Behind the Nautical Chart

Surveying, reliability and use

3rd Edition

This edition of **Behind the Nautical Chart** has been corrected to 21st December 2018

Danish Geodata Agency

Preface

Geodatastyrelsen issues the publication "Behind the nautical chart" as an auxiliary tool to help in understanding the hydrographical surveying, the composition of the chart and its reliability. The purpose of this publication is to describe the various hydrographical data collection methods, which have been utilized through history in the production of the nautical map.
The improved accuracy of the satellite systems and the increased use of electronic navigational charts, result in greater expectations to the accuracy of the charts, than they are usually able to live up to. This publication offers the reader an opportunity to better evaluate and understand the survey data, which is used in today's chart production.
The language and contents is described in a lively and interesting way, meant to be interesting both for professional navigators as well as for people interested in yachting.

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Chapter 1.

1.0 Introduction

Due to its position, its many islands and narrow straits, Denmark has always been dependent on sailing. The publication of reliable charts and sailing directions, have for two hundred years contributed to maintain a safe traffic in, and through the Danish waters.

In the beginning, this information was only available for the navy, but now it is available to everybody. As part of an international cooperation digital chart data are exchanged between the Hydrographic Offices in the different countries, and paper charts are about to be replaced by Electronic Navigational Charts, ENC's.

The need for human understanding and interpretation is very significant even though the combination of electronic charts, DGPS, gyro, radar etc. (integrated bridge systems) almost steers the vessel for the mariner.
This publication describes the methods of hydrographic surveys used throughout the years for gathering data contained in the Danish charts. The purpose is to point out the limitations of the modern charts, which the navigator should be aware of. The information is meant as help for the navigator to better understand and interpret the hydrographic data of the chart and the degree of confidence he or she, should have in these.

If the navigator is cautious and careful when using the modern navigational aids like DGPS and ENC's and in addition uses the classical methods like radar, gyro and log and furthermore remember to look outside at the real world, accidents are less likely to occur.

Sailing is a dynamic process with many human, astronomical, meteorological, technical, environmental, educational, developmental and economical aspects. Like all other methods of transportation, sailing involves a certain risk, and every year ships are lost.

Chapter 2.

2.0 Danish Survey status

In figure 1, an overview of the Danish waters is shown, marked with corresponding age of charted areas. The figure shows that a major part of the hydrographic surveys have been conducted in the period from 1858 to 1907. The technological development of hydrographic surveying, ranges from using a hand held led line and 3 point sextant fixing, to employing multi beam swath mapping with DGPS positioning. In the following part of this publication, a description of how hydrographic surveys were carried out in the last 140 years is given. It contains examples of surveys stressing the problems of the different methods of surveying and the steadily increasing quantity of survey data, forming the basis of the choice of soundings in the charts.

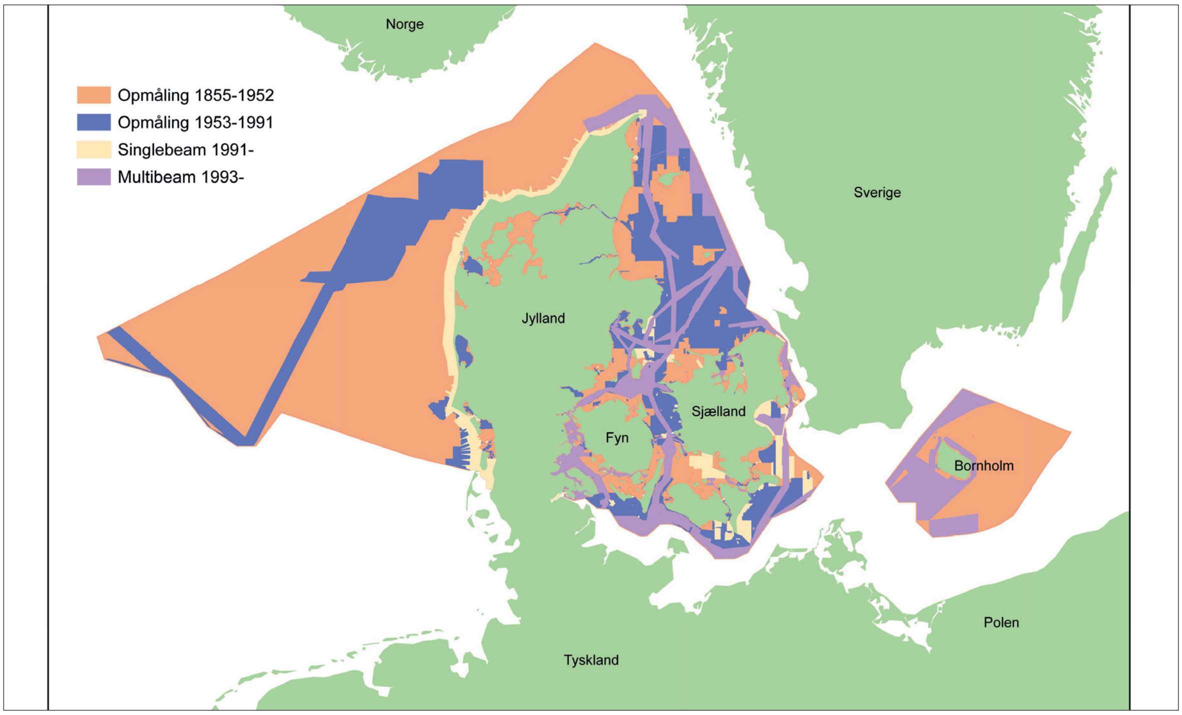


Fig. 1 Outline of the time periods of the Danish surveying. Due to the scale of the chart the details of the area shown are not correct.

2.1 The Faroe Islands

A triangulation and a land survey of the Faroe Islands were carried out in 1791 to 1795, and were for many years the basis of the charts of the Faroe Islands and the surrounding waters. Based on this land survey a survey of the waters surrounding the Faroe Islands was carried out in 1899-1903 and in 1908. Supplemented only by a few recent surveys this survey still forms the basis of the naval charts of the Faroe Islands.

2.2 Greenland

After the introduction of radio navigational positioning systems, the surveys of the Greenland waters were truly organized. With a few exceptions oceanographic surveying ships have been outfitted and surveying in the Greenland, waters from the late 1940s to 1980 and again from 1989 until now.

Many areas, inshore as well as off shore, have been surveyed through the last 50 years, but there are still huge areas with only a few survey soundings, which have been measured by passing ships. The surveying of the Greenland waters depends not only on the weather, but also on ice conditions, which may hamper surveying and navigation.

Chapter 3.

3.0 The period 1855 – 1884

In the years after 1855, steam ships replaced the sailing ships, and thereby the opportunity and interest in surveying the deeper waters increased. The methods of surveying improved and the result was large areas surveyed, with evenly spread soundings. Oceanographic surveying was at the time done in a straight line, perpendicular to the coast. A method giving the greatest precision when producing and drawing the contour lines in the naval chart.

This technique was intensively utilized in the areas close to the coast, in the deeper waters, the line spacing[1] increased. This was done without any certainty that shoals and other obstructions could exist between the surveyed lines, and present a danger to the navigator.

From around 1875 to the beginning of the 1880s, a large part off the west and north coast of Jylland was surveyed. During this period, sounding equipment was introduced that enabled the survey vessel deep-sea surveying, without the need to reduce speed. This breakthrough meant that detailed information about the ocean floor that previously had been given a low order of priority was now readily available.

3.1 Positioning

The oceanographic surveys conducted after 1855 were the first to be accomplished by using trigonometrically[2] determined points ashore. Sailing ships were used for surveying, in the years up to 1855. There were hardly any technical aids, which meant that it was difficult to get evenly distributed soundings, in the area surveyed.
In order to concentrate on the, at the time, significant and prolonged work of oceanographic surveying, the deeper parts of the sea were only sporadically surveyed.

1 Line Spacing:
When conducting an Oceanographic Survey, the line spacing (distance between surveyed lines) is calculated, according to the equipment used. When using a single beam echo sounder, the line spacing is calculated by using a percentage of the nautical chart scale. When producing a nautical map with the scale of 1:20.000, the line spacing would become 10% of 20.000 = 2.000 metres. When using Multi beam echo sounder, the kind of coverage that needs to be achieved and the general water depth calculate the line spacing.
When using a system with a swath coverage of 120 degrees and a general water depth of 30 metres, the line spacing would become 2*TAN (60) *30m=103m, when aiming for a coverage of 100%. To allow for errors in the outermost beams, an overlap of 10% is often used, so that the resulting line spacing would become approx. 90m e.g. 3 times the water depth.

2 Trigonometric points are points taken from the Danish triangulation network, which are physically marked and surveyed points on land. In connection with modern GPS observations they form the background for the geographical reference network, as we know it today. The network was built as a rational surveying based on a coherent triangulation, base observations and astronomical position fixing.

Survey description
In shallow waters soundings were taken by hand held lead line. In deeper waters, a mechanical sounding instrument was used.

