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DEFINITION OF THE SEABED IN NAVIGATION ROUTES THROUGH MUD AREAS

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ABSTRACT

Over most types of seabed the interface between the seabed sediment and the overlying sea water column is sharp and clearly identified by survey echo sounders. However, in areas with a large mobile population of cohesive sediment (mud), dense layers of suspended sediment occur which are intermediate in character between muddy seawater and the settled mud of the bed.

Such suspensions (fluid mud) may create a surveying problem, owing to the multiple layering they produce on echo-sounder records. Echo-sounders alone do not allow an objective decision on which reflector should be regarded as the seabed for navigational purposes.

A new technique has been devised involving detailed profiles of *in situ* density through the suspensions using gamma-ray densimeters. This information, together with knowledge of ship behaviour in dense media, facilitates decisions on what values of *in situ* density should be defined as the seabed. A density value of 1.2 gm/cm^3 is now used by the Netherlands Rijkswaterstaat to define the "Nautical Depth" since research has shown that suspensions of lower density do not significantly impede the passage of ships.

In Europort sudden influxes of sediment during storms produce layers up to 3.0 m in thickness which are detected by echo-sounders, and once the presence of such a suspension resulted in the temporary closure of the

port to supertanker navigation. However, density surveys reveal that on arrival these suspensions are of very low density and thus do not present a hazard to navigation.

Density surveys are also used to guide the maintenance dredging fleet to areas where the 1.2 gm/cm^3 density level is shallower than the nominated datum for the channel or to areas where consolidation has progressed to a point where high production is possible.

INTRODUCTION

Estuaries and other coastal inlets commonly have circulation systems which retain silt, and the navigation routes approaching many of the major ports in the world have a mud deposition and a static suspension (fluid mud) problem.

Recent work on cohesive sediment suspensions in coastal areas (KIRBY and PARKER, 1977) [1] has revealed the behavioural link between sediment suspended in the water column and dense cohesive sediment suspensions on the seabed. This work shows that high energy events (tidal currents or storms) erode cohesive sediment and transport it into navigation channels. When first eroded the sediment is mixed throughout the water column as a homogeneous mobile suspension. As energy levels decline, the mobile suspensions begin to differentiate by settling, forming marked steps which continue to subside through the water column until dense layers several metres thick with density approximately 1.15 gm/cm^3 are observed flowing along the bed. When the energy levels decrease sufficiently these mobile layers stagnate to form dense static suspensions. It is implicit, therefore, that in any areas where static suspensions occur, deposition has been rapid. Mobile suspensions commonly show multiple stratification, and although layering within the static suspensions is also common there is as yet no unequivocal causal link proving the origin of layering in the static suspensions.

Following stagnation the static suspensions continue to settle, and within a few hours they consolidate to a stage where they can be detected by normal hydrographic survey echo sounders (figure 1).

Once they become detectable these suspensions, variously termed fluid mud, creme de vase, slib, sling mud, etc., may present a survey problem since there is no evidence which can be confidently interpreted from the echo sounder record on which layer should be regarded as the seabed. The essence of the problem is that such static suspensions appear very suddenly after storms, commonly have two or more layers and may reach 2-3 m in thickness, enough to intrude significantly above the channel datum.

These suspensions have long been recognised by hydrographic surveyors. In the early days of lead-line techniques a special "mud-lead" was devised to cope with static suspension areas. Latterly echo-sounders have

