frac{\pi h}{\tau} e^{-kz_1} \qquad \text{and} \qquad u_2 = \frac{\pi h}{\tau} e^{-kz_2}$$

all the mean orbital velocities being variable exponents ranging from z_1 to z_2. Table 1, on the contrary, shows that the differences between the orbital velocities may even amount to 2.06 knots for waves of $\lambda = 20$ m and $h = 4$ m.

Of course, it must be remembered that the differences of the orbital velocities mentioned will only appear if point A does not change its coordinate in relation to the calm water level or to the sea bottom during the time of observation. This point A will be under the influence of the horizontal components of the orbital velocities of values varying from 0 to u_1 and from 0 to u_2. Observations of current velocities in the undulating water zone are useless unless the wave elements are known. They sometimes contain quite considerable errors.

It appears, therefore, that the authors' reasoning concerning the reversible current-meters is not entirely right. They are only right when it comes to current-meters placed on the wave-surface, or possibly, in a position where the variables concord with the tracks of the water molecules below the water surface.

As for the irreversible meters, providing that point A is preserved at a constant level in relation to the calm water level, it is possible to obtain velocities that are means both of the average horizontal components of the orbital velocities with their centres of rotation above level z, and of the same components with centres of rotation below z :

$$u_m = \frac{u_1 + u_2}{4}$$

For example, for a wave of $\lambda = 20$ m and $h = 4$ m, on level $z = 2$ m we shall obtain the following mean value :

$$u_m = \frac{2.38 + 1.35}{2}$$

$= 0.93$ m/s $= 1.86$ knot.

The authors have come to the reasonable conclusion that current meters of the irreversible type are of no use for measurements of sea-current velocities, although they have used different arguments. In cases where the measurements are taken in zones of undulating water and when the flow is lacking, irreversible current-meters will indicate the existence of the apparent current, as is clear from the above example.

4. — VERTICAL POSITION OF THE CURRENT-METER

Carrying out measurements of the sea-current from a ship or a floating station, the vertical position of the current-meter is exposed to continuous possible changes in level of the carrier holding the measuring device, due to undulation of the water surface.

Thus in the undulating zone, when the floating object is under the influence of vertical oscillation, the current-meter will also change its system of coordinates in a continuous way. Of course, in the case where a research ship is used, the length of which exceeds two wave lengths, provided that the ship's longitudinal axis is directed parallel to the wave propagation, it will be possible to retain the position of the current-meter at a fixed level. Since, however, no attention was paid to this point when carrying out the observation it may be assumed that the positions of the current-meters underwent vertical oscillations. There might also have been cases where the coordinate of the current-meter in relation to the water level at rest decreased during the passing of the wave troughs, whereas for the crests it increased. If, for instance, taking a wave of $\lambda = 50$ m and $h = 4$ m, z decreased to 2 m during the passing of the wave trough, then $u_1 = 2.06$ m/s. If, however, during the passing of the crest, z increased to 4 m, then $u_2 = 1.14$ m/s and accordingly $u_1 - u_2 = 0.92$ m/s. Of course much more drastic cases may certainly have occurred, and this may explain the fairly high velocities obtained. However it might also be that the current did not in all probability exist in fact.

Among the great number of measurements performed there may have also been the case where the current-meter did register orbits concording with those of the undulating water molecules. Such an occurrence is, however, unlikely and should be excluded. Thus we come to the conclusion that the present results of the processing of measurements of the sea-current have been obtained from data not in accordance with the actual facts.

5. — MEASUREMENTS OF SEA-CURRENT DIRECTIONS

Model tests on the behaviour of current-meters in undulating water were carried out at the Hydraulic Engineering Institute of the Polish Academy of Sciences in Gdansk in 1959. The tests were performed in a two metre wide experimental channel. During the tests the current-meter suspended on a rope took a position perpendicular to the wave propagation, with some slight deviations. From the position assumed by the current-meter it is deduced that the current flows in a direction transverse to the channel. This was by no means to be expected.

Some experiments were also carried out with flat plates of rectangular shape. When the plate was suspended from the point of its centre of gravity so that the surfaces on both sides of the axis of suspension were equal, the plate assumed a direction perpendicular to the wave propagation. In the case of asymmetrical suspension, on the approach of crests the larger side of the plate deviated in the direction of the wave propagation, whereas on the approach of troughs it deviated in the opposite sense. Figures 17 and 18 illustrate the results of this experiment.

In any case neither experiment gives the possibility of determining the direction of the current in undulating water by means of current-meters suspended on a rope.

It is true that no experiments were carried out with a toroidal ring, but it is to be supposed that in spite of a small value for the K/J ratio the current direction will not be properly indicated in undulating water.

The freedom given to the movements of the current-meter by suspending it on a rope seems aimless.