3.2 Survey example 1869 - 1870

In 1869 the steamship "Ægir" surveyed the Schultz Ground in Kattegat. Below is an extract from the survey report:
"The Schultz Ground is located at a flat with between 4 and 5 fathoms of water (approximately 7,5 to 9,4 metres). It covers a 1-quarter mile (approx.1 nautical mile) area south west of the shoal and therefore it stretches even longer than the printed chart indicates. This flat, on which the shoals have been found, with between 22-23 feet (6,9-7,2 metres) of water, has a rather hard and uneven bottom. To be completely surveyed, it should be thoroughly searched by vessels, but because of foul weather, this was not done. On the other hand, the flat was closely crossed by the ship and in this way; its full extent was found. The lightship that was laid out last autumn in 14½ fathoms of water south of the flat, will surely contribute in making the navigation easier between this place and Sjællands Rev. By using lead and the chart, it will not be too difficult even under foggy conditions to find the lightship, and in this way get a good place of departure."

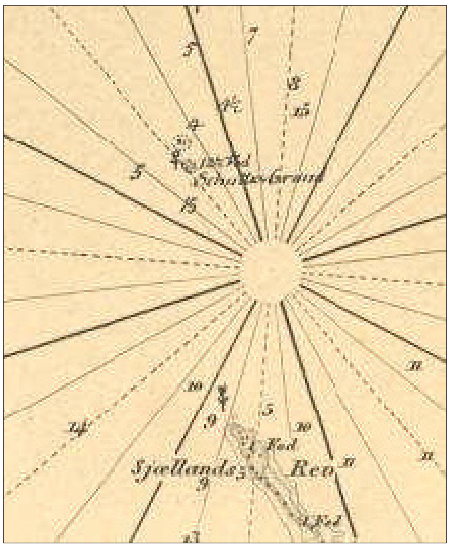


Fig. 2 This is an extract dated 1837.
(It has been updated to 1843)

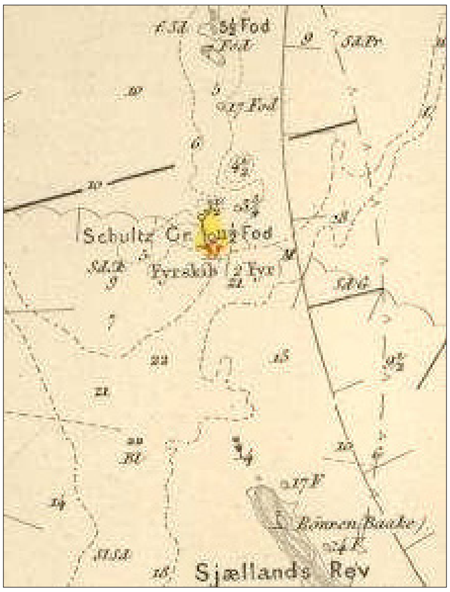


Fig. 3 Extract dated 1874.

As recommended, by the surveyor on the steamship "Ægir", the area was thoroughly searched in 1870 with vessels. Compared with the survey from 1869, shallow depths were found.

Fig. 3 shows an extract dated 1874. It shows the shoals and the mentioned lightship ("Fyr-skib").

3.3 Survey evaluation

Surveying by means of lead line is unreliable, due to the changing texture of the seabed. The plumb bob will sink into the sea floor, if it lands in clay or sand. There is also a high probability that it will fall between the stones, on a sea floor covered in stones, thereby presenting a false depth. In the period from 1855 to 1884, full coverage has been far from achieved. The accuracy and reliability is at best, very poor.

Chapter 4.

4.0 The period 1885 - 1934

The introduction of steamships meant a rapid development of the shipping trade and the result was a high demand for precise and accurate naval charts. The number of soundings in the naval charts had to bee increased, and the surrounding aids to the navigator had to be improved. Aids like lights, light boats and fog signals, were necessary in order to secure the navigator the ability to safely navigate through the Danish waters, in all weather conditions.
Due to the small scale of the maps, the additional information made them unreadable. It therefore became necessary to produce naval maps in a larger scale. A comprehensive oceanographic survey was conducted during the years around 1900, to facilitate the production of the necessary large-scale maps.

4.1 Positioning

It is worth noticing the survey of Kattegat, conducted in the period from 1893 to 1899. In this oceanographic survey, a complete triangulation between marker buoys and marker ships, were the basis for the survey vessel positioning. The survey vessel was able to triangulate its position, without the need to utilize known landmarks.
In order to be able to service ships with a greater draught than previously, many harbours began the extensive work of extending the mooring space and dredging the harbour area, including access ways. The focus was therefore shifted to finding shoals and obstructions corresponding to the dredged depth of the harbour.

4.2 Survey description

Descriptions of how surveys were carried out at the time are scarce. One of the authors on the subject was Commodore H.O. Ravn. He wrote the textbook for the cadets of the Royal Danish Naval Academy, in oceanographic surveying. In the following text, H.O. Ravn gives an account on how the oceanographic survey in planned and executed in 1928:
"All coastal surveying is carried out from vessels. As the littoral berm almost everywhere in Denmark consists of evenly upwards-sloping sand, the sounding lines are laid with intervals of 200 metres. In narrow waters or places where the depths are uneven, the interval between the lines is reduced to 100 or 50 metres under the circumstances. The positioning is done by simultaneous measurement, from the vessel and the survey ship.
From the vessel, the vertical angle to the top of the ship is measured and on the survey ship

the horizontal angle between the vessel and a fixed point at land is measured. In this way, you get the direction and the distance between the vessel and the ship. The ships position is determined by resection[3] to fixed points at land. The position of the ship is measured and the navigator always takes out several bearings so that it is possible to check the calculations.
During the movement of the ship, soundings are constantly taken, and the single soundings are allocated between positions, defined with an interval of 2-300 metres by means of the time, which is constantly noted.
The utmost limit for laying a survey line is 800 metres from the vessel and it is only done when it is absolutely necessary. This way the distance from the vessel to the ship will not exceed approximately 1000 metres. With the height of the present survey vessels and with an allowed error of measuring, of ½ minute in the height angle, this will result in a distance error of approx. 6 metres. In the 1:20.000 scale, of the survey chart, this will result in an error of 0,3 mm. This is the defined limit of the allowable error.
Outside the coastal zones, the survey is performed from the vessel and the distance between the lines will be 300-400 metres unless there are specific reasons for a smaller line distance. The positions are taken by measuring the angles between fixed points and are drawn with a station pointer. The plumb bob is in constant use, and the revolutions of the engine are ascertained as well as the soundings and positions. The depths are found in the same way as described above."

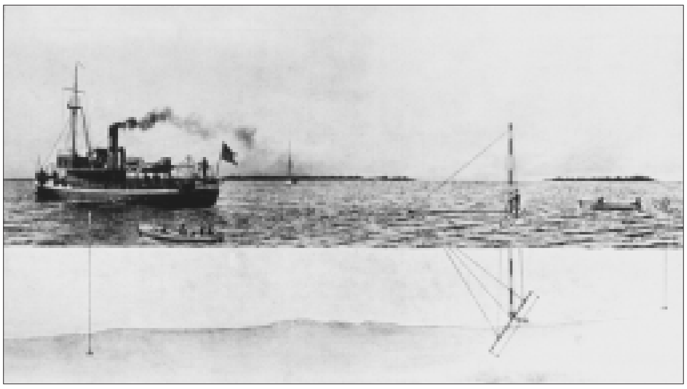


Fig. 4 A Survey ship tows a sweeping device in a shoal investigation.

H.O. Ravn refers to the survey method as old-fashioned, so it is likely that the procedure has been used throughout a longer period, supplemented only by new methods of sweeping the ocean floor. These methods were line sweeping, between to vessels or between to poles attached to a single vessel. These sweeping methods were difficult and time consuming to use and in 1911 a specially designed sweeping boom was constructed. It was named "Trallen" and

3 Resection is a geodetic name for the surveying method used to establish points. By resection the point is positioned by observations of angles from the new and unknown position to known points. By intersection the point is positioned by observations of angles from known points to the new and unknown positioning.

it was towed after the survey ship at a preset depth. "Trallen" made it possible to determine the shoalest depth, in an area with rocks and obstructions.
In 1926, the "Trallen" device was improved and sweeping could now be done at a much higher speed, than previously. This development meant that shoal investigations became the primary survey work, in the latter half of the period.
Fig. 4 shows the sweeping device in use. Sweeps and investigations were time consuming and resource demanding.

The draught of the ships increased and it became necessary to investigate the shoals, which had earlier been of no interest to the vessel traffic. A difference of 2 metres in the depth now became of vital importance for the safe navigation through the Danish waters.
Towards the end of the period, a new technical improvement for measuring the depth is mentioned. The echo sounder was going to be installed in all the new survey ships. It is described as a brilliant device capable of surveying at great depth, even when the ship is doing full speed.

4.3 Survey example 1911 - 1913

The following is an example of a survey in Flinterenden from 1911 to 1913. It shows the difference between the number of soundings gathered when surveying and the number of soundings shown in the chart. The same principle is used in modern surveying described later.

