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DREDGING THE HATTER BARN ROUTE

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1. INTRODUCTION

1.1 One of the requirements a hydrographic surveyor may encounter in his work is to check dredging carried out by dredgers to determine whether or not the required depth has been obtained.

1.2 The article describes the hydrographic control survey in the newly dredged route in Hatter Barn from the point of view of a hydrographic surveyor, giving the background for the route, the preliminary survey, the contract and the control survey. The dredged route itself is of exceptional importance for the scheme for its implementation denies certain ocean shipping use of a traditional transit area in the interests of safer navigation.

1.3 The article by Mr. J.M. BARBIER and Mr. M. CHAUMET-LAGRANGE [1] is used as a guideline for a technical description of the survey system, the navigation system, and the echo sounding and side scan sonar systems of the survey launch SKA 11 [2] which performed the survey.

2. BACKGROUND

2.1 The DEEP WATER ROUTE, Route T, passes through Danish waters, following the deepest possible path from the North Sea to the Baltic Sea. Yearly, some 20,000 ships use this route. The Hatter Barn is situated midway (see figures 1 & 2) with its characteristic 80° turn. Furthermore, this area is characterized by the following :

- depths varying from 5 to 60 m
- currents either NE or SW up to 3-4 knots
- minimum width of the route 800 m

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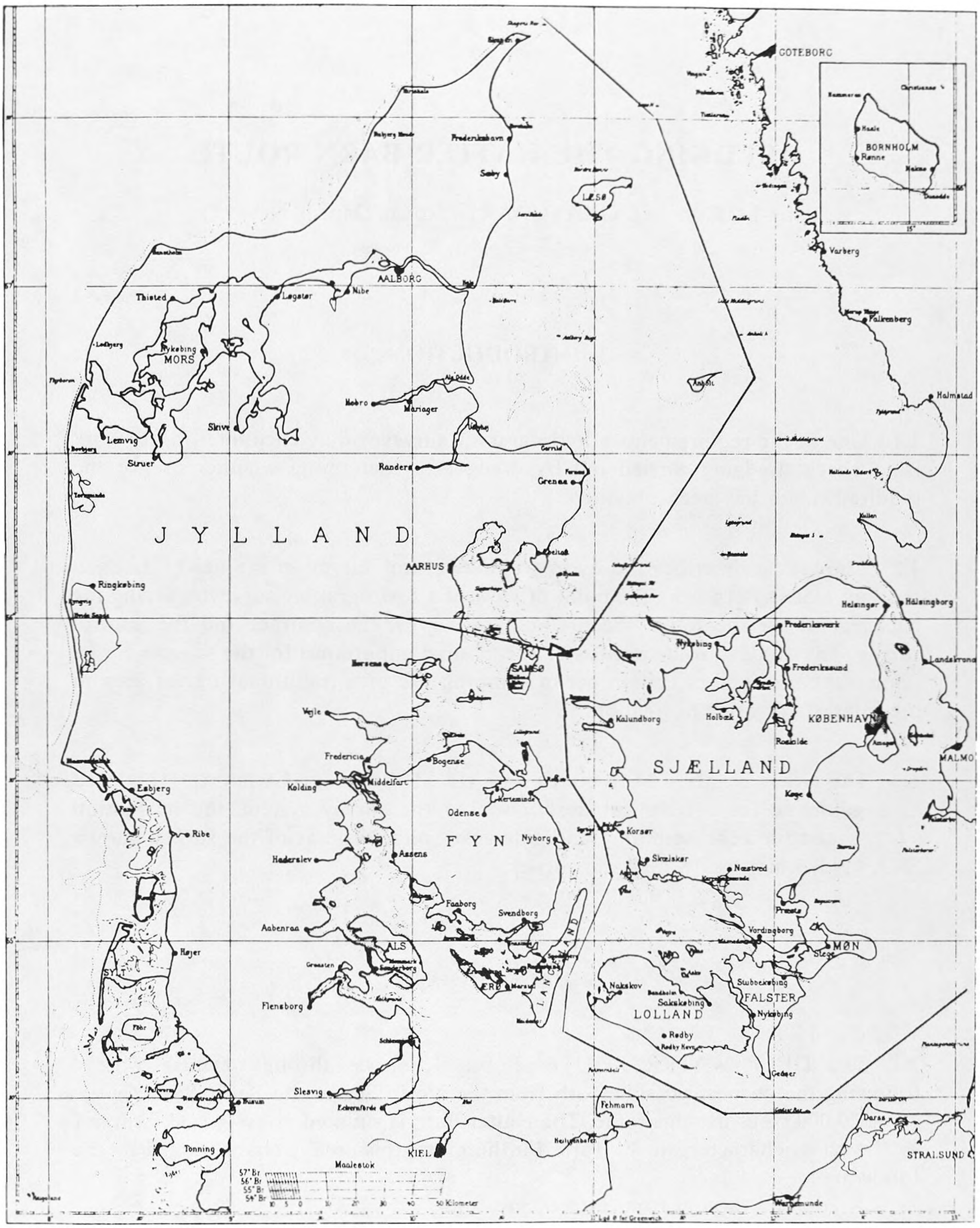
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BORNHOLM
Rønne
Varberg
Falkenberg
Halmstad
Frederikshavn
Sæby
LÆSØ
AALBORG
Nibe
Løgstør
Thisted
Nykøbing
MORS
Skive
Lemvig
Struer
Hobro
Mariager
Randers
Grenaa
J Y L L A N D
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FIG. 1

