CHAPTER 4

THE USE OF RADAR IN HYDRODYNAMIC SURVEYING

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INTRODUCTION

During several kinds of surveys at sea or in the wide estuaries in the South West of the Netherlands the location of moving objects presents a problem. When studying the various systems of radio location it appeared that radar, an instrument which gives a birds eye view of a fairly extensive area, could be a useful aid in solving this problem. Especially when it was shown that with the newly developed short-wave radar sets wave crests were clearly visible on the radar screen, it was considered worth while to carry out some tests to see whether radar would really be useful for surveying purposes. In 1958 the Rijkswaterstaat hired an 8 mm radar set for a trial period. The tests were carried out at the mouth of the entrance channel to the Rotterdam harbour, the Rotterdam Waterway.
During these tests it became evident that radar could solve several problems and that valuable information about wave patterns could be gathered with this instrument. The set was bought and then used to determine

1. flow patterns
2. wave patterns
3. the behaviour of ships in fairways.

In paragraphs 2 and 3 some basic principles of radar are discussed in order to establish the special requirements the radar equipment must satisfy for this particular purpose. [1]
In paragraphs 4-7 the methods of observation and the results obtained for the purposes mentioned above are discussed and some practical examples given.

GENERAL PRINCIPLES OF RADAR

A radio transmitter, operating on a very short wavelength radiates frequent and regular pulses of energy. These pulses travel out into space like a train of short radio waves of a certain length. By means of a suitable aerial system the transmitted energy is focussed to form a narrow pencil or beam.
When the wave train hits an object a certain amount of the radio energy is reflected, generally in many different directions. Only a very small amount of energy travels back to the point of transmission in exactly the opposite direction. Here the returning energy is received by an aerial and amplified in the radar receiver unit.

The time that has elapsed between the moment of transmission of a certain pulse and the receipt of its echo is a measure of the distance between the transmitter and the reflecting object, using the known speed of the propagation of radio waves, which is about 300,000 km/sec.

The aerial system that focusses the transmitted energy is rotated mechanically at a constant speed of about 20 revolutions per minute, consequently, the transmitted beam of energy "scans" the horizon. For this reason the aerial system if often called the scanner.

The distance and the azimuth of the object appears on a cathode-ray tube.

The cathode of the tube radiates a stream of electrons which is focussed to a beam with spot-size diameter at the inner surface of the tube.

By gradually increasing the current supplied to the deflection coils this beam is deflected radially from the centre of the tube to the edge, starting at the moment of transmission of a pulse. The radial line followed by the beam at the surface of the tube is called the time base.

According to the range scale selected by setting the range switch the time base current rises at a rate appropriate to the speed at which the beam should travel from the centre to the edge. If, for instance, the radius of the tube has to represent a target range of 10 kilometers, the electron beam has to reach the edge of the tube in the period that the pulse radiated by the radar transmitter makes the trip to the target and back of 20 km, i.e. 67 microseconds.

The inner surface of the tube is coated with a substance that becomes fluorescent when it is hit by a sufficiently strong beam of electrons. The beam following the time base, is not strong enough to make the trace visible. The reception of an echo by the radar receiver unit, however, results in an extremely short momentary increase in the intensity of the beam of electrons, sufficient to make the coating fluorescent. The afterglow of the coating causes the spot to remain visible for some time. The distance of the brillant spot from the centre, measured along the time base is proportional to the distance between the transmitter and the reflecting object.

The time base appearing on the screen as a radial line is rotated with the scanner by means of a servo system, which synchronizes the rotation of the scanner with the rotation of the deflection coils of the cathode ray tube. By this arrangement the difference in azimuth of the various targets in the field is shown on the screen and the location of the objects is visible on the screen in their correct relative positions.

CHOICE OF EQUIPMENT

Resolving power. If it is desired to use radar for surveying purposes the apparatus used must be capable of working very accurately indeed.
One of the most important points to watch when choosing radar equipment is its resolving power. [2]
The resolving power of radar can be divided up into two categories, viz., radial and tangential. Radial resolving power is determined by the duration of the pulses transmitted.
Two targets situated at a radial distance ΔR can only be distinguished when the difference in the time taken by a pulse to reach and return from both targets is longer than the pulse-length τ. If c is the propagation speed of radio waves the resolving power is $\Delta R = \frac{c\tau}{2}$
A short pulse-length is required to obtain high resolving power. For technical reasons the pulse-length cannot be shortened indefinitely. However, the shorter the wavelength is the shorter the pulse-length can be made.
For a radar set with a wavelength of 3 cm the minimum pulse-length is about 0.1 μ sec giving a resolving power of 15 m. When a wavelength of 8 mm is applied the pulse-length is about 0.05 μsec giving ΔR = 7.5 m.
For a wavelength of 4 mm the min. pulse-length is about 0.01 μsec and ΔR = 1.5 m.
Tangential resolving power is determined by the width of the horizontal beam of the energy radiated.
For longer ranges the width of the beam θ is proportional to $\frac{\lambda}{D}$ when λ = wavelength and D = width of the scanner. Good tangential resolving power can be obtained by using a short wavelength or a large scanner. For a 1.5 metre scanner we find the following data for θ and the resolving power $R\theta$ for a distance R = 1000 m for various wavelengths.