The survey area was 4,25 Nm by 2,25 Nm (7,9 Km by 4,2 Km). In this area, the minimum depth had to be guaranteed. On the most used chart (scale 1:300.000) you will find 36 soundings and on the higher scale chart (scale 1:60.000) you will find 167 soundings. During this survey, 15,500 soundings were collected and the "Trallen" was towed for approx. 180 Nm (333,4 Km).

4.4 Survey evaluation

An evaluation of the surveys conducted in the period from 1855 to 1952 reveals that full coverage of the sea floor is still far away. Data accuracy and specifically position accuracy is still poor.

Chapter 5.

5.0 The period 1935 – 1952

The period is characterized by great technological improvements of the survey methods. As previously mentioned, the first echo sounders were installed in survey vessels in the beginning of this period. However, a certain reservation towards the new technology is evident. A description from 1942 says:
"A shoal has been found by means of the echo sounder and the depth controlled by means of a plum bob".
Another surveyor reports that a shoal has been found by means of the line investigation device (like the "Trallen"), and then found again by means of echo sounder and finally the minimum depth was obtained by the use of a diver and a measuring pole. The use of line investigation devices was almost abandoned after World War 2 due to the danger of mines. Compulsory mine swept traffic routes were introduced.

When using an echo sounder, the knowledge of certain factors is very important, e.g., how the echo sounder is calibrated, interpretation of the echo sounder traces (definition of the sea floor). This is described in detail, later in this text. As many circumstances such as frequencies, installation, echo sounder construction, the composition of the ocean floor, water area etc. will influence the result of surveying by means of echo sounder; a general accuracy cannot be claimed. Today surveying by means of echo sounder is much improved, with respect to data density, accuracy and the knowledge regarding the use of the echo sounder.

5.1 Positioning

Until the end of the 1940s terrestrial positioning was still the most important positioning method. After World War 2, radio navigational methods became available and a new epoch within positioning started. It was now possible to survey with a much higher accuracy, far from land and under reduced visibility. The Decca system was the first post war radio electronic navigational system, applied for surveying. The accuracy of the Decca system depended on the time of the day for the survey and how well the surveyor was able to make corrections for the local inaccuracies that the system had. Without correction, the inaccuracy might be up to 200-300 metres. The probability of rediscovering objects again on the sea bottom positioned by means of Decca coordinates, were high, and therefore the system has been very useful to the fishermen to locate fishing grounds.

Tidal observations or self-registration tide gauges were used to correct the soundings to chart datum. The registrations were carried out in the nearest harbour, or if there were several harbours in the neighbourhood of the survey area, registrations were carried out several places and interpolated afterwards between the survey area and the harbours.

5.2 Survey description

Fig. 5 shows an example of the echo sounder survey method. Objects and shallow waters may easily lie undetected, in between the surveying lines.

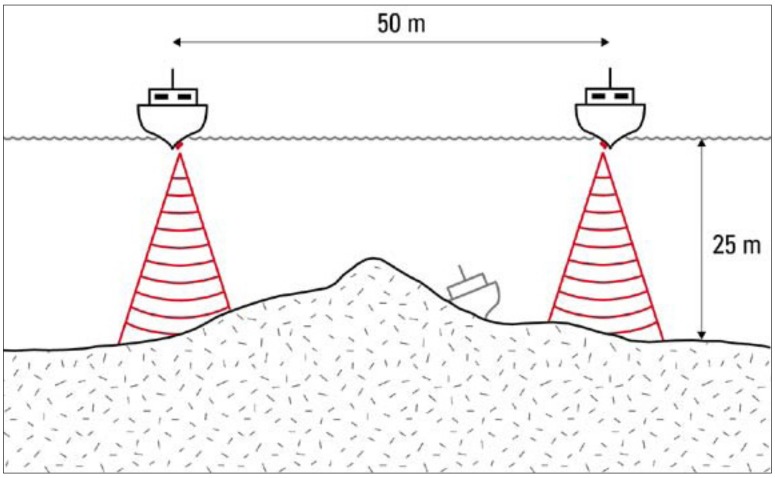


Fig. 5 When surveying with echo sounder, without 100 % coverage of the sea bottom objects and shallow waters may pass undetected.

In 1951, the following surveying procedure is recommended to increase the accuracy of surveying, when using the Decca system:
The survey ship positions itself close to the survey area, e.g. a pier, a lighthouse or a large buoy. Interfering objects such as cranes, storehouses containing iron and the like must not occur. From this position, a resection is carried out and the position is calculated. While carrying out the resection it is stressed that only well defined points are used.

By using this method, the surveyor was able to determine the Decca correction on the spot. It was done every day, before and after commencing the survey.

If the control is carried out at the position of a buoy, then in each case the ship has to be positioned by use of double angle plot, to adjust the position of the buoy and in doing so accuracy of the Decca coordinates.

5.3 Survey example 1950

In connection with surveying at Hals Barre in 1950 Vejdybet was surveyed too.
The survey was carried out with different types of ships and surveying methods. The Decca system was used to deliver bearing and distance information, to the ships.
Stations were created as close to the survey area as possible, in order to achieve the highest possible positioning accuracy. These were coordinated and provided with distinct colours.

In the southern part of Vejdybet, which is an extremely narrow strait, lines have been sailed along side and between the shoals which confines the narrow deep. Line positioning is done by double angle plot.
Soundings are taken with intervals of approximately 5 seconds, and they are reduced to mean sea level, based on corrections observed in Hals harbour.
Sounding poles are used on depths below 3 metres and a Kelvin Hughes echo sounder on depths of more than 3 metres.

5.4 Survey evaluation

An evaluation of the surveys conducted in the period from 1855 to 1952, shows that full coverage of the sea floor is still far way. Data accuracy and specifically position accuracy is still poor and because of this, objects might exist on the sea floor, which are not shown on the nautical charts. This obviously constitutes a risk when navigating in an area of the Danish waters, surveyed in this period.

Great care should be taken when navigating close to shoals or obstructions, and an allowance should be given for the inaccuracy discussed above.

In the beginning of the period, the error of positioning by optical position fixing exclusively is estimated to be 100-200 metres near the coast and outside optical range approx. 300 metres. In the end of the period, the position fixing comes close to 10-30 metres near land, and by means of the Decca radio navigation system the accuracy is estimated to be better than 100 metres (95% of the time).

For soundings made by use of a plum bob the accuracy is estimated to be within 20 centimetres concerning depths below 20 metres. However, uncertainty as to corrections of water level may influence the accuracy of the sounding on the chart.

Tidal corrections depend on the chart datum used and on the geographical area. There is a big difference between the corrections in The Baltic Sea and corrections in The North Sea. Variations also depend on whether the surveyed area is close to the tide gauge or far away from it. The variations also depend on if an interpolation between the different observations and the survey area has taken place. All together, the error due to the tide is expected to be 10-40 cm in the inner Danish waters and up to 1 meter in the North Sea, during this period.

It appears that surveys conducted before 1953 has an uneven distribution of soundings. There is no guarantee that the least depth has indeed been found and no indication of shoals or obstructions between the lines. The preferred line distance was approx. 400 metres according to the survey methods used and the resources available, though it could vary due to the circumstances of the survey.

Fig. 6 gives an example of a survey conducted from 1869-70. This data is still used on chart 128.

It is evident from the methods of surveying described that the determination of the minimum depth is not an easy matter. Even by means of echo sounder and small distances between the lines, it might be difficult to determine shoals.

Great care should be taken when navigating close to shoals or obstructions, and an allowance should be given for the inaccuracy discussed above.

An evaluation of the surveys conducted in the period from 1855 to 1952, shows that full coverage of the sea floor is still far way. Data accuracy and specifically position accuracy is still poor and because of this, objects might exist on the sea floor, which are not shown on the nautical charts. This obviously constitutes a risk when navigating in an area of the Danish waters, surveyed in this period.