SAMSØ BÆLT Nuværende ruter/Existing routes

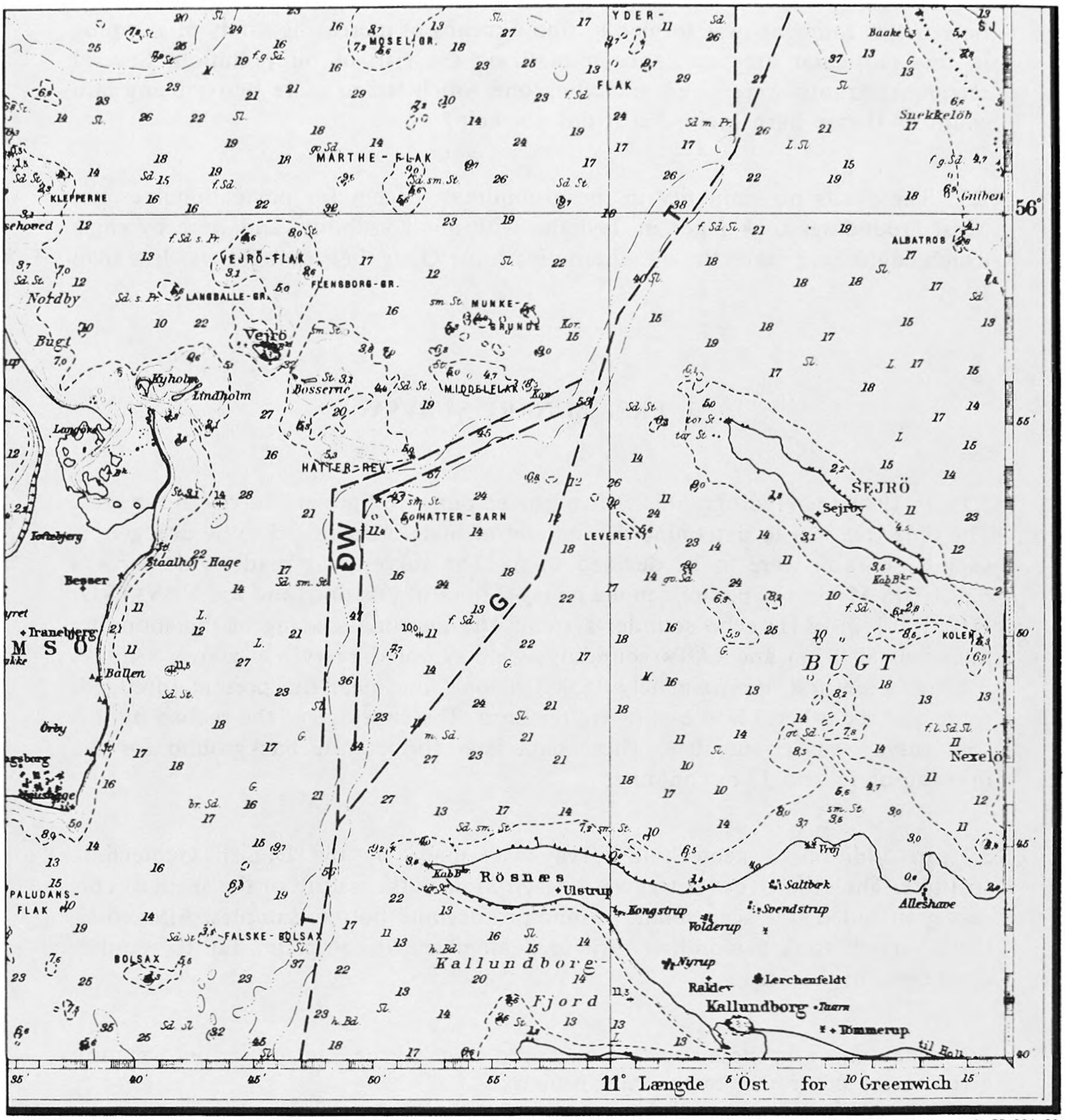

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FIG. 2

- formed in the last glacial period
- seabed of blue clay and boulders up to 20 tons rising 3-4 m from the seabed
- average wind force more than 5 m/sec for 75 % of the year
- wind and current in opposite directions result in a very rough sea state.

2.2 Due to several groundings in the Hatter Barn area — fourteen since 1974 — and, especially, three in 1978 with the risk of major oil pollution in the northern part of the Great Belt, a group of advisers from the Ministry of Industrial Affairs, Danish Administration of Navigation and Hydrography and Danish Administration of Environments was formed to find a means of increasing safety of shipping in this particular area and thus minimizing the risk of oil pollution. Several recommendations were given, including one which led to more buoys being laid south of Hatter Barn Light, but it did not help.

2.3 There was no similarity in the groundings, except for navigational errors. Most groundings took place in daylight, with good visibility, and were by ships which could have taken the old alternative route G, as their draught was less than 10 m.