λ = 3 cm	θ = 1.2°	$R\theta$ = 21 m
λ = 8 mm	θ = 0.4°	$R\theta$ = 7 m
λ = 4 mm	θ = 0.2°	$R\theta$ = 3.5 m

A short wavelength must be used to obtain a high tangential resolving power to avoid making the scanner awkwardly large.
It will be evident that the resolving power of the cathode ray tube of the display unit will have to match the resolving power of the radar set itself. The spot diameter of the electron beam on the radar screen is about 0.3 mm. The max. screen diameter of radar sets is mostly 30 cm, giving for a max. range of 3,000 m a scale of 1:20,000. Then the diameter of the spot on the screen represents a circle of 6 m in the field.
This implies that the resolving capacity of the tube and the max. scale which can be applied during the survey in view of the accuracy desired determines the max. range at which the radar can be used. In most cases this max. possible range does not exceed 5 km.

Radio-wave propagation. During the propagation of radio-waves through the earth's atmosphere the transmitted energy attenuates. The ratio of this attenuation depends largely on the wavelength. Oxygen gives an attenuation which has sharp peaks at 5 mm and 3 mm wavelength. The presence of water in the atmosphere gives an additional attenuation which depends again on the form in which the water appears. An increase in the amount of water in the atmosphere causes greater attenuation. [2]
Fig.1 shows the attenuation for wavelengths under 32 mm for oxygen and water in various forms in the atmosphere.
From this graph may be concluded that the wavelengths of 5 and 2-3 mm is unsatisfactory for radar in any case. Of the very short wavelengths 8 mm and 4 mm are the most satisfactory for this purpose, but these wavelength will only be useful for radar sets for special short-range purposes.

Response of targets. A natural target is very seldom an ideal reflector and usually only a very small amount of the energy striking it is reflected, while an even smaller amount will be reflected in exactly the opposite direction.
The reflection properties of a target depend on the size, shape orientation and material of the object. Metal or water have better reflecting proporties than wood or sand. It has been observed that a wet wooden pole reflects much better than the same pole dried by the sun. Size and shape however, are the main factors. Given a certain shape and material and a given inclination of the surface with respect to the radar waves, the amount of energy reflected will increase roughly proportionally to the size. Sizes larger than the cross section of the radiated beam of course do not contribute to the echo strength.
If the transmitted energy is E_t, the energy hitting the target per unit of area will be $\frac{\gamma E_t}{4 \pi R^2}$

γ is a factor expressing the degree of focussing.
A target with a reflecting capacity σ reflects a quantity of energy unit of area near the receiver of

$$\frac{\sigma}{4\pi R^2} \cdot \frac{\gamma E_t}{4\pi R^2}$$

If the receiver aerial has a cross-sectional area of F_R the energy received will be $E_R = \alpha \frac{\gamma E_t \sigma F_R}{16 \pi^2 R^4}$

α is the atmospheric attenuation discussed in 2.1. As mentioned in 2.1 the narrowness of the beam of energy transmitted increases as the wavelength decreases. So γ depends on λ and the energy received will increase, too as the wavelength decreases.
This R^{-4} relation only holds good up to a certain distance from the radar mounting. This area is called the near zone. Outside this range an R^{-8} relation obtains. This division into two zones has been shown to be due to an interference phenomenon caused by reflection from the surface of the water. In the far zone the target is wholly below the lowest lobe of the interference pattern, so that the illumination of the target is less than the free space value, and becomes progressively less as the target moves

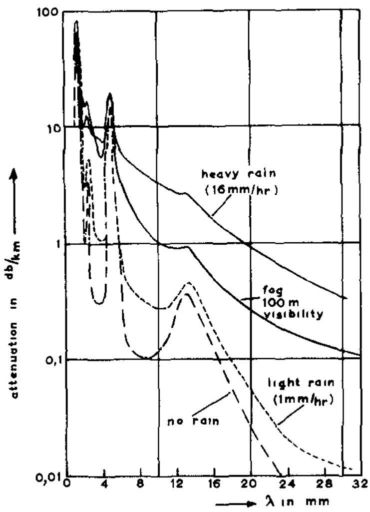

Fig. 1. Atmospheric attenuation of radar waves.

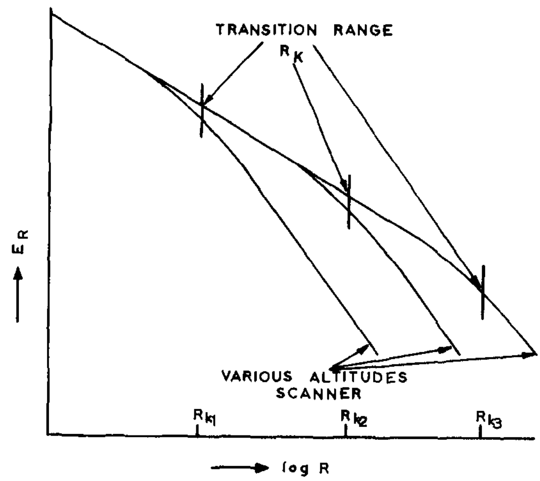

Fig. 2. Position of the transition range of various altitudes of the scanner.