6. — SUGGESTED METHODS OF MEASURING THE CURRENTS

From the above remarks it will be seen that the measurement of sea-currents is not easy. The construction of an ideal current-meter is still more difficult. As far as the measurement of the current at the actual

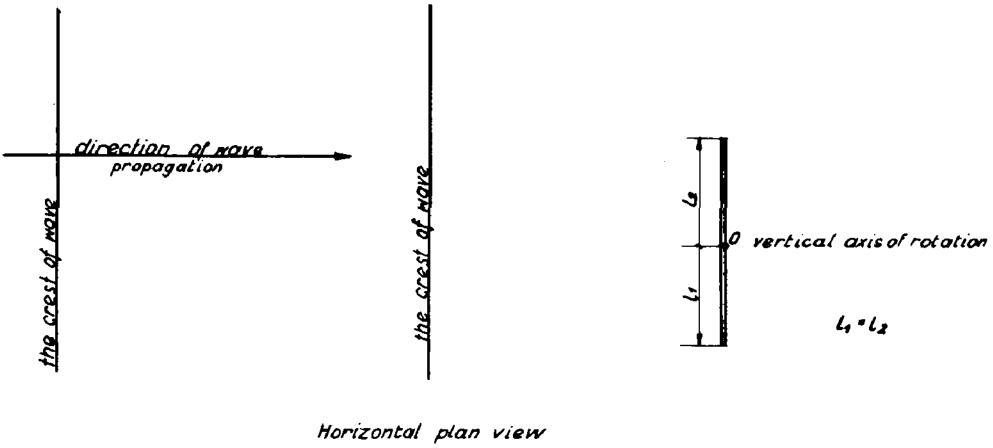


FIG. 17. — Position of the rectangular plate suspended through its axis of symmetry during undulation

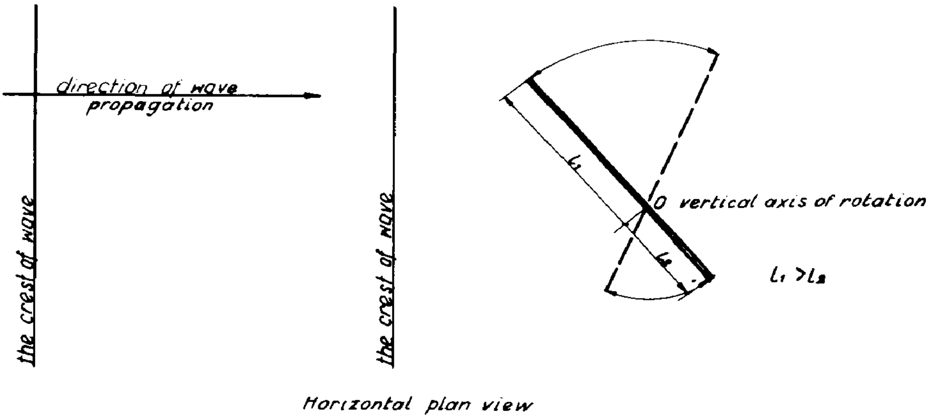


FIG. 18. — Movements of the rectangular plate suspended through a point out of the axis of symmetry during undulation

surface of undulating water is concerned, this has only been possible up to now by employing the geomagnetic-electrokinetographic method, provided that the two electrodes are on the water surface at the time the measurements are performed. If the electrodes are submerged and each one is on a different level, the measurements may provide completely false results.

For measurements of currents below the water surface in an undulating water layer it seems necessary that the following requirements should be fulfilled.

The wave characteristics due to the wind, that is the short-period ones, should first be measured. The basic wave elements are length, period and height. These data will be helpful in the working out of the observation material for reproducing the actual field of orbital velocities. For the sake of certainty, the water depth at the place where the surface water observations are carried out should always be measured to make quite sure whether the orbits of the waves involved are elliptical or circular.

The next condition is the advisability of using a research ship whose length should exceed the length of two short-period waves. The tests will probably show that there is a possibility of using shorter ships for correctness of operation as far as the stability of the coordinate of the current-meters is concerned. While performing the measurements the ship should be steered with her longitudinal axis parallel to the wave propagation in order to avoid vertical oscillation. When this condition is fulfilled it will be possible, after having plotted the field of orbital velocities, to eliminate the influence of short-period undulations.

Some rigid rods should be fixed vertically to a horizontal beam placed either in the bow or in the stern of the ship. Current-meters, even those of simplified construction, can be rigidly attached at appropriate intervals on the rods. The current-meters are equipped with impellers rotating upon the horizontal axis, and may or may not have a protective cover and a speedometer. Two current-meters should be used simultaneously at a given depth; their horizontal axes would then make an angle of a little over 90° and considerably less than 180° : e.g. 110° - 120°. The horizontal axis of one of the current-meters should be oriented parallel to the longitudinal axis of the ship. This will be helpful for the determination of direction.