3. PRELIMINARY SURVEY

3.1 In 1980, the Hydrographic Office carried out a preliminary survey in the area. The objective was to determine the amount of material required to be dredged, if such a solution were to be decided upon. The survey was made with Sercel's SYLEDIS MR3 in hyperbolic mode giving 2 lines of position, and the NAVITRONIC RT 1 210 kHz echo sounder system. The interline spacing of the sounding lines was 50/25 m and LOPs/soundings were sampled every 8 m across 2 tracks 2 000 m wide and approximately 16,000 m long, one near the present (dredged) route and the other 5 NM east of Hatter Barn. The coverage of the seabed by this spot survey was about 10 %. These data later formed the background for the drawing of 15 and 17 m contours.

3.2 In addition, a geotechnic survey was made by the Danish Geotechnic Institute. The objective was to give a description of the nature of the seabed. This survey included side scan sonar, seismic profiles and bottom samples. Altogether, these surveys took 5 months (April to September) to complete, due to weather conditions in the area.

3.3 The data from these surveys comprised some of the background information given to the contractor in the later project.

4. THE CONTRACT

4.1 Late in 1982 it was decided to dredge a route just south-east of Hatter Barn (see figure 3), to the depth of 15 m, allowing transit by ships with a maximum draught of 13 m to relieve the congestion in the Deep Water Route. Theoretically, 66,500 m^3 of sand, clay and boulders were to be removed from approximately 10 areas throughout the 16,300 m-long, 1,600 m-wide channel. Shipping would then be able to pass almost straight through Hatter Barn with only 1 turn of 30°.

SAMSØ BÆLT Trafiksepareringssystem/Traffic separation scheme 1. apr. 1984

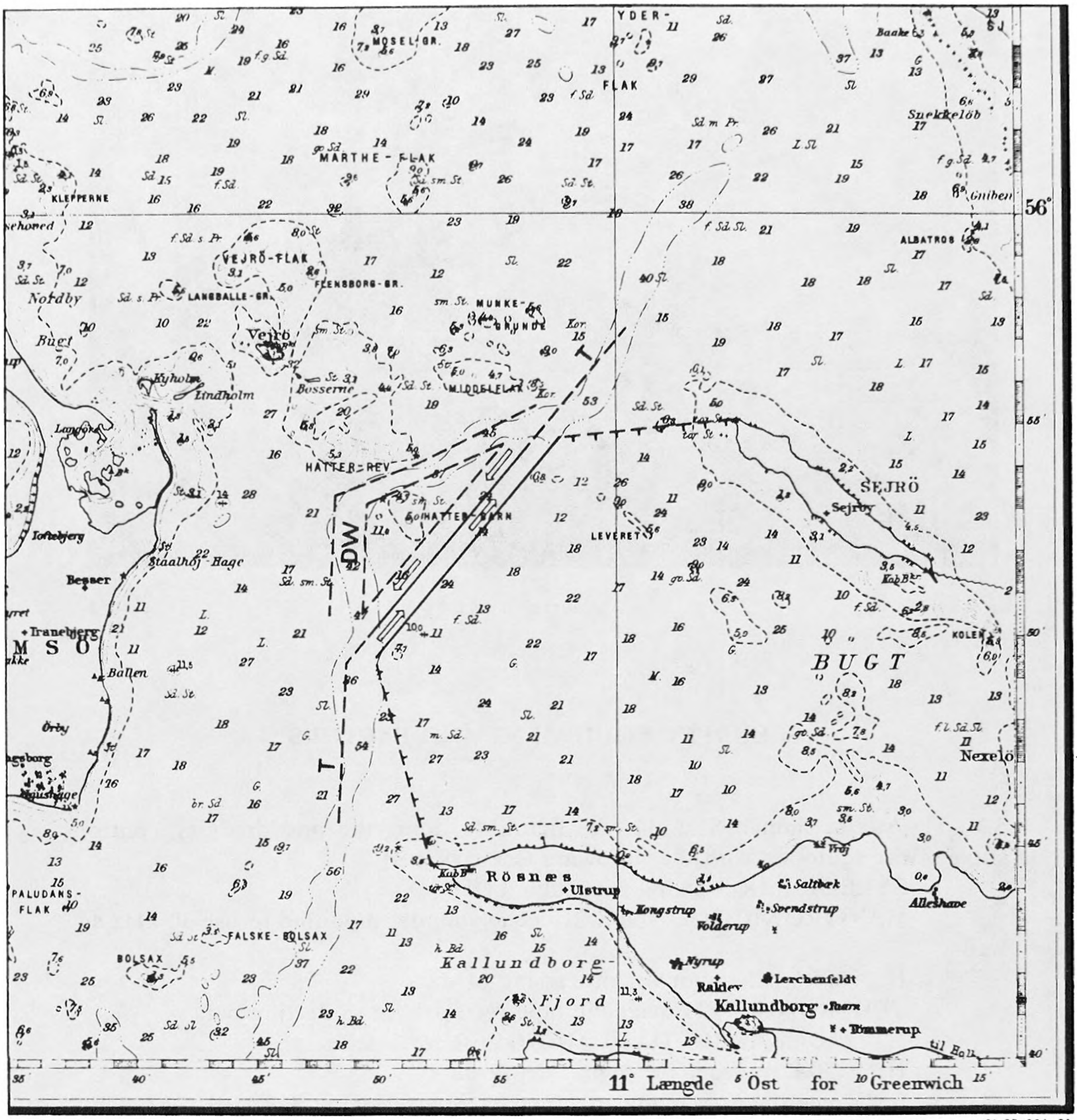

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FIG. 3

4.2 From a hydrographic surveyor's point of view, the following considerations were important :

— in all areas with less than 17 m there should be a minimum depth of 15 m

— no hydrographic survey had been made, but the spot survey from 1980 could to some extent indicate soundings in the area