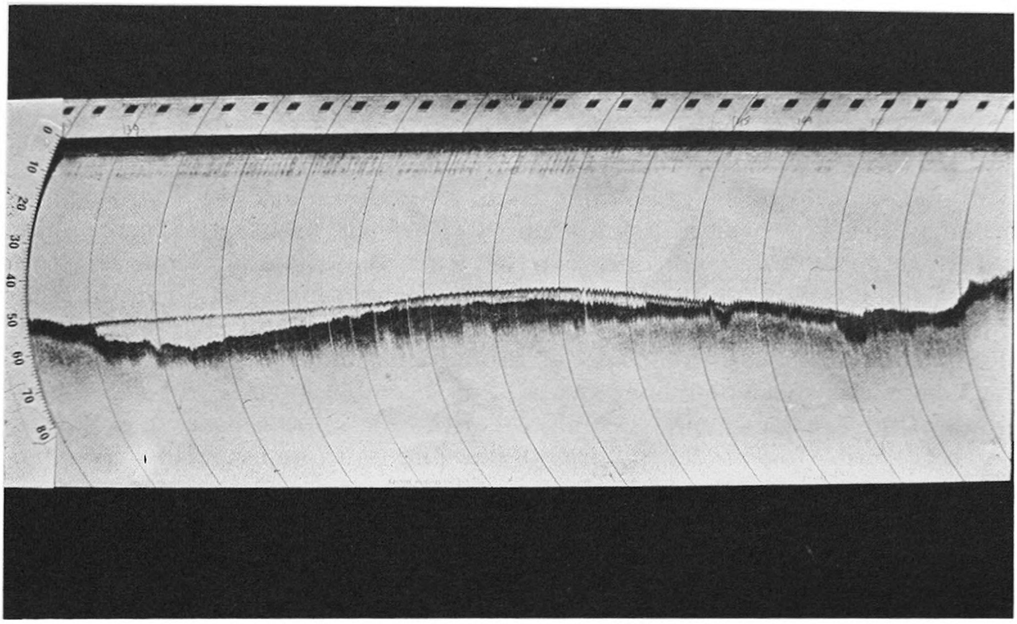

FIG. 1. — 30 kHz echo-sounder record showing dense static suspension overlying settled mud. Scale in feet.

largely replaced the lead line. However, echo-sounders respond to both the density and acoustic velocity gradients of the medium. These acoustic properties cannot be readily converted into information on the altitude within the suspension at which its mechanical properties may significantly affect ship handling. Thus, the information echo-sounders produce in such areas does not allow an objective decision to be made on where the seabed should be. The consequences of arbitrarily choosing one layer or another on the echo-sounder record in the absence of supporting information are considered by PARKER and KIRBY, 1977 [2].

To overcome this problem information is required on the resistance of the static suspensions to the movement of the vessel. This requires two types of investigation. Firstly, measurement of the resistance of the substrata in ideal circumstances requires the *in situ* measurement of the shear strength or "viscosity" of the medium. However, neither can be measured with the degree of precision and rapidity necessary to be practical techniques for hydrographic surveying. Fortunately, both these properties are closely related to the density of the suspension and rapid *in situ* density measurement is now possible (KIRBY and PARKER, 1974) [3]. Secondly, to complement the work on density structure, information is required on the behaviour of vessels sailing through such areas.

TECHNIQUE DEVELOPMENT

In situ bulk density measurement may be achieved by the use of scattered or transmitted radiation from a small radioactive source. The Atomic Energy Research Establishment, Harwell, backscatter probe has a fast response rate and thus can be traversed rapidly. However, the spatial resolution is limited by the source/detector separation. The Harwell transmission gauge has a limited response rate but if it can be traversed slowly enough it has a high spatial resolution. The performance of these densimeters is discussed by PARKER, SILLS and PASKE, 1975 [4]. When either of the density gauges is combined with a pressure sensor, the outputs can be recorded on an XY flatbed plotter and continuous vertical profiles of density versus depth obtained. By making many measurements within a designated area and applying the tidal correction, charts of depths to particular density horizons can be compiled. A survey echo sounder provides some continuity between each vertical profile.

The behaviour of vessels sailing close to the surface and in the upper layers of dense suspensions has been studied on behalf of the Netherlands Rijkswaterstaat. Extensive model tests with a two-layer system to study the sailing and manœuvring characteristics of supertankers in a channel with a soft bed have been carried out in the Netherlands Ship Model Basin. Prototype field tests were made with the 240,000 dwt supertanker *Lepton* sailing in the Europort Channels. Extensive investigations have also been made by NEDECO in the Chao Phraya River, Bangkok, and along the coast of Surinam where ships sail in mud with a negative underkeel clearance. On the basis of these investigations and a literature search it was found that densities up to 1.2 gm/cm^3 had only a slight influence on manœuvrability. It was therefore chosen as the "Nautical Depth" which is defined as "a density within the suspension above whose altitude vessels can safety sail" (figure 2).