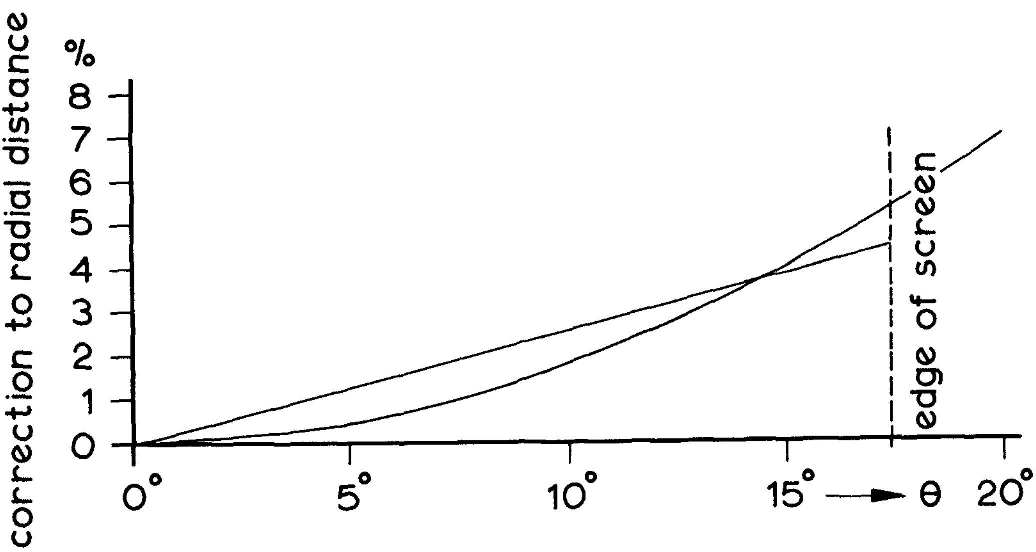

Fig. 3. Correction curve for radar photographs.

out of range. [3]
The location of the transition zone between the near and the far zone is expressed approximately by the formula

$$R_K = 2\pi \frac{h_1 h_2}{\lambda}$$

in which R_K = range of the transition zone
h_1 = height of the scanner above sea level
h_2 = height of the target above sea level
λ = wave length.

From this formula it appears that the range of the transition zone increases in proportion as the wavelength decreases. In the following table some values for R_K are given for various wavelengths, scanner heights and target heights [2]

λ	R_K h_1 = 5 m h_2 = 1 m	R_K h_1 = 5 m h_2 = 5 m	R_K h_1 = 10 m h_2 = 1 m	R_K h_1 = 10 m h_2 = 5 m
32 mm	1 km	5 km	2 km	10 km
8 mm	4 km	20 km	8 km	40 km
4 mm	8 km	40 km	16 km	80 km

The response of wave crests is of special importance to the use of radar in hydrodynamic surveying.
It has been shown that a swell itself does not reflect radar waves, but that the small wind-generated facets which overlie the main large-scale wave pattern are due to the reflecting properties of the waves.
The phenomenon of sea return, what is known as "sea clutter", has been studied for several purposes, but mainly with the aim of suppressing it in the receiver unit, because it tends to obscure the echos of ships.
Out of the many publications on the subject attention is drawn to [3].
It will be evident that only facets of a suitable size and orientation will reflect in the desired direction.
The distribution of these facets has been studied statistically and it has been shown that scattering is concentrated in the vicinity of wave crests. Ideal reflection is from perpendicular facets facing the radar equipment. They have also been shown statistically to be most frequent near the wave tops, especially to windward, where the crests of the waves tend to be steepest. When the angle of incidence of the radar waves is small the wave crests screen the troughs and only the wave crests facing the radar equipment are irradiated by the radar waves. If radar views an area-extensive target like a choppy sea the azimuthal extent of the surface illuminated is equal to $R\theta$. So here instead of the R^{-4} relation for a target of limited dimensions discussed above an R^{-3} law holds for the intensity of the energy received in the near zone. Outside the transition zone for sea-clutter an R^{-7} law holds instead of the R^{-8} relation for targets of limited size. It will be evident that outside the transition zone the naturally weak response from wave crests will soon cease to be

detectable on the radar screen. Therefore a radar set with a short wavelength, giving a big range for the transition zone is required for wave research. The values of the energy received on a given wavelength from the sea surface, for different altitudes of scanner and under the same sea conditions should give a group of curves as shown in fig.2. Here the transition zone is only a function of the height of the scanner.
For this reason the scanner should be placed as high as possible, consistent with local conditions.

Conclusions.

1. A short wave-length radar set is suitable for getting high resolving power both radially and tangentailly.
2. The use of short wavelengths implies that these sets can only be used for short-range work because of the relatively strong attenuation of radio energy in the earth's atmosphere. However, as radar is only practicable in hydrodynamic surveying for relatively short ranges (about 5 km max.) short-wave sets are satisfactory.
3. The energy received from the target is stronger for short wavelengths, owing to the better focussing of the energy transmitted.
4. The range outside which targets reflect rapidly decreasing amounts of energy increases as wavelengths shorten.
5. A short-wave radar set is required for wave-research.