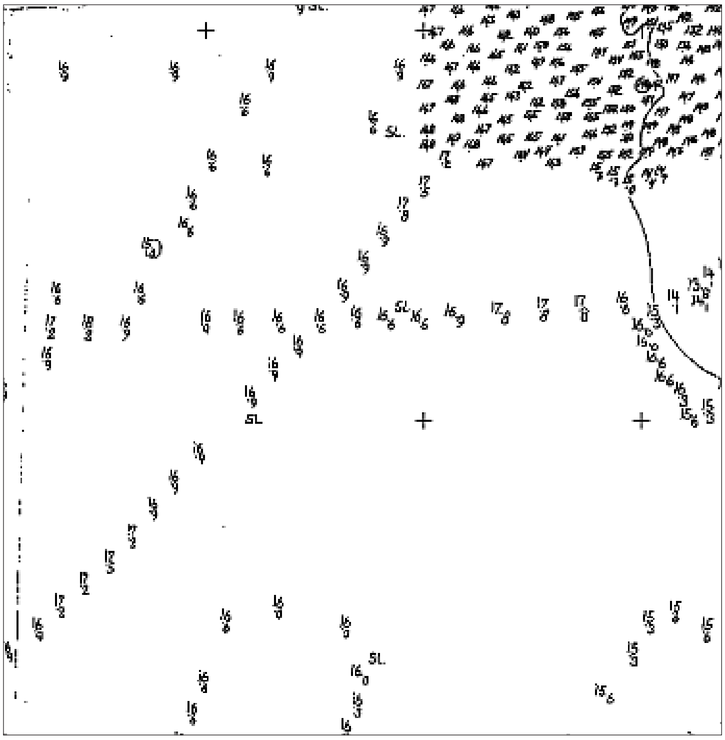
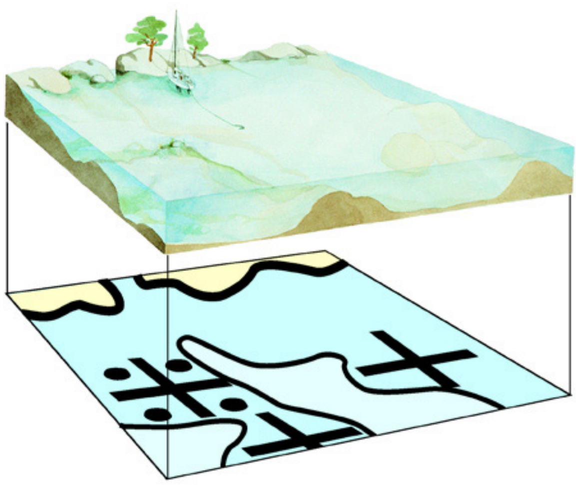


Fig. 6 An example of a survey conducted in 1869-1870. The data is still used today in chart 128. Scale of the extract is 1:20.000 (1 cm=200 metres).



Example of a chart generalized version of the actual depth ratio and the presence of stones or rocks in level of the chart datum and underwater stones or rocks.

Chapter 6.

6.0 The period 1953 – 1991

As mentioned in the introduction, the shipping has always been imperative to Denmark. Due to the deeper draughts of the ships and the expansion of the shipping industry, there will always be increasing demands for the surveyor to find all shoals and obstructions, with the technology and resources available. Up until the beginning of the 1950s, the draught of the ships were less than 10 metres. The surveyor therefore worked hard to find all shoals less than 10 metres. As the draughts increased to 17 metres and some years later to 25-30 metres, the strategy for the surveyor changed. Shoals between 10-30 metres became interesting and decisive for safe navigation through straits and other waters.

To obtain and guarantee the minimum depth, various types of modernized line scanning devices were used in surveying up until the beginning of the 1980s. Paravane gear was trailed by a minesweeper and wire drag devices were trailed by the survey vessels.

In 1981 the Side Scan Sonar was introduced and used by the survey vessels. The Side Scan Sonar pictures the ocean floor. Trawl tracks, lost cables, stones, shoals and similar things on the ocean floor become visible and this generates 100% coverage. Shoals and obstructions between the survey lines became easier and quicker to find.

During this period, main shipping routes for the vessel traffic were established, like Route T in 1976. In these routes, the minimum depth can be guaranteed because they have been surveyed with 100% coverage.

The coastal zones, mainly frequented by yachts, were not necessarily surveyed with the same care as the main shipping routes. The navigator should take extra care when sailing through such places, the depth information could be of a very old date, and 100% coverage might not be guaranteed.

The following text (6.3) gives a description of a survey, as it was conducted in the period. It also describes the inaccuracies in the survey and in the nautical publications.

6.1 Positioning

As already mentioned, radio navigation methods have been used for positioning in surveying since World War 2. The advantage if compared with the optical methods is that it is possible to measure with great accuracy under reduced visibility. The Decca system has accuracy from a few metres to several hundred metres depending on the area and the time of day. The accuracy also depends on if it is possible to correct for the locally derived errors.

When using the radio navigation methods in the period 1971-1991, the survey ship position errors have generally been from 1 to 10 metres. The radio navigation methods have made it possible to produce continuous, digital position recording of the ship even when travelling at high speeds. When using the traditional position of surveying methods it can be difficult to follow a line or a curve with better accuracy than 10 metres, if currents or swells appear across the survey line. With the introduction of radio navigation methods and with the use of continuous positioning of the ship, the transfer error and the human error is accounted for.

The relative position of the radio navigation system antenna on the ship will in principle have to be vertically above the echo sounder. The measurement of depths and position recording has to be taken at the exact same time.

However, this is not always the case, and therefore the time difference between the depth measurement and the recording of the position, has to be measured and taken into consideration. The offset of the antenna in relation to the echo sounder also has to be measured and taken into consideration.

The decision of which position fixing system to use, takes experience and depends on the area of survey. A determining factor is also the technological possibility. Surveying in the period, distance systems as well as hyperbola systems have been used. The following outline shows the use of systems in the period 1953-1991:

Radio navigationssystem	Dictance	Hyperbola	Year
Decca		X	1949
Hydrolist		X	1962
Raydist	X		1968
Seafix	X	X	1971
Toran		X	1976
Motorola	X		1979
Syledis	X	X	1982
Total Station	X		1991

Before commencing the survey all positioning systems are calibrated. That means that the ship is moored beside a well-known point at a pier. The position of the antenna is calculated in relationship to the well known point. The error of the position navigation system is realized and corrected in several ways. Another option is to cross the different position lines at sea in order to ascertain the errors and then calculate the sum of corrections for the radio navigation system.

The Differential Global Positioning System, which is mentioned later, appears in the end of this period.

6.2 Survey description

Fig. 7 shows the principle for surveying in the last half of the period. One or more ships sail on previously planned surveying lines with a certain line distance. This distance depends upon water depth, and the texture of the sea floor. The master ship uses radio navigational signals from land to establish position fixing of the ship. The master ship's computer steers and thereby keeps the ship on the survey line and collects both its own and, with the aid of a depth data transmission system, the depths of the side boat(s).
The side boat(s) position themselves relatively to the master ship with the aid of optical tools. Before the survey is started, the echo sounders and positioning systems are calibrated, and measurements are taken of the sound velocity through the water column.

Positions are taken with even spaces at the same time in both ships and they are plotted in a working sheet. This enables the surveyor to watch the survey work continuously.
If the surveyor suspects shallow waters, wrecks or the like, the area is marked in the working sheet and followed by a search with closer line spacing. To claim that the area has been completely covered, requires the use of Side Scan Sonar (or earlier in the period the different types of line sweeping devices). This is to ensure that there are no shallow waters in between the surveyed lines.

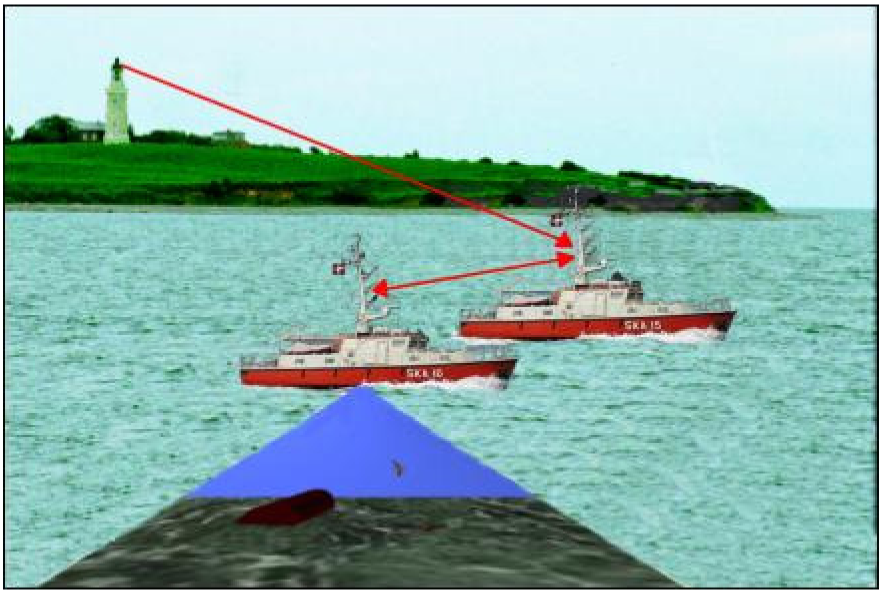


Fig. 7 The principle of surveying in the period.

The surveying is normally carried out in the summer season when the weather is reasonable. The post processing and the drawing work is carried out in the winter. The data is drawn out in fair-sheets[4] in scale of 1:20.000, and sent to the Hydrographic Office to be incorporated on the charts.

The Side Scan Sonar (SSS) is a supplementary acoustical registration of the topography and objects on the sea bottom. Fig. 8 shows the advantage of using SSS. It is clear that the small footprint of the echo sounder on sea bottom requires the distance between the survey lines to be only a few metres in order to cover the topography of the sea floor 100%. SSS on the other hand has a wide emission, which covers the sea bottom from just below the transducer out to a distance, which depending upon the height of the transducer above the bottom, can be up to 500 metres or more across the sea floor. Wrecks, stones and other submerged obstacles will therefore be detected by SSS, which makes it possible to measure minimum depths with the echo sounder on the found objects afterwards. Fig. 15 shows a picture from a modern SSS.