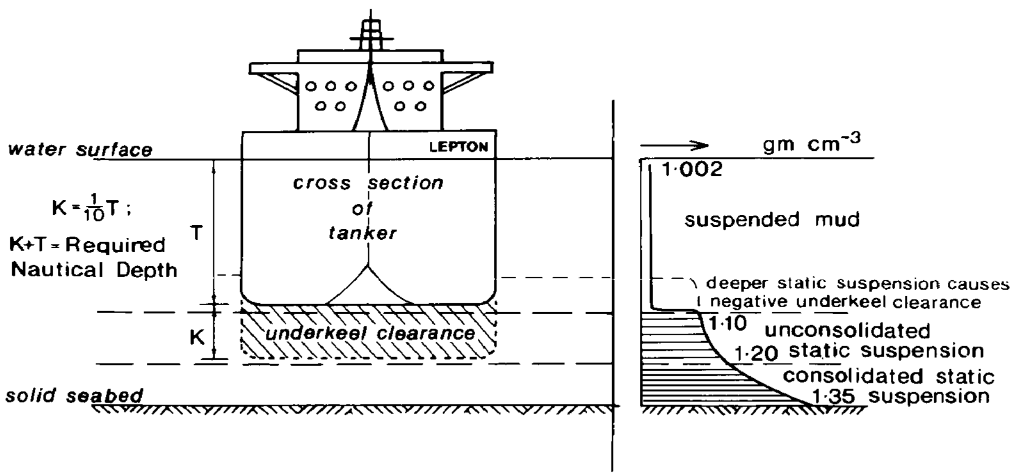

FIG. 2. — Comparison of density profile and tanker cross section to illustrate the concept of "Nautical Depth".

Thus channel datum increases are possible when the upper layers of the static suspensions are included in the underkeel clearance of supertankers. Following evaluation of the technique for surveying the three dimensional density structure, and research into ship behaviour in dense media, the approach has been applied to the Europort channels where dense suspensions at times present difficulties for supertanker entry.

OPERATIONAL EXPERIENCE

Background

The area of the approach channels and waterways of Rotterdam-Europort is about 80 km² (figure 3). In the open sea supertankers are

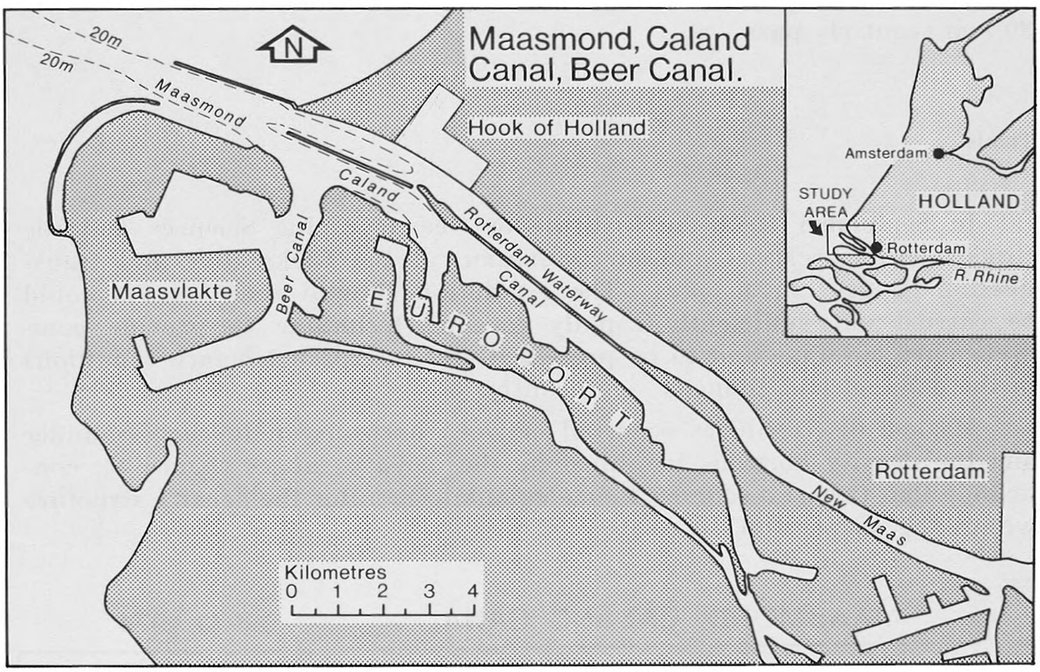

FIG. 3. — The Rotterdam-Europort area, Netherlands.