The angle between the two axes of the current-meters should naturally be measured exactly.

The measurement of two currents with different direction components will enable us, after reducing the influence of the short-period waves, to determine their resultant.

The use of a long ship for sea-current measurements has still another advantage, namely that it will simultaneously be possible to define exactly the elements of the actual short-period waves and the water level at rest — a level known to be not at half the wave's height, but at about the following distance below :

$$\varepsilon = \frac{\pi h^2}{2\lambda}$$

Before beginning the measurements in natural conditions it is first of all necessary to test the current-meter in an experimental channel with the aim of establishing whether the vanes of the current-meter placed in a cylindrical protective cover are subject to motion in cases where the current-meter is oriented perpendicularly to the direction of the water flow, and of finally determining the size of these movements.

As some parts of the presently used meters, besides the vanes, are oriented perpendicularly to the current direction it seems probable that these also have an influence upon the movements of the impellers.

It may also be useful for measurement control to instal an additional pair of rigidly fixed current-meters in another position near the research ship. For instance, if the first pair is placed ahead of the bow, so the other pair might be fixed off the stern, or perhaps amidships but at a safe distance guaranteeing no disturbances from the ship.

The fixing of current-meters upon floating stations in a non-rigid way seems useless, especially on account of difficulties in preserving a constant level for the meter in relation to the sea level at rest.

By conserving the above mentioned conditions it would be possible to eliminate the influence of short-period waves when processing data.

In addition to short-period waves, seas and oceans constantly have long-period waves in the form of tides and baric waves of long periods. The orbital velocities of these waves are, however, of small significance but they give rise to assumptions concerning the existence of currents, particularly because the directions of these velocities are unchanged for many hours. Hence the necessity of taking into account the course and the magnitude of the long-period waves during the observation, as well as for the further data processing. To determine the long-period waves it is necessary to know the baric, tidal and deep-water conditions over a large area.

As is clear from the above remarks the problem of sea-current measurements is not only a problem of the registration of revolutions of a current-meter suspended on a rope that is liable to twirl, but includes also the complicated processes connected with sea dynamics and meteorology.

It should of course be remembered that, with the exception of the geomagnetic-electrokinetographic (GEK) method, the present-day ways of measuring sea-currents cannot give reliable indications concording with the real ones when applied to measuring surface water currents.

The process of one of the experiments carried out at the Hydraulic Engineering Institute of the Polish Academy of Sciences in Gdansk is given below to exemplify an instance leading to false conclusions.

A vertical plate had a suspension point above the undulating water surface. Its specific weight was a little over that of water. Its horizontal axis permitted discretional deviations from the perpendicular. The plate was placed perpendicularly to the direction of the wave propagation (figure 19). During undulation it was observed that the plate deviated in

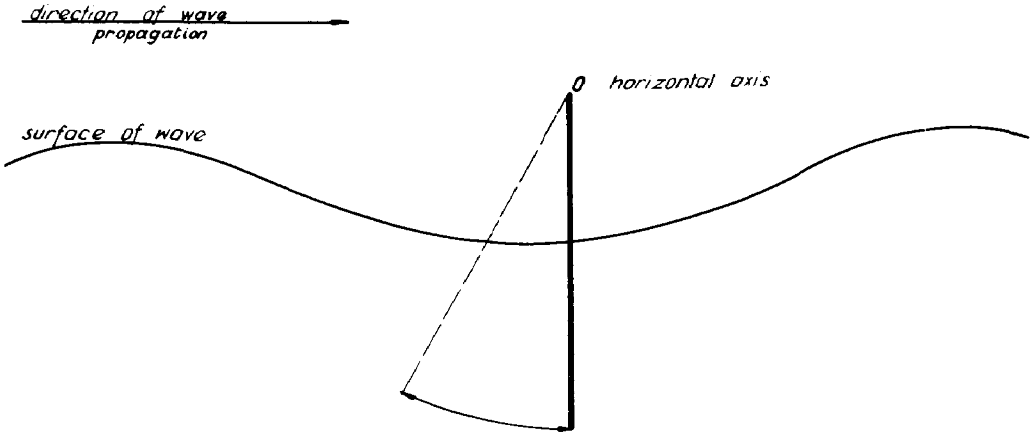


FIG. 19. — The behaviour of the vertical plate with its axis of rotation above the water surface during undulation

the opposite direction to the wave propagation. Faced with this fact we might deduce that the plate deviated owing to the existence of water currents having a direction opposite to that of the wave propagation. This supposition, however, would be a false one, as has been proved by the next experiment.