— if a complete survey were wanted by the contractor, he should perform this himself

— the dredger would be supplied with a SYLEDIS SR 3 for positioning

— the control sounding should be done with a 210 kHz echo sounder.

FIG. 4. — The survey launch SKA 11.

5. SURVEY EQUIPMENT AND FACTORS

5.1 The survey launch SKA 11 (see figure **4**), doing the post-dredging control survey, was equipped with the following (see figure 5) :

— SYLEDIS MR 3 giving 3 circular LOPs
— NAVITRONIC SOUNDIG 210 echo sounder modified to use 30 kHz as well
— HP 9825A calculator for processing of data
— TEKTRONIX 4924 magnetic tape recorder for collecting data
— HYDROGRAPHIC DATA HANDLER for interfacing
— HP 7130A recorder for digital depth data
— EPC recorder for analog depth data interfaced by GRAPHICAL RECORDER INTERFACE
— TREND 800 printer for print-out of data
— HP 9872A plotter
— PATH GUIDANCE UNIT for steering repeater data
— EMRI STEERING SYSTEM
— EG&G SMS 960 SIDE SCAN SONAR.

5.2 The survey system was basically divided into three parts (see figure 5) :

— an automatic part
— a back-up and control part, and
— a side scan sonar part.

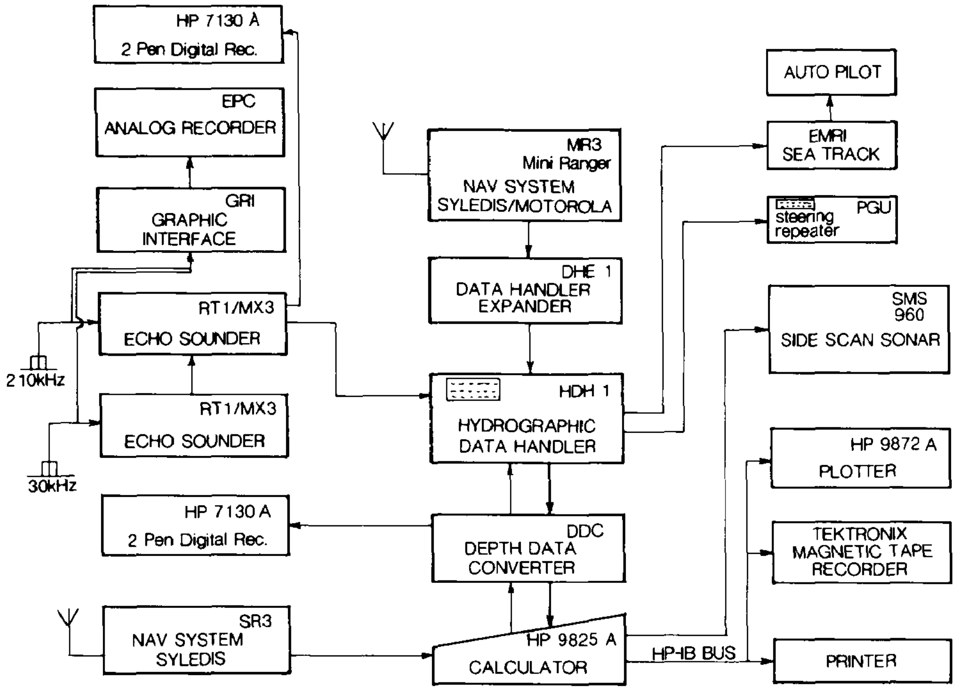


FIG. 5. — Survey system aboard the survey launch SKA 11.

5.3 The automatic part consisted of the MR 3, the E/S, HDH, calculator and the tape station. The objective of this was to collect the LOPs, depths and time to be stored on magnetic tape for further processing in the Hydrographic Office. In addition, information was sent to the helmsman.

5.4 The back-up and control part was for the immediate real time checking and control of survey data. In addition to the above mentioned instruments, it consisted of graphical, digital and analog recorders, a plotter and a printer.

5.5 The SSS-system was interfaced to the calculator, so that the system could be controlled from the calculator station with the position, time, line and fix number, etc., written on the SSS-trace in order to measure and determine the position of a depth anomaly.