All the above-mentioned conclusions point to the desirability of using short-wave radar for hydrodynamic surveying.
As mentioned under 3.2 of the very short wavelengths the 4 and 8 mm waves show a relative minimum attenuation and are therefore most suitable.
Since 4 mm radar sets are not yet being manufactured commercially an 8 mm radar set is being considered. A Decca 8 mm radar set is being used for surveying purposes in the Deltaworks.
Specifications:

aerial system	
reflectors	Double 6 ft "cheese" (one transmitting one receiving)
horizontal beam	of the order of 23'
vertical beam	of the order of 14°
pulse characteristics	
pulse length	0.05 μsec
recurrence frequency	4000 per sec
display	
screen diameter	30 cm
scales	0.5, 1,3 and 10 nautical miles

Most navigational radar sets work on a wavelength of 3 cm. The use of these sets for surveying purposes is only justified when the objects are of the same size as or bigger than objects lying within the resolving power of the equipment, e.g., ships. For

the determination of the courses of ships a good 3 cm radar specially adjusted for short-range use like river-radar sets are satisfactory.
A set working on a shorter wavelength is required for the determination of wave patterns and flow lines.

RECORDING OF DATA AND ACCURACY THEREOF

The moving objects which have to be located appear on the radar screen and their continuously changing positions relative to objects known to be stationary, such as the shore line is observed.

In most cases the situation at a particular moment must be retained at regular intervals. This can be done in several ways, viz.,

1. by measurement on the radar screen direct
2. photographically.

A fluorescent circle of any desired radius can be made to appear on the screen by means of an electronic device (the variable range marker) built into the 8 mm radar set mentioned before. The radius selected can be read off a scale direct. The distance an object is from the radar set can be determined instantly by making the circle pass through the image of the object.

The azimuthal location of the object can be determined by means of a rotatable cursor fitted on the top of the screen. The scale factor of the variable range marker and its zero correction can be determined by checking the variable range marker against some suitable landmarks the coordinates of which are known.

If these constants are applied to the scale readings reasonable accuracy of location can be obtained.

If a maximum range of 3000 m is used for the radar picture the standard error of range measurement is of the order of 15 m, which includes an error of about 5 m caused by backlash in the gearing of the mechanical part of the device. The standard error in the measurement of the azimuthal location of the object is of the order of 0.3°.

This method of location however takes much time and is therefore not suitable when numerous objects have to be located. Then it is better to take photographs of the picture on the radar screen. This method has the advantage that the situation at a given moment can be recorded, thus facilitating subsequent examination. A standard 6 x 6 cm^2 camera is used for photographing the 30 cm tube of the 8 mm radar.

In order to avoid geometrical distortion as far as possible care should be taken that the camera axis is in line with the axis of the cathode ray tube. The camera should be rigidly attached to the radar set.

A radial distance on the curved surface of the cathode ray tube appears on the photograph as a straight line. That is the main problem connected with the geometrical interpretation of radar photographs. The degree of distortion depends on the radius of curvature of the cathode ray tube, on the radial distance of the image from the centre of the tube and on the distance between

the camera and the tube.
In our case the camera is 48 cm from the tube, which has a radius of curvature of 40 cm. Fig.3 shows the magnitude of the distortion for this case in expressed as a percentage of the radial distance as a function of the angle θ between the axis of the camera and the line joining the centre of the objective to the echo of an object on the radar screen. From this figure it can be seen that the correction which has to be applied to the radial distance shown on the photographs increases progressively up to 5.5%. However, this percentage can be reduced considerably by applying a correction increasing proportionally to θ , which in fact merely means attaching another scale to the photograph.
Fig.3 shows a max. correction of about 0.9% when this is applied. This means that if the max. range is fixed at 3000 m the correction at 1500 m is about 15 m; at 2200 m the correction is negligible, beyond this range the correction increases sharply up to 27 m at the edge of the screen. In most cases this degree of accuracy is satisfactory.

If greater accuracy is desired the actual corrections must be applied but this is very laborious when numerous locations have to be determined.

If the approximation of the correction curve to a straight line is acceptable it is a simple matter to deduce the information required from the photographs.

Then the negatives can be projected direct on to a chart bearing the desired scale.
Standard photographic enlarging apparatus can be used for this surpose. Care should be taken that enough landmarks can be distinguished on the negatives equally distributed through out the range. Their echos are used to place the projected image correctly on the chart.
All the data can then be filled in on the chart. When dealing with moving targets like floating buoys the successive negatives should all be projected on to the same chart, thus indicating the flow lines direct.

CURRENT MEASUREMENTS

The way in which currents are measured depends largely on the purpose for which they are intended. In the complicated estuaries in the south-west of the Netherlands it is often necessary to determine the total flow as a function of time in various gullies and over adjoining sandbanks. Here simultaneous measurements are required, because measurements carried out on different days are not easy to compare because of the variations in the tides, in the discharges of rivers, in the wind, in the density differences, etc.

Current velocity is determined at numerous points on lines running at right-angles to the gullies. This indicates the flow in the gullies and over the sandbanks. The flow across each of these lines can be ascertained by measuring the velocity and direction of the current at fairly short time intervals at a sufficient number of spots and at several depths at each of these

spots. This method calls for a large number of vessels, instruments and operators, especially in extensive areas.
By this method information can be obtained about the flow distribution in a cross-section at any moment and about the variation in time of the total flow through a cross-section of an estuary. In many cases however, detailed information is also desired about the patterns of the flow lines, so that they can be compared with the results obtained from model tests and used for the study of erosion problems. These data cannot be derived from simultaneous measurements. Floats are used to determine the flow pattern. Especially in wide estuaries, like those in the southwest of the Netherlands, the main difficulty is how to locate the floats.
They can be located as follows:

1. Terrestrially, with the aid of sextants from a survey launch, following the floats.
2. With the aid of a radio location system, e.g., the Decca system, on a following launch.
3. Photogrammetrically.
4. By radar.