sailing at full speed and the minimum underkeel clearance permitted is 20 % of the draught. When the vessels slow in the approaches to Europort the minimum underkeel clearance allowed is 15 % of the draught. The approach channel is maintained at a depth of 24.5 m below chart datum. From the breakwaters inwards the channel datum is – 23.5 m whilst the mud areas of the Maasmond, Caland Canal and Beer Canal are maintained at – 22.5 m. Tankers drawing 68 ft (20.7 m) traverse these confined waters very slowly with a minimum permitted underkeel clearance of 10 % (approximately 2.0 m).

The inner parts of the Europort channels require virtually continuous dredging to maintain − 22.5 m owing to mud deposition. Accretion is not a steady process, but is particularly severe in the winter when storms in the North Sea bring in large quantities of cohesive sediment in very short periods. The resulting suspensions may exceed 1.04 gm/cm^3 density and have been recognised as layers more than 1.0 m in thickness moving upstream in the Caland Canal (KIRBY and PARKER, 1977) [1]. Following several days of severe weather during which these mobile suspensions penetrate into the Europort area, static suspensions up to 3.0 m in thickness containing as much as 5–600,000 m^3 of sediment have been found. Over 70 % of the silt dredged from Rotterdam-Europort is believed to enter in this way from the sea, contributing to an annual maintenance dredging production of 13.5 million m^3.

Following stagnation and initial settling these suspensions become acoustically detectable. With a 3.0 m static suspension the first echo on a survey echosounder would come from a depth of 19.5 m below chart datum in a channel maintained at − 22.5 m through which supertankers drawing 20.7 m regularly pass.

Trials

In September 1974 the Institute of Oceanographic Sciences and the Rijkswaterstaat carried out an evaluation of the backscatter and transmission gauges in Europort. The evaluation showed that surveys could be carried out sufficiently rapidly for the technique to provide comprehensive coverage and to be processed and interpreted before conditions in the channel had changed significantly.

Marked discrepancies occurred between horizons on the echo-sounder and the density horizons identified by the density gauges (figure 4), confirming that the echo sounder is inadequate to monitor the density structure within the suspension.

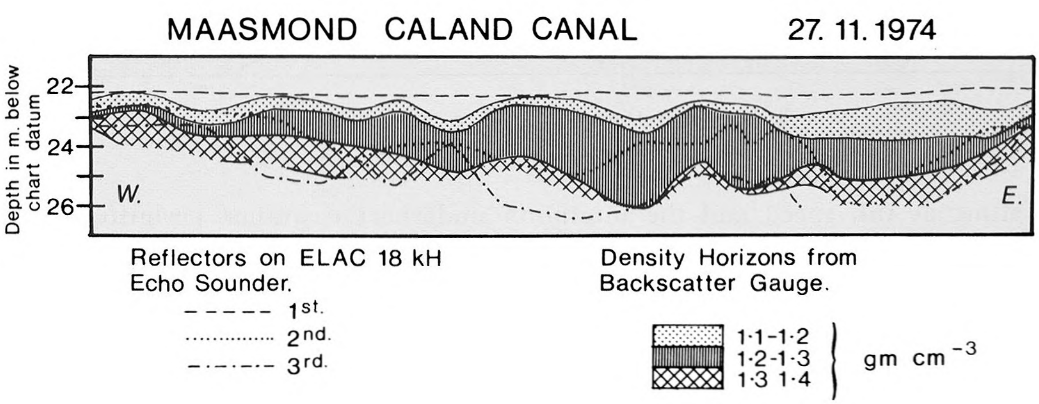

FIG. 4. — Comparison of echo-sounder and backscatter gauge profile along the axis of the Europort channels. Note that echo-sounder reflectors do not follow the density horizons.