A plate whose specific weight was a little less than that of water was placed at the same place; its horizontal axis of rotation was below the water surface. At rest the plate took a vertical position, whereas after undulation occurred the plate had deviated in the direction concording with that of the wave propagation (figure 20). Thus, apparently, the plate would be under the influence of the current concording with the direction of the wave propagation. Thus at one and the same spot two currents would occur, each having a direction opposite to the other, and only the situation of the plate's axis of rotation would be similar. This is patently nonsense. After plotting the field of the velocity of undulating water in the vertical plane, we may easily arrive at an explanation for this phenomenon.

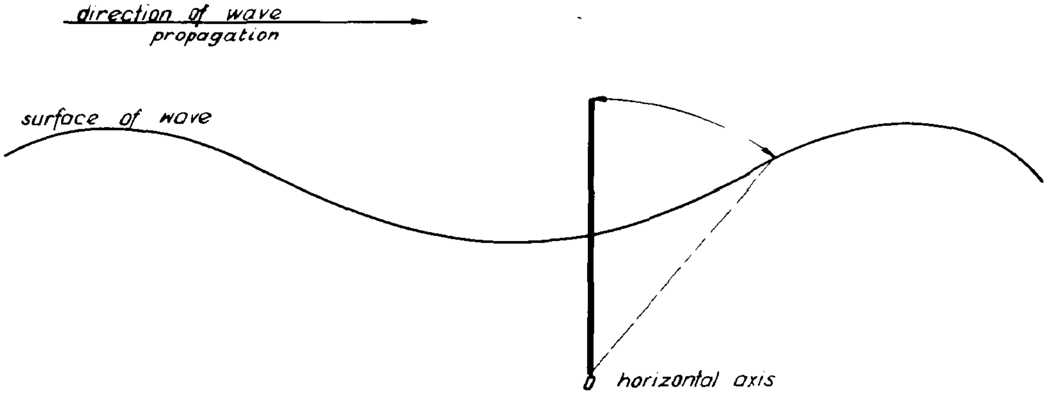


FIG. 20. — The behaviour of the vertical plate with its axis of rotation below the water surface during undulation

A sum of moments of forces acts upon a plate whose axis is placed above the water surface. These moments are the result of the orbital movements of the water molecules, and they act upon the surface of the plate in relation to its axis of rotation during the whole period of the wave. The sum of these moments acts in a direction opposite to that of the wave propagation and causes some oscillation of the plate in the direction opposite to that of the undulation.

In the case where the axis of rotation is located below the water surface, the sum of the moments of forces caused by the orbital motion of water and acting upon the plate takes the same direction as the wave propagation.

The above experiment shows that it is too soon to draw any conclusions from the phenomena concerning currents observed in the undulating water zone, and that special attention to this factor must be paid in all measurements of sea-currents.

7. — GENERAL REMARKS

It is clear from the contents of their article that the authors have not heard that papers in both Polish and English were published in 1959-1960 [2], [3], [4], [5], on the subject of sea-current measurements in general, and by means of current-meters in particular, and that the defects of the sea-current meters employed were analysed in these publications.

In the light of the problems discussed in the present work the authors' advice for working out the observation data concerning the influences of the undulating water layer seems to have relatively little value, since drawing conclusions relating to sea-currents on the basis of the present observations without regard to the influence of the actual waves gives rise to doubts as to the existence of the sea-currents charted on maps.

The first of the authors' conclusions concerning the uselessness of employing current-meters of the irreversible type is completely correct. On account of the fact that their other conclusions are based on principles that are not quite accurate, these are rendered somewhat valueless.

8. — CONCLUSIONS

From the above considered problems we may draw the following conclusions concerning ways of carrying out observations of sea-currents.

1. The geomagnetic-electrokinetographic method (GEK) is the only one which should be employed for measuring sea-currents at the water surface.
2. For measurements of sea-currents below the water surface in the layer of undulating water, it is best to perform the observations with at least two current-meters of the reversible type and fixed rigidly with a set horizontal angle between the meters.
3. Before starting the measurements it seems advisable first to test in the laboratory the behaviour of the speedometer, which should be oriented perpendicularly to the water-flow.
4. The elements of the short-period waves must be measured simultaneously with the sea-current observations in order to permit the subsequent elimination of the influence of such waves.
5. The ship used for the measurements should be steered with her longitudinal axis parallel to the direction of wave propagation, and her length should exceed two wave lengths.
6. In the course of processing the data gathered the influence of long period waves must be taken into consideration, i.e. the tidal, barometric and seismic waves of long period.

7. Because attention has not been paid to all these requirements either in the measurements or in these authors' research work there is not yet any possibility of confirming the actual existence of currents marked on maps.

8. Observations of the currents should be carried out without regard to the present so-called ' sea-currents '.

9. Current-meters equipped with speedometers of the anemometric type are absolutely unsuitable for measuring sea-currents [1].

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