The number of floats usable in the first two methods is limited because there are limits to the number of operations that can be carried out on board a launch. When the velocity of the current is fairly high readings must be taken every few minutes and the number of floats which can be handled by one launch is limited. to two or three . This means that for wide areas to be covered with numerous floats the first two methods can be rejected. Therefore, they are only used for incidental detailed surveys of small areas.

The use of the third method employing airial photography requires that the aircraft return to the same point at regular intervals to photograph the area concerned. This means that as a rule not more than two points can be taken from which the whole area must be seen, unless more than one aircraft is used. This means that the aircraft must fly at a fairly high altitude if the area is at all extensive. This in turn calls for very good visibility and clear recognisability of the floats. If readings must be taken continuously throughout a tidal cycle two planes will be required as a rule and thus the use of this method will be still further restricted when the days are short.

The last method of location, with the aid of radar, has the advantage that with two launches numerous floats can be tended. One boat drops the floats and the other picks them up again, so work on board is reduced to a minimum. This method is also independent of daylight and visibility. Only very heavy rain and a rough sea can reduce the visibility of the floats on the radar screen but under such conditions operations at sea are also impossible.

The floats have to be provided with radar reflectors to make them visible on the radar screen.

Radar reflectors consist of prisms and pyramids similar in shape to those used in optics. They look like the corner of a box so they are called corner-reflectors. For use on buoys the corner reflector has to be designed in such a way that its wind resistance is as low as possible. A Swedish invention the spiral reflector has been chosen for this purpose. It consists of a folded sheet metal strip twisted into a spiral with transversely welded plates to produce a large number of horizontally directed corner reflectors (fig.4). [4]

The spiral reflectors used here are 9 cm in diameter and are 47 cm high.

Comparative tests on stagnant water have shown that the wind catch of these reflectors is less than or does not exceed the wind catch of other traditional markers on buoys such as flags or the foam-rubber plates used for making them clearly visible from the air.

Finally, an example of current measurement will be discussed, one which was carried out in the Haringvliet during the construction of the building pit for the big sluices. It was evident that such an obstacle, occupying about one third of the cross-sectional area of the estuary would lead to an important change in the flow pattern and that these changes in turn would cause considerable erosion in the neighbourhood of the pit. For this reason an extensive survey was carried out to determine the changes in the flow pattern. Along four lines perpendicular to the main gullies simultaneous measurements were carried out at various stages in the construction of the pit.

The changes in the velocity-distribution in the cross sections could be derived from these measurements and an overall picture of the flow lines in the entire estuary could also be worked out from them.

Fig.5 shows the cross-sections along the axis of the pit before and some months after its construction, together with the corresponding current diagrams. The overall picture of the flow-patterns of the maximum flood and ebb currents before and after the construction pit was built are shown in figs. 6 a/d.

These patterns, however, do not give enough information about the flow pattern in the immediate vicinity of the pit, which is 1400 m long.

In order to establish this flow pattern additional float measurements with 8 mm radar have been carried out.

Fig.7 shows the results of a reading taken during construction at the instants of max. ebb en flood currents. The position of the Decca 8 mm radar set is marked. The radar apparatus was working on a max. range scale of 3000 m so that the scale of the image on the radar screen was 1 : 20.000. Two boats which had continous radio contact with the radar post were used to handle the floats. Every 2 or 3 minutes the location of the floats was recorded by photographing the radar screen.

WAVE MEASUREMENTS

Information with regard to the waves can be obtained by making use of weather maps or wind data measured direct. Wind fields over a certain sea area can be determined with the help

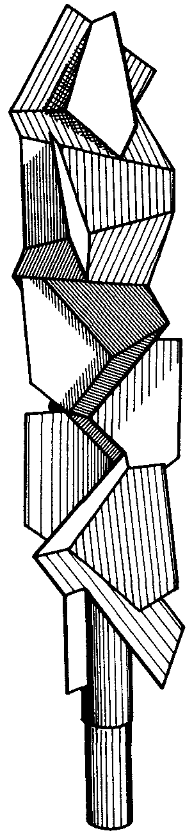

Fig. 4. Spiral radar reflector.

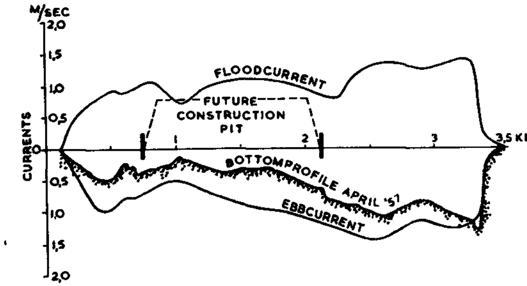

Fig. 5a.