In this period, SSS has not been used for inshore surveying of routes at Greenland. The risk of loosing or destroying the equipment while surveying in the very varied terrain of the sea floor is very high.
Therefore use of visual observations of obstacles at low water and, depending on the area, and close spacing of survey lines are important at Greenland.

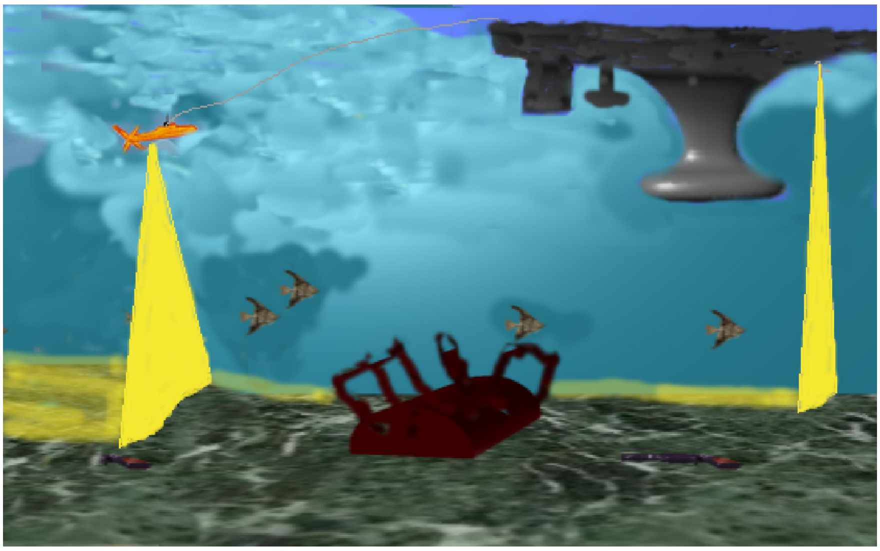


Fig. 8 The advantage of using Side Scan Sonar is a broader coverage of the sea floor.

4 Fair-sheets are the raw material of charts and the aim of A-sheets is to make it possible to find the information, which is necessary to plot a chart, in one place. The A-sheets will therefore always be updated with the final corrections or the last processed surveying. Each A-sheet is a standard sheet in scale 1:20 000 and it covers 10 minutes in latitude and 10 minutes in longitude.

6.3 Survey example

Fig. 9 and fig. 10 shows extracts of a fair sheet covering the southern part of before and after resurveying. The surveying in the western part of fig. 9 was carried out 1895-1896. The same area is shown in fig. 10 only this is surveyed in the beginning of 1990. Many more shallow depths are present in the most recent survey; the soundings are also equally spaced in the chart. The result is that important additions and changes have been made to the depth contours. In the recent survey, depths of up to 2 metres less water depth, are found between the surveyed lines from 1895-1896.
Wrecks are found on the same positions, which is probably a result of newer wrecks investigations in the area. However, the depth of the wreck THETFORD has been changed in the resent survey from 10,1 down to 9,9 metres.

The example shows the big differences, which can be found when conducting a new survey. If the area had not been resurveyed, the depths from 1895-1896 would still exist in the electronic navigational chart.

6.4 Survey evaluation

An evaluation of the surveys conducted in the period from 1953 to 1991 shows in general, that without supplementary use of wire drag or Side Scan Sonar, full coverage of the sea floor, is not achieved.
Data accuracy and completeness is poor. Because of this, there might be objects on the sea floors, which are not shown on the nautical charts. These objects might constitute a risk for the navigation in or through Danish and Greenland waters.

In the waterways, the demand of 100 % coverage of the sea floor has been achieved with the use of wire drag or Side Scan Sonar (SSS). SSS is mainly used in main shipping routes, dredged channels, anchorages, entrances to harbours, harbour areas and harbours and other similar areas, with special conditions. Data in these areas can be classified as being of good quality.

The accuracy, which the ships are able to achieve by using the satellite based navigation systems conflicts with the depicted accuracy of the Greenland coastline.

In the Faroe Islands no governmental surveying has been carried out during this period, but generally deep water is found quite close to the coast.

Side Scan Sonar has not been used in the Greenland inshore routes. Therefore data accuracy and completeness is poor.

Calculations of positions by using the Decca system are generally considered as defective with errors beyond 100 metres. Surveys carried out with the use of the Decca radio navigation system for positioning fixing has to be resurveyed to achieve satisfactory data accuracy and completeness.

An evaluation of the surveys from 1953 to 1991 in general will show that without supplementary use of wire drag or Side Scan Sonar full coverage of the sea floor has not been achieved. Data accuracy and completeness is poor. There might be objects on the sea floor, which are not shown in the nautical charts. These objects might constitute a risk for the navigation in or through Danish and Greenland waters.

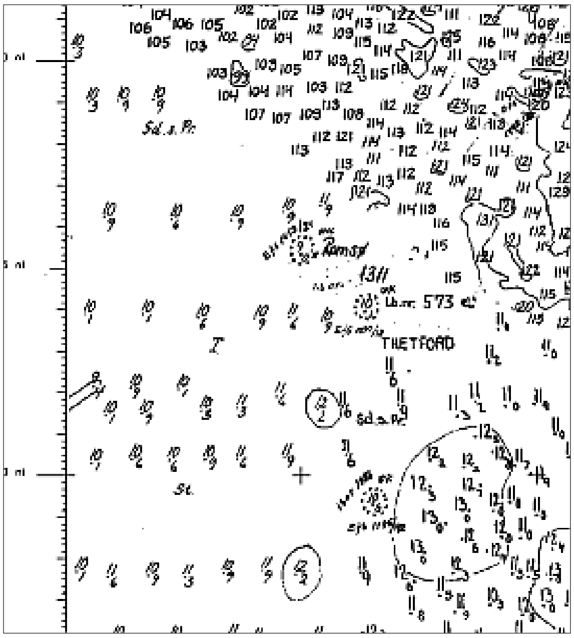


Fig. 9 Surveying from 1895-96 in A-sheet 5530/1240. Extract in scale 1:20.000.

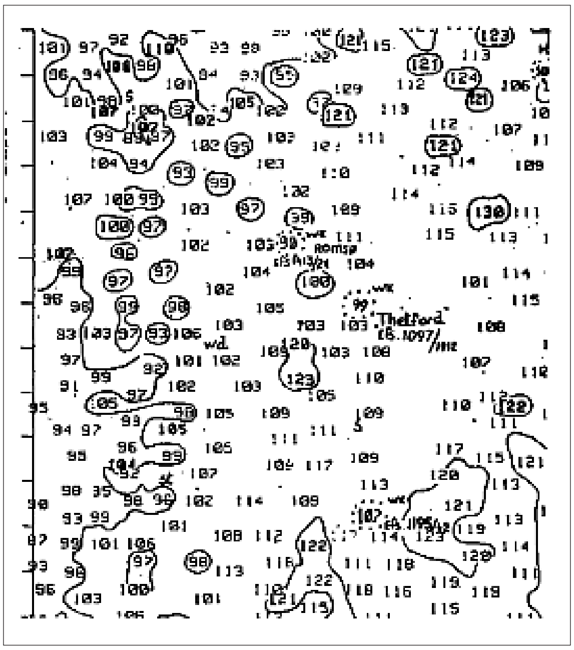


Fig. 10 The same area as shown in fig. 9, after the recent survey. Extract in scale 1:20.000.

Chapter 7.

7.0 The period 1992 – 2004

Nowadays the production of electronic navigational charts demands more of surveys with respect to quality and quantity. The demand of modern surveys is 100% coverage of the sea floor. The traffic at sea, air planes and highway traffic is in hard competition on transport time, safety and environment. The majority of bigger cities in Denmark are harbour cities.
Waterways are being used for conveyance of goods. Fast ferry routes are established with catamarans ships which are able to transport more than a thousand passengers and more than a hundred cars with speeds of 45 knots (approximately 83 km/h). The consequences of grounding will be fatal for human beings, the society and the environment. Electronic navigational charts are produced with data from old surveys, and errors or lacks in the basic data are transferred to the electronic navigational charts. The majority of ships uses modern technology; especially concerning the satellite based navigational systems such as GPS. This used together with a differential correcting reference station provides accuracy of the positions within a few metres.

The technological improvements with respect to accuracy of positions by DGPS with precisions of 0,5 metres together with multi beam echo sounder covering 100 % of the sea floor presents an occasion to re-evaluate the data used in the electronic navigational charts.

Experiments with new methods of surveying using laser beams from helicopters are carried out. The range is limited to the depth interval from approximately 0,3 metres to approximately 30 metres of water. The optical quality of the water is very important as muddy or polluted water reduces the range and increases the number of errors. The system is well suited for use in areas with many shoals and rocks, where a traditional survey with vessels would be difficult and time consuming. Furthermore, experiments with satellite based observations from ERS-1 and ERS-2, where statistical deviations in the sea surface can be assigned to the topography on the sea bottom. ERS-1[5] and ERS-2 are able to operate in all weather conditions, day and night above oceans, polar areas, shore areas and land.