This is because the echo-sounder does not respond to progressive density changes, only to major density inflections and other features within the suspension which provide a major change in acoustic properties. These are not necessarily related to specific density values.

By applying a tidal correction to the density soundings, bathymetric density charts reduced to various density horizons were produced. An early example of such a chart is shown in figure 5.

By contouring this chart it was possible to recognise areas where the critical 1.2 gm/cm^3 density horizon had shoaled to less than the critical -22.5 m datum for the channel. Such a chart provides non-subjective information upon which a harbourmaster can base a decision as to whether vessels can safely traverse the channel in the presence of deep static suspensions.

Routine surveying procedure

Following this evaluation a system was developed which now incorporates a backscatter gauge, depth sensor and two-component inclinometer. When the survey vessel reaches the sample station the equipment package is traversed through the lower few metres of the water column and the static suspension at a lowering rate of 20 cm/sec. Each profile takes 20–25 sec to complete, and profiles in which the package inclination exceeds 3° are repeated.

For more than three years the normal weekly echo-sounding surveys have been supplemented by these regular density surveys in which 60–100 stations are measured each Monday, the data is partially processed on board and datum corrections are made so that the new density chart can be printed each Tuesday. Early on Wednesday a new density chart showing the altitude of the 1.2 gm/cm^3 contour and other density information (figure 6) is issued to the various departments concerned.

The main value of this density data is in its ability to guarantee the altitude of the 1.2 gm/cm^3 horizon. Routine monitoring of this horizon over the last three years has revealed that it is far more stable than the top of the suspension indicated by the densimeters or echo-sounders. This allows a more realistic judgement to be made on the longer-term trends of sedimentation in the channel and allows the more extreme fluctuations to be recognised and accommodated within the survey and dredging programme.

Figure 2 shows how in these exceptional circumstances supertankers can have a negative underkeel clearance according to the echo sounder although the underkeel clearance with respect to the 1.2 gm/cm^3 horizon will still be 10 %. The most serious influx of suspended sediment into Europort occurred in the first weeks of 1975 following gales in the North Sea. Echo-sounding surveys carried out immediately after these storms showed a least depth of 19.5 m due to the sudden arrival of a sediment body 3.0 m thick in places. Density records showed that this was chiefly