5.6 As Mr. J. M. BARBIER and Mr. M. CHAUMET-LAGRANGE pointed out in their article, many equipment factors should be considered before conducting a survey such as the one under discussion here, namely :

(a) Oscillator position linked with the movements of the vessel :
- depth of oscillator,
- squat due to speed,
- roll, pitch and importance of narrowness of beam,
- heave;

(b) Echo sounder calibration;

(c) Echo sounder frequency (interpretation of echo trace);
(d) Tidal correction;
(e) Position errors :
  — selection of a positioning system,
  — relative position of antenna and oscillator;
(f) Selection of profiles;
(g) Selection of soundings.

5.7 *Depth of oscillator* : On both sides of the survey launch an oscillator draft mark was placed. The oscillator draft was preset on the echo sounders to give the actual depth measured.

5.8 *Squat* : As squat of the survey launch was not actually exactly known, speed was reduced and kept constant at 6 — 7 knots during the whole survey, thus minimizing the squat or at least keeping it constant. Repeated surveying in the same area showed differences within the specification of the echo sounder, ± 0.1 m, except where dredging had been done between surveys.

5.9 *Roll, pitch, heave and narrowness of beam* : Being an inshore survey launch, the boat was subjected to heavy rolling and pitching due to weather in open areas like Hatter Barn. This affected soundings obtained, especially as the beamwidth of the echo sounder was 15°, which was required to give a good correlation between sounding and fix. This had the effect that the survey often had to be stopped when waves were about 0.5 m, or wind more than 5-6 m/sec, because then the sounding trace was oscillating ± 0.2 to ± 0.3 m, which was greater than the accuracy tolerance specified. As mentioned earlier, a narrow beam was preferred because of the correlation between sounding and fix, making it easier to relocate an obstacle, but on the other hand, interline spacing had to be reduced to give an acceptable coverage of the seabed, which resulted in much more time being spent on a job. With this echo sounder, a study shows that at 15 m depth a cone of 4 m is covered at the seabed. At the outer edge it measures 0.1 m less than the depth vertically beneath the oscillator, so a wider beam would cause errors larger than the required specifications.

5.10 *Calibration of echo sounder* : Before sounding, daily temperature and salinity were measured at every 2 m from the surface to the bottom in the area to be surveyed for calculation of mean sound velocity, which was then preset on the echo sounders. In this area it was very significant, as there normally was a temperature/salinity layer in 10-12 m depth due to less dense Baltic Sea water flowing north on the surface and the denser North Sea water flowing south at the seabed. Furthermore, a bar check was carried out once a day to check the echo sounder.

5.11 *Echo sounder frequency — interpretation of echo trace* : The E/S on SKA 11 was a dual channel sounder with frequencies of 210 kHz and 30 kHz, both recorded on digital and analog recorders. Only the 210 kHz soundings were recorded on magnetic tape, so the 30 kHz was used as control and back-up or, rather, interpretation. Generally, the 210 kHz will sound the top of material on the seabed, while the 30 kHz will reflect the more solid material. This means that, in a case of seaweed on the bottom, it will be recorded as "the bottom" by 210 kHz but omitted by 30 kHz. On the other hand, soft material such as mud may not be recorded by 30 kHz but is recorded by 210 kHz. Some of these phenomena were experienced in this area and the dual channel sounder proved very valuable, e.g. in one area the top of a shoal was covered with sea anemones which were recorded by the 210 kHz as less than 15.0 m, but not by the 30 kHz. A diver clarified the situation. Regardless, soundings in dredged areas where the seabed comprised hard clay showed no significant differences between the two. Also, the mix of digital and analog recorders proved useful for interpretation of echoes, e.g., boulders were better seen on the analog recorder, whereas depths were better read on the digital, when another run over the position had been done at slower speed.

5.12 *Tidal correction* : From the survey of 1980 a bench mark was established in Sejeroe Harbour and it was agreed that this would be used as a reference point throughout the survey and dredging. Two automatic tide gauges were established there, one with and one without a radio link. The one with a radio link was used by the dredger to obtain real time water level, while SKA 11 had to pick up water level data after each survey to correct soundings. Some discussion ensued about the proximity of the tide gauge to the survey area, but as no alternatives or relevant data for differences were available, this had to be accepted. Surveying the same area twice at different times gave values within ± 0.1 m.

TABLE 1

Calibration test in Ballen Harbour, February 28, 1984

	Beacon 1	Beacon 2	Beacon 3
Geodetic distance	16 465.8	4 611.7	29 768.8
Minimum distance	16 465.0	4 611.0	29 767.7
Maximum distance	16 466.6	4 612.9	29 769.1
Mean distance	16 465.9	4 611.7	29 768.5
Standard error	0.24	0.28	0.18
Difference	— 0.12	— 0.03	0.27
	Northing		**Easting**
Calibration position	6 187 168.57		602 947.39
Calculated position	6 187 168.71		602 947.51
Standard error	0.05		0.03
Differences	0.06		0.08
Error ellipse	0.26		
Distance test-calculated position	0.10		

	123	111	222	333
Presetting on MR 3/3	2 3	9 2 0	1 1 3	9 8 5

5.13 *Position errors*: The radio navigational system used was, as noted, the SYLEDIS B MR 3 giving three circular lines of position. To give a good fix the system had to be calibrated and checked. This was done once a month with a stationary test in a coordinated point at Ballen Harbour outer pier, a small harbour on the island of Samsoe. A computer program sampling 3 × 1 000 distances from the MR 3 gave data needed for calculations of differences in geodetic distances, UTM coordinates, standard errors, min./max. distances, error ellipse, etc. For calibration of the system, see Table 1. The inputs were UTM and geographical coordinates of the calibration point and beacons, and output was as shown in the table.