If the survey area is nearby, tidal corrections are downloaded from oceanographical gauges in Denmark, Greenland and the Faroe Islands. Otherwise, tide gauges are established on location and used. Three-dimensional DGPS measurements in good quality can be carried out.

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5 The ERS-1 satellite (European Remote Sensing Satellite) was launched in 1991 by ESA (European Space Agency) to solve environmental and scientific aspects on the earth. ERS-1 is equipped with active and passive micro wave sensors, radar height measurers etc. For hydrographic purposes such as interpretation of bottom topography SAR (Synthetic Aperture Radar) pictures are used. In 1995 ESA launched ERS-2, which is a further development of the ERS-1. In 2002 the ENVISAT satellite was launched with Advanced Synthetic Aperture Radar (ASAR) for the production of high-resolution pictures.

7.1 Positioning

The Danish Maritime Authority has established permanent GPS reference stations at Hammer Odde, Blåvands Huk and Skagen. The use of these stations provides accuracy better than 10 metres (95%) depending upon the user's distance from the stations.

This accuracy is not good enough for modern surveying and therefore separate differential stations are set up with faster updating times and with accuracy of positions of 0,5 meter. Surveying in 3 dimensions by the use of RTK, Real Time Kinematics, is also used. The range is limited to approximately 10-20 km and signals from 5 satellites are required.

The accuracy, which ships these days can achieve by the use of the satellite based navigation systems, is not in harmony with the drawing accuracy of the Greenland coastline. In this way inaccuracies of more than 3 nautical miles have been observed in the period in the chart in the Greenland east-coast near Illoqqortoormiut (Scoresbysund) relative to the GPS positioning. Because of this, a ship in the Nordvestfjord, a fiord from 4 to 10 km wide, in several cases had the course of the ship across land. In these cases the navigator has to use relative navigation by the use of radar or terrestrial navigation.

Compared to DGPS measurements the Danish coastline can also in some places be inaccurate but the accuracies are better than 20 – 30 metres depending on the basic data used. The digital topographical data base FOT[6] is used when issuing new Danish nautical charts, thereby providing a new and improved depiction of the coastline with an accuracy better than 10 metres.

This explains why the navigator must use GPS or DGPS with great care when passing through shallow waters, which have been position fixed with other systems than DGPS.

7.2 Survey description

The survey ships equipped with the multi beam echo sounder system operates independently of each other. When planning the surveying lines and line distance, the water depth must be taken into consideration. To achieve 100% coverage the line distance must be planned by using the least expected depth at the surveying lines. By using multi beam echo sounder it is not so important to survey across the contours as when surveying with single beam echo

6 FOT stands for "FællesOffentligT geografisk administrationsgrundlag" (common public geographical administration data), which refers to the geographical data that central government and municipalities produce and maintain jointly. All objects are defined as points, lines or surfaces in a coordinate system, where themes can be chosen or left out.

sounder. The surveying lines are planned with 25% overlap at the least expected depth, and the outermost beams are cut off afterwards because of their reduced accuracy.

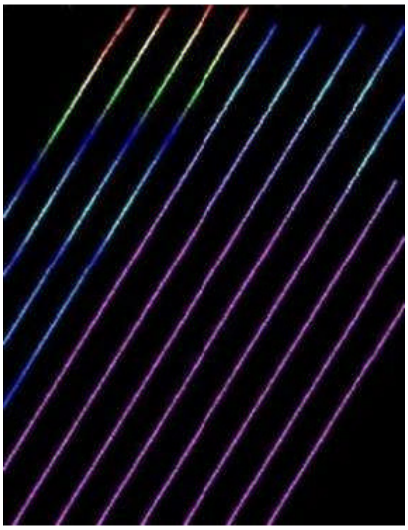


Fig. 11 Data from 12 lines with single beam.

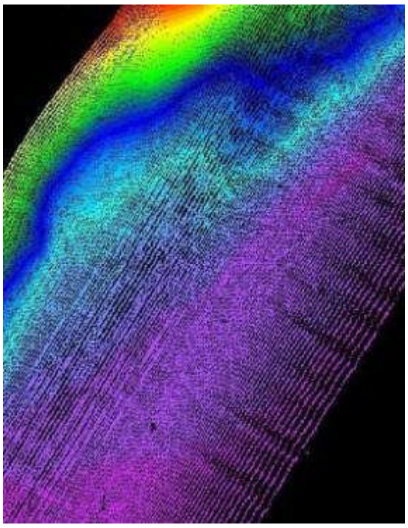


Fig. 12 Data from 2 lines with multi beam

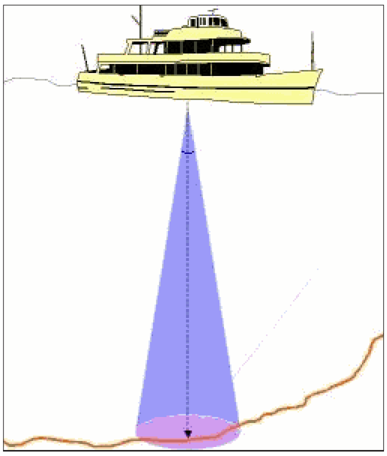


Fig. 13 Single beam echo sounder.

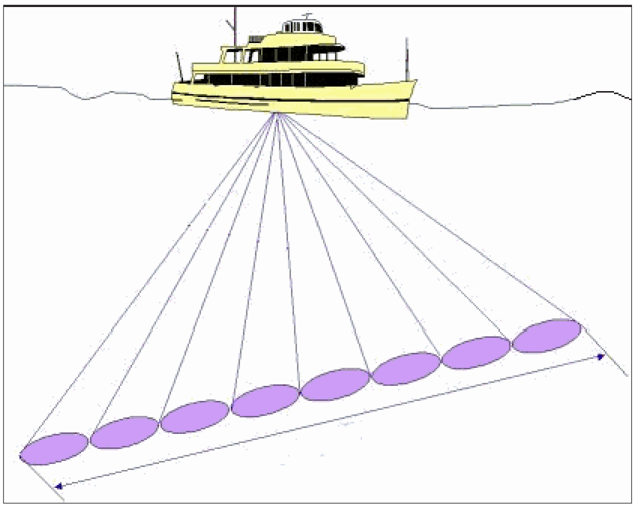


Fig 14 Multi beam echo sounder.

7.3 Survey example

The difference in density of data surveying with single beam compared with multi beam echo sounder can be seen on fig. 11 and 12. With multi beam echo sounder it is possible to achieve 100 % coverage of the sea bottom, saving time and resources. The shown extracts are 1200 x 1400 metres.
Surveying with multi beam echo sounder is supplemented by the use of Side Scan Sonar, SSS.

The principle concerning mode of operation and use of SSS is the same as described in 6.3. SSS has however been further developed and now data can be stored and analysed on a computer as a supplement to surveying with multi beam or single beam echo sounder. Fig. 13 shows an example of a SSS picture of a wreck in Kattegat.

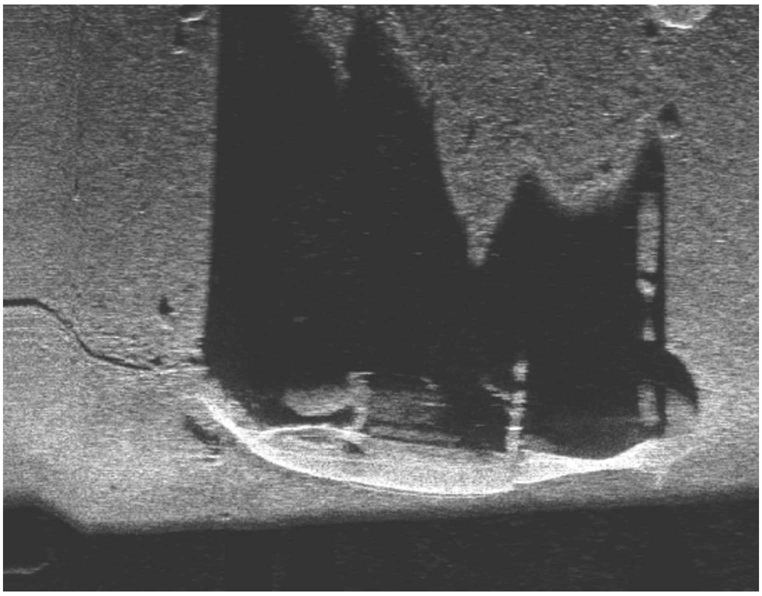


Fig. 15 Side Scan Sonar picture of a wreck approximately 35-metres long in Kattegat east of Læsø. The anchor chain can be seen to the left.

The post processing of the huge amount of data, which is collected, requires good analytical tools in the form of algorithms, which are able to detect and select errors. In a short period of time many millions of data are collected and all of these data will have to pass quality assessment and then be stored in a depth database.

For a chart in scale 1:50.000 a depth plotted for every square of an area of 6 x 6 m2 corresponds to an area of 0,12 x 0,12 mm2 on the chart. Before plotting depths in the chart, a heavy data reduction of minimum depths is carried out, in order to achieve clarity and provide a representative picture of the information.