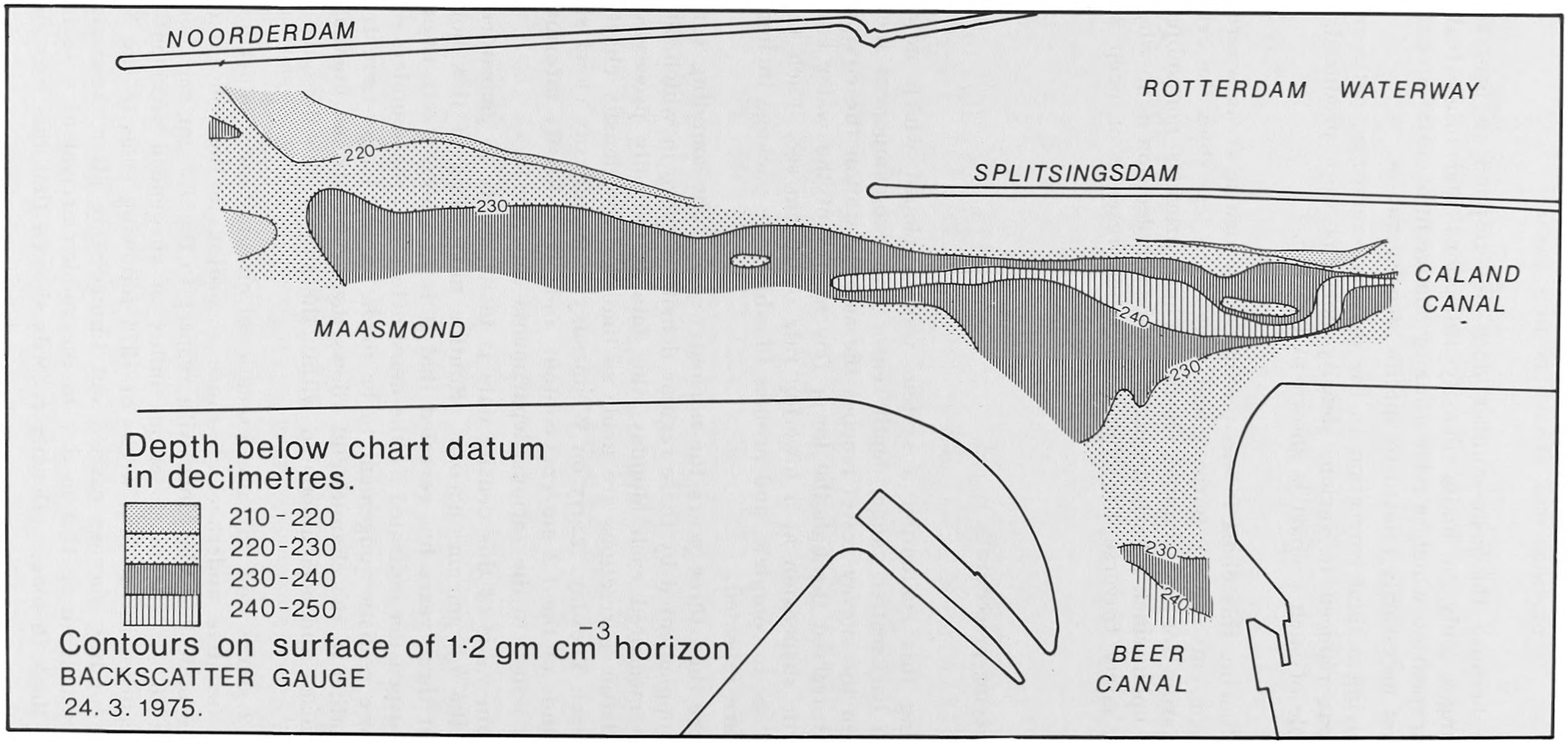

FIG. 5. — Early density chart showing density values contoured to show the altitude of the 1.2 gm/cm^3 density horizon.