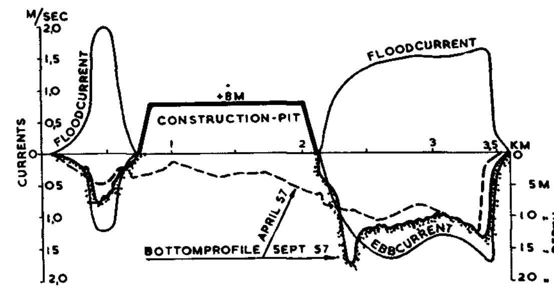

Fig. 5b

Fig. 5. (a) Currents and cross-section in axis of pit before its construction. (b) Currents and cross-section in axis of pit after its construction.

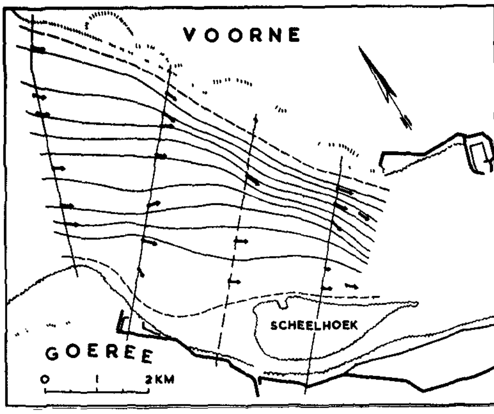

Fig. 6a

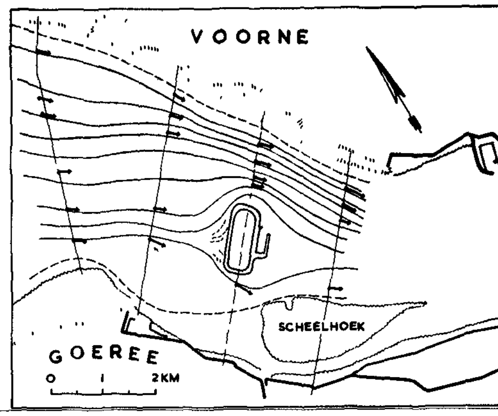

Fig. 6 b.

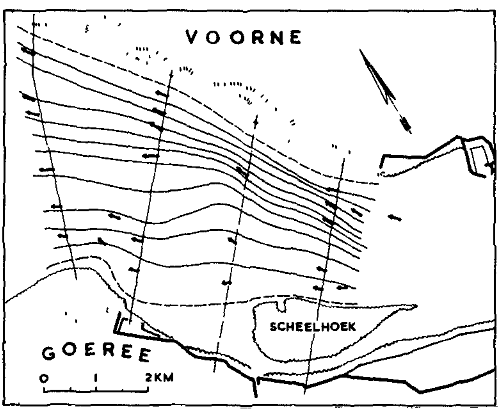

Fig. 6c.

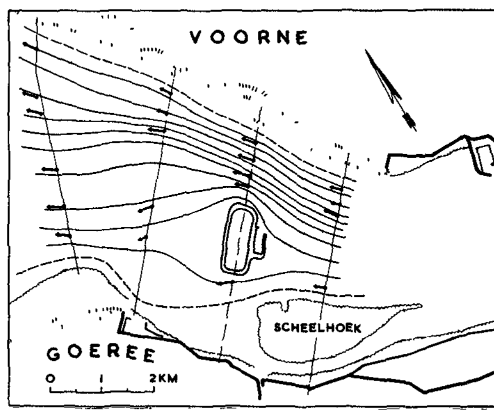

Fig. 6 d.

Fig. 6

(a) Flood current in Haringvliet without construction pit.
(b) Flood current in Haringvliet with construction pit.
(c) Ebb current in Haringvliet without construction pit.
(d) Ebb current in Haringvliet with construction pit.