5.13.1 Checking was done 2 - 3 times during each test. After the first check, the navigational set was adjusted till distances were within ± 0.3 m and standard error ± 0.5 m, and then another check was run, and sometimes yet another, until data were stable. Each test took 1 - 2 hours. As can be seen from the table, the range between min. and max. distances is only ± 1 m. This was not always so, as individual ranges could be as large as ± 5 to ± 7 m. Checking such ranges showed, however, that they were caused by a few random data, possibly reflections, not influencing the mean when the data sample was large.

5.13.2. When working with the system, the maximum distance was about 20,000 m to 1 or 2 beacons and the minimum 7,000 m. On average, the working distances were 10,000 - 15,000 m. Using Sercel's theoretical error for a position line in the system, 0.3 m ± 30 ppm, it means that the standard error on each position line should be ± 0.75 m and on the position ± 1.3 m. Experience proved that this value corresponded well as it was possible to return to a position, e.g. a boulder or a shoal, 9 out of 10 times, even in bad weather. Near baselines, positioning errors were larger due to the effect of small fluctuations of the system. Here, errors could be from ± 2 m to ± 4 m. Large fluctuations of several hundreds of metres were experienced, too, but it was only in a single data sample and very seldom. When SR 3 was installed, it showed the same repeatability.

5.14. *Relative position of antenna and oscillator*: Due to vibrations from the main engine, the oscillators of SKA 11 were moved 2.75 m in front of the receiver antenna. This distance had to be allowed for and this was done at the Hydrographic Office.

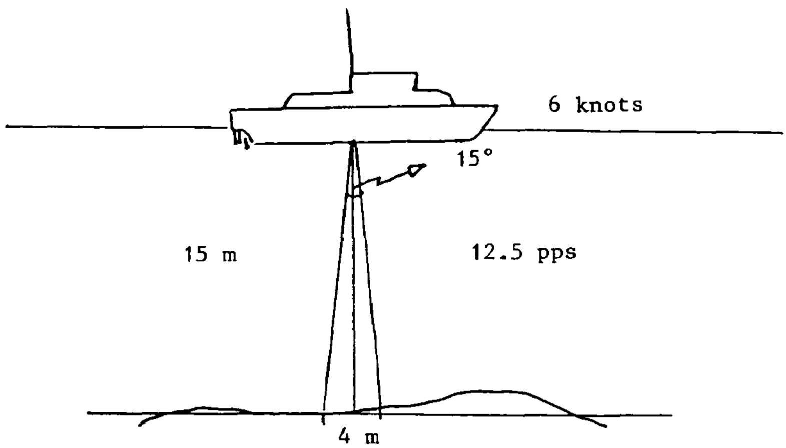
5.15 *Selection of profiles*: With use of the SYLEDIS system the full benefit of the EMRI steering system was obtained, as sounding profiles could be run within ± 1 m to ± 2 m of the preplanned survey lines. This also made it possible to use a small interline spacing and thereby survey an area with a very high percentage of bottom coverage.

To declare a dredged route "cleared" to required depth needs good seabed coverage, dependent on a small spacing between sounding lines and good steering, but also on other factors. As steering has been mentioned, some consideration will be given to coverage and spacing. In Table 2 the longitudinal coverage is described.

TABLE 2

Longitudinal coverage

Ship's speed	6 knots	3.1 m/sec
E/S range 0 - 25 m	12.5 pulses/sec	
1 pulse every...	0.25 m	
15° cone at 15 m	4.0 m at seabed	
No. of pulses within 4 m....................................	16 pulses	
Program updating time.......................................	0.6 sec	
No. of updating pulses..	3 within the 4.0 m at seabed	



5.16 An updating by the E/S every 0.25 m ensures that the seabed is well covered in the longitudinal direction, i.e. shoals and boulders are recorded at the digital and analog recorders, but not necessarily handled by the computer, due to different data sampling rate.

As stated above, a 15° beamwidth gives a cone of 4 m at seabed. From Table 3, which gives seabed coverage percentage as a function of interline spacing of sounding lines, it is clear that a high percentage is only achieved by a small spacing.

TABLE 3

Seabed coverage percentage as a function of spacing

Spacing in m.....................	50	25	10	5	3
Percentage	8	16	40	80	133

Due to small variations in positioning and steering this survey had to be carried out with 3 m spacing and doubtful areas were sounded at least twice.

5.17 *Selection of soundings* : The survey software was designed to collect data to be handled at the Danish Administration of Navigation and Hydrography as the hardware on board did not facilitate on-line data processing. This was primarily caused by the limited calculator capacity, 23 Kbytes and, therefore, the relatively slow updating rate, 0.6 sec. Furthermore, soundings were not corrected aboard for tide as no automatic tide gauge was connected to the system.

5.17.1 In the calculator, a selection of depth data took place within a certain time interval, here, 10 sec, so that minimum and maximum depths for the interval were collected together with the depth every time the timebase shifted. The selected depths with their LOPs and time were then stored on magnetic tape of 200,000 bytes capacity. This was filled in 4 hours.