With the huge amount of depth data, it is possible to draw 3 dimensional digital terrain (DTM) models. Fig. 16 shows an example of such a model in the size of 5 x 5 nautical miles.

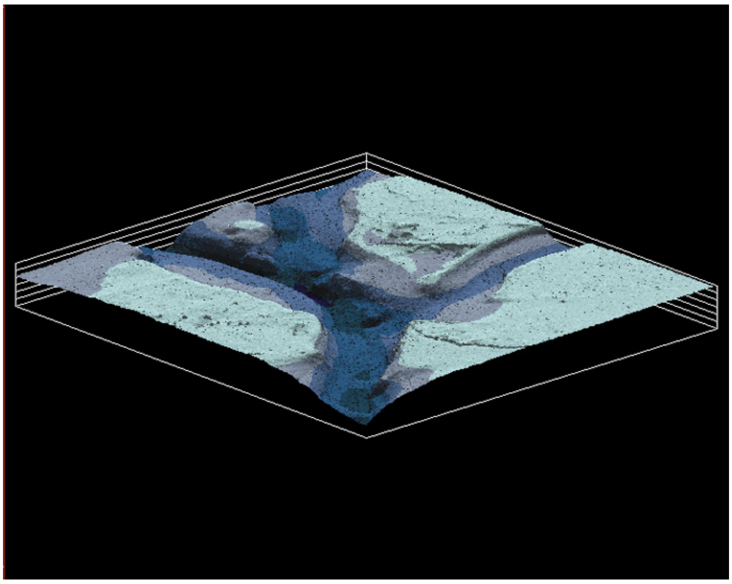
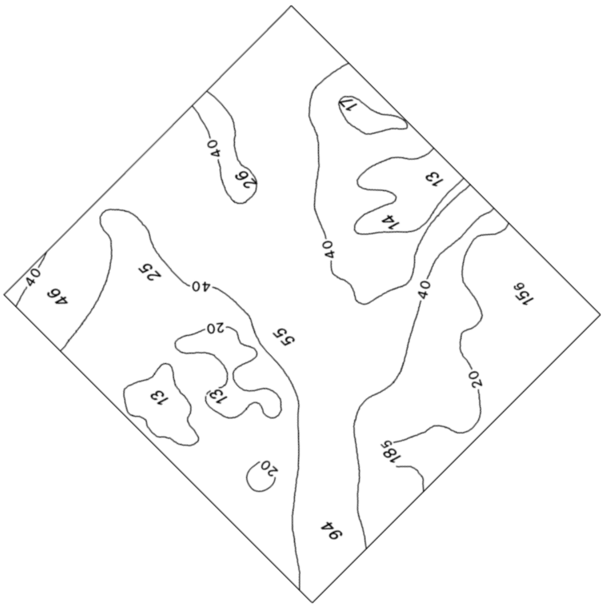


Fig. 16 DTM picture of an area south east of Læsø.



The extract is turned so that both the model fig. 16 and the extract is viewed from north west

7.4 Survey evaluation

The navigator must never, uncritically and without the necessary precaution, base his navigation on (D)GPS in waterways, which have not been surveyed with the same accuracy, as that achieved with a (D)GPS system. The navigator should furthermore consult all available

nautical publications for areas, which he passes.
If the area in the chart is has been surveyed according to modern standards (DGPS, multi beam echo sounder and Side Scan Sonar), the accuracy and density of data will be adequate and complete. All objects on the sea floor endangering shipping will be shown on the chart.

The coastline is not necessarily updated recently. A certain inaccuracy must be expected; especially if the navigator uses DGPS.

It is important that the navigator uses all nautical publications, which are available for a given area. It is not possible to show all information on the chart. Harbour pilots, light list, sailing directions etc. gives information about precautionary rules that the navigator should take before passing or calling at areas.

If there are discrepancies between publications and charts, the navigator should be very cautious. He should pay attention to the risk of incomplete information, which may result in a difficult situation and a fast manoeuvre.
If information about waterways differs, the navigator should use the latest information.

The navigator must never, uncritically and without the necessary precaution, base his navigation on (D)GPS in waterways, which have not been surveyed with the same accuracy, as that achieved with a (D)GPS system. The navigator should furthermore consult all available nautical publications for areas, which he passes.

Chapter 8.

8.0 The echo sounder

The navigator should gather experience with the use of an echo sounder, as the registration of depths depends on many factors. With the increasing size of the ships and the decreasing amount of under keel clearance, accurate depth information is of the outpost importance.

From the beginning of the 1930's, when the first echo sounders were used for surveying purposes and to the end of the 1990's, there has been a gigantic technical development. The accuracy has become far better, and the reception time for the sonic impulses has decreased substantially, which means better coverage. Certain factors are important and do not depend on the quality of the equipment, but may nevertheless lead to considerable errors. The navigator's knowledge of these factors is essential, if he wants to exploit the possibilities of the echo sounder to the full. The following factors will influence the soundings:

1) The exact position of the echo sounder compared to the movements of the vessel.
   - Vertical distance from the water surface to the echo sounder.
   - How far down the ship will squat when moving through the water.
   - Transversal and longitudinal movements.
   - Heaving due to waves.
2) Sound velocity in the water column.
3) Calibration of the echo sounder.
4) Interpretation of the echo sounder traces (definition of the sea floor).
5) Tidal reduction.

8.1 Echo sounder position

Vertical distance from the sea level to the echo sounder depends on how heavily the ship is loaded and the density of the water. (The content of salt in the Baltic Sea is approximately 8 ‰ and in the Atlantic Ocean approximately 35 ‰).

How much a ship squats when sailing depends on the sea level and its speed. Calculation of a speed contour of the ship and its echo sounder is recommended, because the error can reach a value of 0,2 meter (10% of the draught) when travelling at more than 10 knots.

The transversal and the longitudinal movements may cause substantial errors in the measurement of the depths, when sailing alongside or near a steep coast. If the vessel rolls, then the distance to the slope is measured and not the vertical distance under keel clearance. Fig. 17 illustrates how the measured depth V, will change according to the amount of roll the ship experiences. The Δh indicates the horizontal displacement.

If the echo sounder has a large opening angle and thus leaves a large footprint on the sea floor, inaccuracies may arise between the soundings (the position of the sounding) and the position of the antenna of the vessel (the position of the vessel) even if the weather is calm. When surveying it is recommended to use a small opening angle (3°- 8°) and always plan the survey abeam to the depth contours. At high speed, in deep water where the rate of data collection is smaller and with an echo sounder with a large opening angle (up to 30°), it is possible to loose details of the sea floor, such as the deepest point of a sand wave or artificially furrows at the sea floor.

Heaving of the vessel caused by bad weather, swells or the passage of other ships at the survey ship may cause substantial errors in the surveying result.

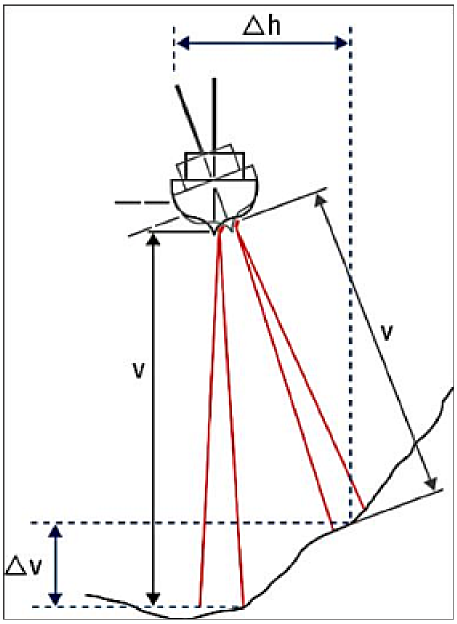


Fig. 17 The horizontal and vertical displacement when rolling.

8.2 Sound velocity

The propagation of the speed of sound through water depends upon temperature, salinity and water pressure[7]. When measuring a water depth exactly, it is important to determine the speed of sound in the water column below the echo sounder. It is important to note that 1 % error in determination of the sound speed would result in 1 % error in the measured depth.

8.3 Echo sounder calibration

Calibration of the echo sounder is imperative to maintain the accuracy. In order to do so it is necessary to know the temperature of the water and the content of salt in the surveying area. For single beam surveys, a "bar check" is the most common instrument for calibration. A reflecting object with a known depth is lowered down under the echo sounder in e.g. the depth of 4, 6 and 8 metres, and then the echo sounder is adjusted to show depths of 4, 6 and 8 metres respectively.

An even bottom with a known depth and with a characteristic possibly artificially placed object can also be used where the echo sounder is tried under different speeds and with different loadings of the vessel.

It might be necessary to calibrate several times during surveying if the conditions change, e.g. if the tides go from low to high.

Mechanical inertia in the echo sounder may cause a delay of the signal (longer time) and as a result, the measurement will show a depth larger than the actual one.

8.4 Echo sounder trace

Interpretation of the echo sounder track means a definition of the sea bottom. This circumstance might have been the cause for errors, as many factors influence the measurement of depths with an echo sounder. When using the plum bob it is not necessary to interpret the measured depth.