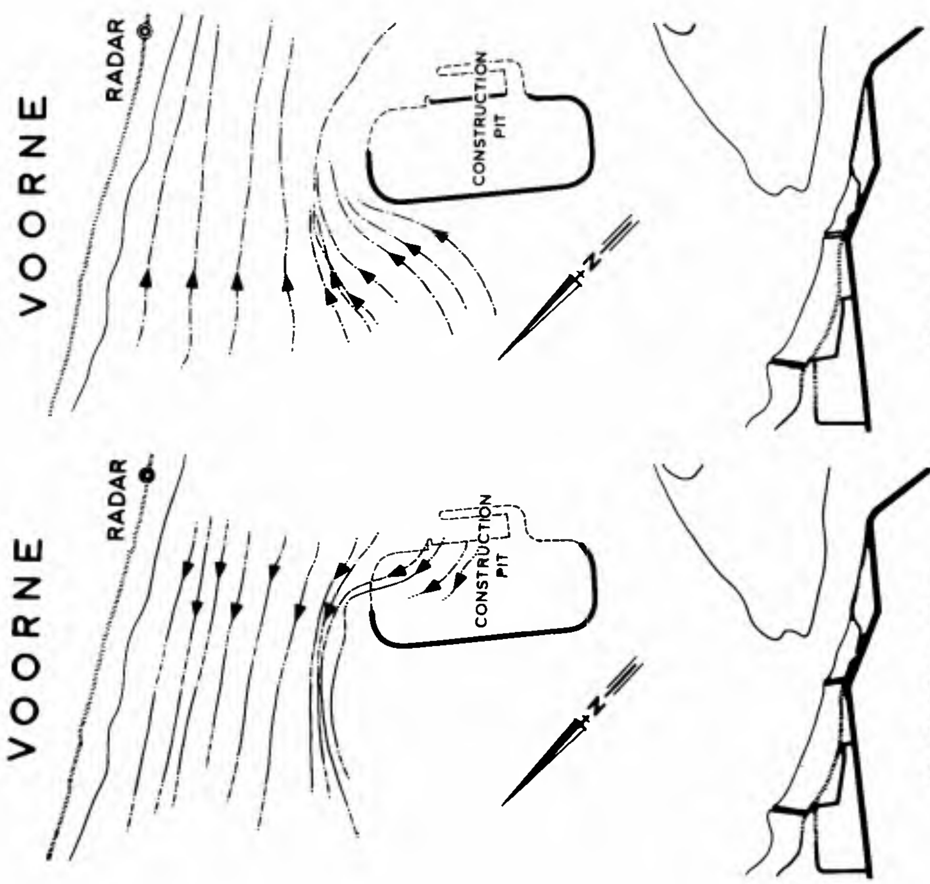

Fig. 7. (a) Ebb flow pattern determined with radar. (b) Flood flow pattern determined with radar.

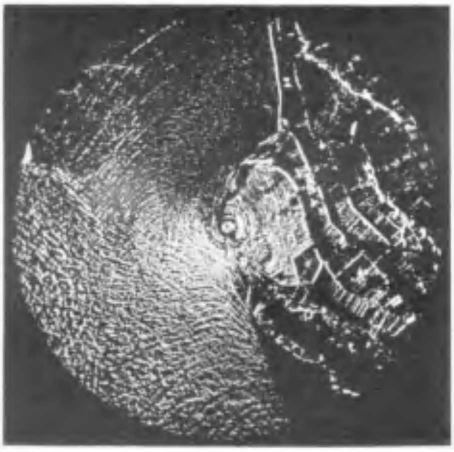

Fig. 8. Radar picture of wave pattern Veerse Gat.

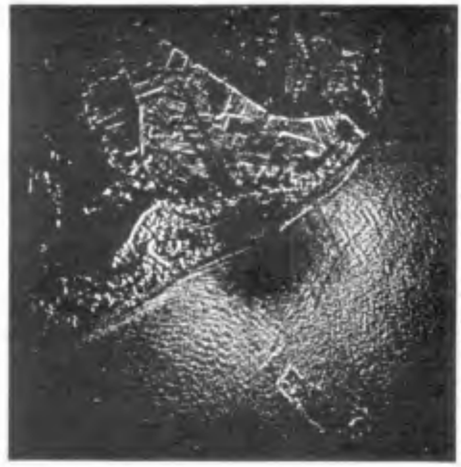

Fig. 9. Radar picture of wave pattern Haringvliet.

of weather maps and the wave motion at a certain place and moment can be determined roughly in the case of a deep sea by means of the relevant well-known formulae or graphs. Similar calculations can also be applied in the case of more shallow waters, but many difficulties are met with when such factors as diffraction, refraction, bottom friction, breaking, currents, etc., play an important part. Many such like problems also arise in the case of the coastal waters and the complicated estuaries in the south-west and here this method is generally impracticable. Then it is necessary to collect all the wave characteristics such as height, period and pattern locally by direct measurement and compare these data with the meteorological conditions.

The measurement of the height and period of waves only as a function of time at certain fixed points can be done visually or with the help of various kinds of instruments developed in recent years. Measuring poles equipped with wave recorders have been at placed at various spots in the Delta area. Determination of the direction of propagation of waves, or more generally the wave pattern, is a more complicated matter.

Visual observation of wave direction is usually unsatisfactory. Only a limited area can be seen from the shore or ship generally. Often it is very difficult to distinguish between waves coming from different directions, especially when the observer is low down. Moreover, short waves generated by local winds often hide the more important ground swell arriving from distant storms so that the observer will often only report the direction of local wind-waves and not that of a swell.

One of the oldest ways of measuring wave direction is the photogrammetrical method. This and the radar method, which will be discussed later, are the only means so far known by which the wave pattern in the coastal region and in the estuaries in the south-west could be studied systematically.

For extensive areas the photogrammetrical method can only be used when the photographs are taken from an aircraft. In the Delta project this method is used to study the deformation of waves during their propagation as they move from the relatively deep sea in towards the shore.
Stereographic aerial photographs are taken from two aircrafts flying at a speed of about 540 km.p.h and an altitude of 5000 ft. The shutter mechanisms of the cameras are synchronised electronically. This method has the advantage that wide areas can be covered in a relatively short period. On the other hand, however, this method can only be used when weather conditions are favourable. They are not often so when gales are blowing. The altitude of the clouds and unfavourable illumination of the sea surface are the main limiting factors. This disadvantage becomes apparent when the wave pattern has to be determined under various tidal conditions and for different wind directions. For this purpose numerous flights have to be made, which is in most cases almost impossible and very expensive. The only alternative is radar. This method is almost independent of weather conditions and observations can be made at night as well as in