5.17.2 The position calculation was a least square adjustment with three circular LOPs based on flat earth computation and was used merely for steering along track and plotting and, in some cases, as a quick reference for the dredger. As such data were not very accurate, however, care had to be taken.

5.17.3 In the program there was a built-in warning for soundings less than 15.0 m which resulted in a write-out giving uncorrected sounding and position.

To control work done by dredgers, one has to be sure that it is done in accordance with the stated requirements. When a depth of 15.0 m is stated in the contract, a reduced sounding of 14.9 m has to be dredged again. This is a very narrow limit and discussions will always arise since the variance from the requirement is within the accuracy specifications of the E/S, ± 0.1 m. One must check internal and external factors, i.e. correct measured oscillator depth and sound velocity and their preset, and ensure that there is no sea state, swell or wake effect to make sure that the sounding is accurate. This can be a very difficult task.

5.18. *Side scan sonar :* The side scan sonar equipment on board SKA 11 was EG & G Seabed Mapping System (SMS) 960, which gives a digital representation of data. The object was to ensure that no obstacles were present after dredging and, especially, in non-dredged areas with less than 17 m where survey lines were not so close as those in dredged areas. The SSS-system was interfaced to the survey system so that position data and ship's true speed were transferred. Position of boulders could be calculated simply from the traces as the SSS-recorder drove with ship's true speed, thus eliminating along-track distortion, and the built-in height corrector eliminated vertical distortion. Positioning of a boulder was carried out as follows. A meter-counter was connected to the cable winch to measure the length of cable from the winch to :

- Fish position (see figures 6 and 7)

  From ship's position, length of cable was read out from the meter-counter and reduced by Pythagoras formula to give the distance in the horizontal plane. Adding distance from the winch to the antenna gave the distance of the fish from the antenna. Using sin/cos to ship's heading gave the fish position in the horizontal plane.

- Boulder position (see figure 7)

  From SSS-trace, distances from fish to boulder along-track and across-track were measured and by sin/cos rules the position of the boulder could be calculated nearly on-line by a simple computer program.

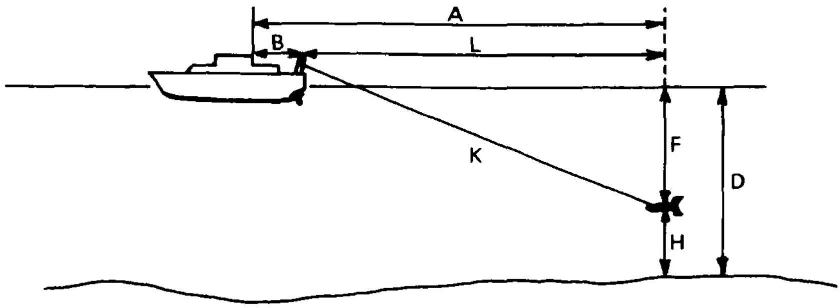


FIG. 6. — Fish distance behind antenna.

K = cable out (read on meter-counter)
H = height of fish above seabed (read on SSS-instrument)
D = depth (read on E/S trace)
F = D − H, fish depth beneath surface
L = $(K^2 - F^2)$, horizontal distance behind winch
B = distance antenna to winch
A = L + B, fish total distance behind antenna.

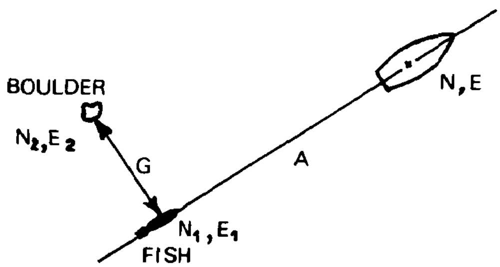


FIG. 7. — Positioning of boulder.

Positioning of fish :
$N_1 = N + A \cos C$, where C is ship's heading
$E_1 = E + A \sin C$
Positioning of boulder :
$N_2 = N_1 + G \cos (C \pm 90^\circ)$, where G is the distance from track
$E_2 = E_1 + G \sin (C \pm 90^\circ)$

As the survey launch always stemmed the current, the fish was almost directly behind the ship, introducing only minor errors in the positioning of boulders.

6. THE POST-DREDGING SURVEY

6.1. Before the survey started, the following was specified :
— in non-dredged areas, interline spacing 50 m
— in dredged areas, interline spacing 10 m
— in SSS-survey, interline spacing 100 m
— the hydrographic survey should be performed across the channel and the SSS-survey along the channel.

6.2 In April 1983 checks were made on some of the spot soundings of 1980 for the contractor to see the correlation between the positions of LOPs and soundings. They were found to agree within ± 10 m.

6.3 The hydrographic survey started by sounding all non-dredged areas with an interline spacing of 50 m. Comparison with the former spot survey was good. Doubtful areas, those with depths less than 17 m but not less than 15 m, were surveyed with 10 m spacing. Here, no obstructions requiring dredging were found.