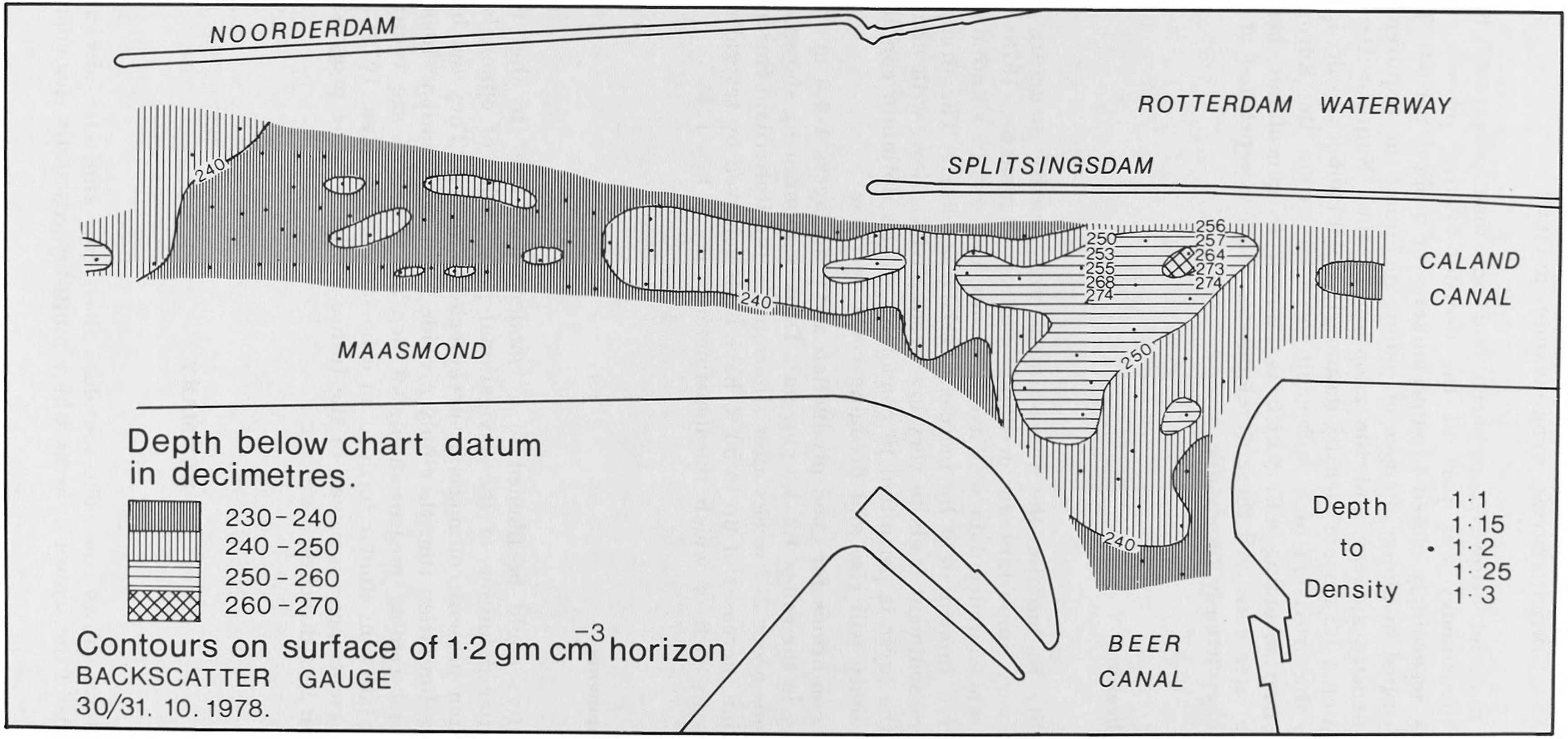

FIG. 6. — Modern density chart contoured to show the altitude of the 1.2 gm/cm³ density horizon. Numbers adjacent to sample stations provide additional data on layer thickness. For clarity, data for only two vertical traverses is shown. The buffer pit dredged to — 26.0 m can be seen.

low density material. However research had not then progressed to a stage where densimetry was part of the decision-making process, and Europort was accordingly closed to supertankers for a short period. This emergency resulted in major changes of policy, including the requirement for regular density surveys and the adoption of the "Nautical Depth" concept based on a 1.2 gm/cm^3 density datum. Parallel changes in dredging policy led to the provision of a buffer pit, dredged within the Europort channels to trap incoming silt, which is allowed to consolidate before dredging at a later date. All these developments make a repetition of the 1975 emergency virtually impossible.

Dredging applications

The ability to monitor the three-dimensional density structure has also proved very important in dredging control (NEDERLOF, 1978) [5]. Whilst only echo-sounder data was available any increase in siltation had to be countered immediately by increased dredging effort. The dredging of such watery sediment leads to very low productivity. Now, with density monitoring, the layer is permitted to consolidate to an optimum condition when productivity will rise and dredging costs decrease.

Optimal conditions for good production are mud layers 1–1.5 m thick with a density in the range 1.2–1.3 gm/cm^3. Density monitoring shows that these conditions occur 2–3 weeks after siltation. In the Rotterdam-Europort area production increases of up to 50 % have been achieved by several new developments in each of which the densimeters play a key role.

Future developments

Densimeters could be likened to a "modern lead line" in that they provide a better definition of the navigational possibilities of channels in mud areas than present commercial survey echo-sounders. They do, however, have the limitation that they only provide point information. Ideally, continuous and remote measurements of density structure are required with a presentation in similar form to an echo-sounder (BAKKER, 1979) [6]. Such developments are some way in the future although some progress is being made in this direction.

SUMMARY

Studies have shown that echo-sounders allow only subjective decisions on the altitude of the seabed in areas where multi-layered static suspensions occur.

Gamma-ray densimeters have been used to measure the three-dimensional density structure of static suspensions in a navigable channel. This development has been accompanied by investigation of ship behaviour in dense media. On the basis of these studies a new concept, the "Nautical Depth" considered to be the 1.2 gm/cm^3 density horizon, has been devised to define the effective seabed in soft mud areas.

Experimental results and operational experience gained during the last few years have demonstrated the operational and cost benefit advantages possible with this technique.

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