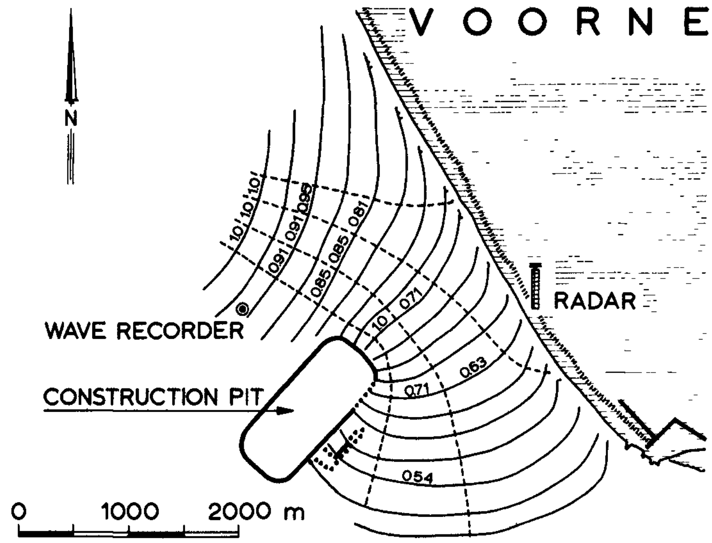

Fig. 10. Schematisation of wave pattern Haringvliet.

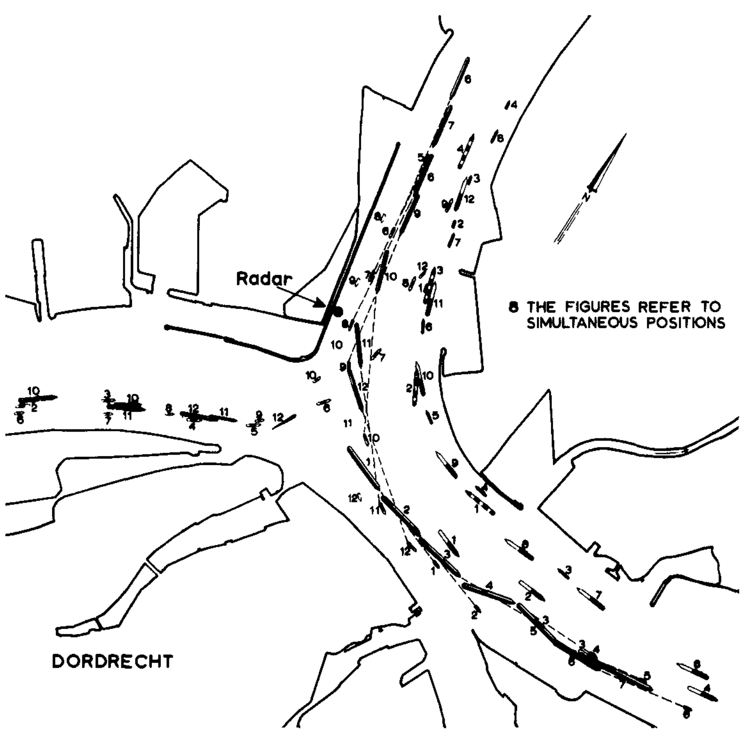

Fig. 11. Ship tracks at Dordrecht junction.

day-light. Readings can be taken continuously throughout a storm and under all tidal conditions.

For this purpose the 8 mm radar set is used with its scanner located about 12 m above sea level. This enables the wave pattern to be determined up to about 3 km from the radar set. Fig.8 shows a radar picture of the wave pattern at Veersche Gat in the south-west. In this picture the wave pattern is visible 2500 mtrs away. Radar photographs obviate the necessity of making refraction computations which can be very laborious for complicated estuaries. Fig.9 shows a radar picture of the wave pattern at the Haringvliet estuary in the vicinity of the building pit.
A simplified wave pattern can be obtained direct from this photograph. Fig.10 shows this simplified pattern on which the orthogonals have been drawn, together with the calculated reduction in the wave height.

A skilled man is needed for this work, one who is familiar with the method of making refraction computations, especially when several wave patterns are superimposed.

DETERMINING THE BEHAVIOUR OF SHIPS IN FAIRWAYS

The changes in tidal movement at several shipping-route junctions due to the construction of the Deltaworks will give rise to some problems. Hydraulic reduced-scale models of these junctions are being constructed in which the future flow-pattern and the consequences of the changes for navigation will be investigated.

In these models the movements of ships are imitated by self-propelled scale models of several types. The model is tested by observing the behaviour of these ships under the present flow-conditions. For this purpose the tracks of actual ships have to be determined in reality.

In view of the high speed of the ships they have to be located at intervals of about 45 sec. This rules out the use of aerial photographs; this method is also very expensive because of the numerous flights which have to be made to get enough material. Shipping is very dense at various junctions from 6 to 10 ships approaching the junction simultaneously. This makes it impossible to determine the positions of the ships in the fairway from the shore with theodolites.

This is where radar comes in. Fig.11 shows the result of a radar shipping measurement carried out in the vicinity of Dordrecht.

A 3 cm Decca 214 river radar was used. This type of radar is specially designed for short-range work, and it is sufficiently accurate when one considers the size of the vessels.

The photographs of the radar screen were taken at intervals of 45 sec. The radar picture extended to 2000 mtrs.

The results of this and numerous other measurements carried out under various conditions were a great help in evaluating the model results.

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