6.4. The first dredged area was sounded with 10 m spacing, giving 2 soundings with 0.1 to 0.2 m less than the required depth. The area was then resurveyed twice with spacing 5 m. This gave 18 soundings with 0.1 to 0.4 m less than the required depth. After further dredging the area was resurveyed twice with a 5 m interval, giving 12 soundings shallower than the design depth. Additional dredging, checked by sounding lines with 3 m spacing, cleared the area. After this experience, the rest of the dredged areas were sounded twice with 3 m interline spacing to ensure the areas were dredged to the required depth.

6.5. As the 17 m and 15 m contours were drawn from the spot survey data, one could expect differences, and indeed they occurred. In some areas, 5 to 10 new shoals were found outside the 15 m contour, but inside the 17 m contour after the first dredging had been done. This meant that some areas had to be dredged and surveyed 3 or 4 times before they were cleared. Especially large isolated boulders caused difficulties to dredgers and these were blasted. Also, a dredger in a relatively open area like Hatter Barn with strong winds and currents, dredging to a depth of 15 m, had difficulty in dredging along straight lines. In the last phase, boulder fishers were hired to move small shoals and isolated boulders. This was done by SKA 11 dropping a buoy at the position and the fisher dredging with a diver to direct the bucket at the sea bottom.

6.6. Throughout the survey, positioning and sounding were excellent on SKA 11 as positioning was done within ± 1 m and sounding ± 0.1 m, which meant that, especially, isolated boulders, when found, could be relocated with the same least depth whenever required. The following example illustrates these performances. A boulder 2 × 3 m and 2 m high, weighing some 20 tons, was to be blasted. After the first explosion, SKA 11 came on top and recorded that 0.5 m of the top had gone and the boulder was split. This was confirmed by a diver and another blast had to be made.

6.7 *Side scan sonar survey :* As the result of experience with the hydrographic survey interline spacing, the SSS-survey line interval was reduced to 50 m and range to 50 m to give the best possible resolution. The recording showed numerous boulders throughout the whole channel, but only 32 of those were of interest, as these were in areas with less than 17 m depth. To find least depth over these the following procedure was used :

— to relocate the boulders, the same track was run around the previous position while comparing the former recorded bottom structure;

- when relocated, the position was checked. This gave only minor changes of ± 3 m;
- the track was then shifted slightly to get the least depth over the boulder by echo sounders. If it did not work out the first time, lines were run on each side of the position with 1 or 2 m spacing. Normally, least depth was found within 4 to 6 runs.

This procedure showed that, in the worst case, there was a difference of about ± 7 m between the position from the SSS-record and the exact position of the least depth over the boulder.

6.8 The height of a boulder taken from the SSS-record was within ± 0.3 m. This was confirmed by diver's measurement with a pressure depth device. The variation was mainly due to the uncertainty of where the shadow starts and stops and, secondly, by the assumption for the height-finding formula that the boulder is lying on level ground. If the seabed behind the boulder deepens, the shadow is longer and thus the height of the boulder greater, and vice versa.

6.9 The SSS-survey and least depths found did not detect any further shoals to be dredged, even though some were quite close.

6.10 *Closing remarks about the post-dredge survey :* Altogether, the effective survey time was 250 hours, but the project lasted 15 months, primarily due to bad weather.

- Around 10 million soundings were measured; 1.3 million were handled by the calculator, of which 70,000 were recorded on magnetic tape. This gave, on a fair sheet at 1:20,000 scale, 1,800 soundings, and on one at 1:5,000 scale, 7,800 soundings.

7. LESSONS LEARNED

- Post-dredging surveys are very time-consuming and expensive, both for the dredger and for the survey unit, as areas may have to be re-dredged and re-sounded many times.
- To ensure that an area is adequately dredged, a very small interline spacing and ensonified bottom area overlap are needed. This requires a well-calibrated, precise navigation system like SYLEDIS, and a good track-steering system.
- The SYLEDIS repeatability was good. Working within 10 to 15 km off stations it was better than ± 1.3 m. The Navitronic Soundig system ensured that soundings were measured within ± 0.1 m. The EMRI track steering system rendered it possible to steer the launch within ± 1 to ± 2 m of sounding lines.
- A detailed survey should be conducted in advance so that shoals and boulders are detected. To reduce the period of this preparation phase, side scan sonar traces could be useful.

— The required depth given to the contractor should be 0.3 to 0.5 m greater than the actual design depth. Though this will result in a larger volume to be dredged, there would be considerable savings in time and expenditure both in re-dredging and in conducting a post-dredging survey.
— Dredged areas should be surveyed with narrow line intervals at least twice to ensure that no obstacles remain undetected before the area is declared as "clear".
— Positions of boulders from SSS-records were within ± 5 to ± 7 m, when later relocated with "on-top" position. Heights of boulders were correct to within ± 0.3 m.
— The computer system should have an up-dating rate that is compatible with that of the slowest of the echo sounder or navigation system to get data for all soundings/LOPs for all depth anomalies of interest.
— The survey ship should be equipped with a datalink for tide data to correct soundings on-line.
— The computer system should do real-time data processing, so that position and depth for a shoal to be re-dredged or a boulder to be removed could be given almost simultaneously.
— A dual channel echo sounder with digital/analog recorders is a useful tool for interpretation of sounding data.

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