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7 Sound: Two more factors influence the spreading of sound through water.
1) Damping of the signal strength caused by absorption: Depends upon frequency and depth – a higher frequency causes bigger damping.
2) Reduction of signal strength because of spreading: Depends upon depth – a larger depth causes larger spreading.

However, the echo sounder is far better for surveying purposes, if you consider the following factors:

a) The nature of the sea floor
b) The frequency of the echo sounder.

a) The nature of the sea floor or even more correctly its ability to reflect the sonar impulse and the energy reflected can be measured if you know the density of the material (of the sea bottom) and the velocity of sound in the material. This calculation is difficult as the sea bottom can vary from soft mud to hard rock. To this may be added loss of energy due to the different layers of water and fish, kelp etc.
These calculations are important for the determination of the possibility of an echo sounder to keep track of the sea bottom.

b) Most modern echo sounders are able to work at frequencies from 5 to 700 kHz and often at 2 frequencies at the same time. When you determine which frequency is most appropriate, you have to experiment and learn by experience when using the equipment. Three factors should be taken into account: water depth[8], the accuracy (resolving power)[9] and the area[10].

8.5 Multi beam echo sounder

It is not likely that ships (except survey ships) will be using multi beam echo sounder for navigational purposes. Therefore, the system will only be described briefly.

Generally the same factors are valid when talking about single beam echo sounder surveying, except for certain modifications.

Many systems have been developed for modern surveying. The following is a description of the Danish Seabat 8101 Bottom Chart System, which is used in Denmark.

The multi beam echo sounder has a coverage across the ship of 7.4 times water depth down to 70 metres with beam direction +/- 75 degrees relatively in proportion to the vertical level, and 2 times water depth down to water depth of 200 metres. There are 101 beams and the numbers of soundings are 3000 per seconds. The system uses phase and amplitude signals for bottom detection, and the working frequency is 240 Khz.

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8 Water depth: The higher the frequency the lower the range. Ex. 210 kHz 100 - 200 metres, 30 kHz 500 -1000 metres
9 Dissolution ability: The higher the frequency the better the dissolution. Ex. 210 kHz 2 cm, 30 kHz 15 cm which means that with a 30 kHz echo sounder it is not possible to measure with accuracy better than 15 cm.
10 Concerning the area: If the bottom is very muddy or overgrown with sea grass, the 30 kHz echo sounder is better at tracking the bottom. The 210 kHz echo sounder has a tendency to ”lock on” the softer bottom layer or sea grass.

The system compensates for the movement of the ship (roll, pitch, heave, gird and the speed of the ship).

Online sound velocity measurements carry out velocity calculations by towing a Danish developed measuring instrument, which continuously sends data to the surveying system. The measuring instrument can be adjusted to oscillate in a sinus curve from sea surface to nearby sea bottom in order to measure salinity, temperature and pressure.

8.6 Tidal reduction

When a survey vessel measures the depth of the water, the result must be corrected for tide height, which means the vertical distance from chart datum to water surface. The estimation of the size of this correction within a water area is the most common error when surveying.

It is important to use a tide gauge in the neighbourhood of the surveying area or even better to place tide gauges on each side of the surveying area. In this way it will be possible to interpolate between them, or simply to use the nearest tide gauge.

It can be difficult to measure the tide far from coastal zones, if it is not possible to find a tide gauge on a light, offshore installation or if a distant controlled tide gauge is not at your disposal. When using tide gauges in coastal zones for correction of depths far from land, a considerable amount of error is introduced, due to the local wind and current effects.

The application of DGPS in three dimensions can solve these problems when surveying in areas far from land. If a well-established geoidal model exists it is possible to survey in real-time and measure the tidal correction, and eliminate the need for a tide gauge. This method of surveying is referred to as RTK (Real Time Kinematic) survey.

The navigator is advised to build up his experience of using the echo sounder because the measurement of depths depends on many factors. With bigger ships and less under keel clearance, exact soundings are of the utmost importance.

Chapter 9.

9.0 Satellite Navigation (Global Navigation Satellite System (GNSS))

GPS

GPS (Global Positioning System) was made and is maintained by the American Department of Defence. The US DoD guarantees that there are always at least 24 satellites in orbit. With this number of satellites it is always possible to receive signals from at least four satellites. This is the minimum number of satellites for position fixing in three dimensions:
Longitude, latitude and height. GPS satellites transmit signals continuously.
Based on signals from a number of satellites a GPS-receiver is able to calculate how long time the signals have been on their way.

When one knows the velocity of the signals, one can calculate the distance from the time the signals have been on their way. At the same time, the satellites transmit information about their orbits which enables the user to fix his position.
From a geometrical point of view, three satellites would be enough to decide a three- dimensional position, but the fourth satellite is necessary, because GPS uses one-way distance measurements. The clocks at the receiver and at the satellite are not synchronous and therefore, signals from four satellites are necessary to achieve the highest accuracy.

GLONASS

GLONASS (Globalnaya Navigatsionnaya Sputnikovaya Sistema/Global Navigation Satellite System) is the Russian Satellite System for navigation. The System has accuracy better than 30 metres (95%). The system is degrading due to lack of funding and maintenance. A reception of both GPS and GLONASS signals will give optimal satellite coverage on major parts of the earth.

GALILEO

GALILEO is the name of the European satellite navigation system, which is established in a corporation between EU and the European air space organization ESA. The system will consist of 30 satellites, which altogether cover the whole earth's surface. It is expected to be to in use in 2008. Compared with the American GPS system, which today is the most widely distributed, GALILEO will have better coverage especially on northern latitudes.
Furthermore, the system will be more precise. Finally, GALILEO is a pure civilian system, while both the American GPS and the Russian GLONASS system are military systems.

EGNOS

EGNOS (European Geostationary Navigation Overlay System) is expected to be in use the coming years and this will improve the accuracy of position fixing by the use of GPS to 2-5 metres.

9.1 Positional errors

1) Ionosphere delay
Disturbances in measurements caused by conditions in the ionosphere depending on the numbers of electrons. This results in errors of approximately 10 metres in the daytime and 2-6 metres at night.

2) Troposphere delay
The troposphere is in the lowest part of the atmosphere. The error is nearly constant and relatively simple to correct even if the delay is up to 1 meter for satellites near the horizon.
Error in the satellite orbit
The difference between the true position of the satellite, and the position calculated from the transmitted signals. The size of the error is normally 1 meter.

3) Multipath
The radio signal can be received from reflections from surfaces in the surrounding area, when passing bridges and buildings. The multipath signal is difficult to separate when it arrives with the same pattern as a normal signal.

9.2 DGPS

The error in the GPS position changes very little from place to place. A GPS receiver in Skagen (northernmost position of Denmark) and one in Gedser (southernmost position of Denmark) will show almost the same error. It is relatively easy to improve the accuracy of GPS, by placing a GPS receiver at a known point in advance, and let the GPS receiver determine the position. By comparing the two positions, it is possible to derive the error. This can also be done in real-time, and the error can be broadcasted to the survey wessels. This is the principle in a reference station.

The accuracy of the positions determined by using DGPS depends on the quality of the GPS receiver used and of the number of satellites, which the GPS is able to lock onto. The more satellites, and the better their mutual geometry, the better the position can be calculated. The accuracy also depends upon the age of the correction signal and of the distance to the reference station where the correction is calculated (fig. 18). Under normal circumstances, when

using observations from at least 5 satellites, it is possible even with cheap GPS – receivers to improve the absolute accuracy from 10-15 metres to 2-5 metres.
The use of DGPS requires that the mobile station, besides the GPS receiver, is equipped to receive the correction signals from the reference stations.

The location of the GPS antenna on the ship must be correctly defined in the electronic system of the ship.

The Danish Maritime Authority runs 3 stations in Denmark, respectively Hammer Odde, Blåvands Huk and Skagen.

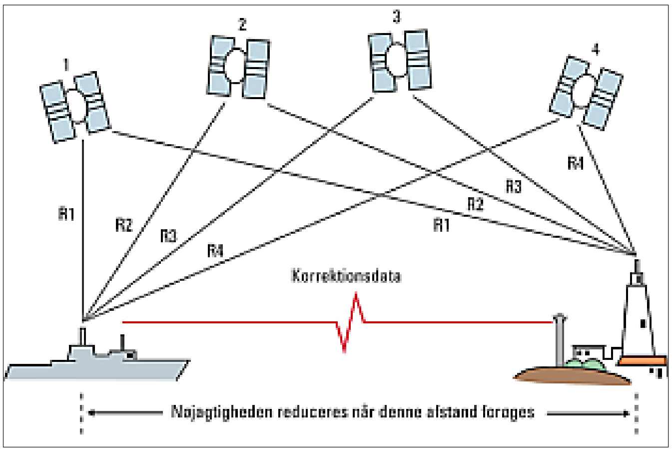

Fig. 18 Principal sketch of differential GPS.

9.3 Spot-FM and NAV-DK

Geodatastyrelsen uses two different methods for emitting the correction signals in connection to the two DGPS services:
In NAV-DK GNM-Data service (data via cellular phone) is used and in Spot-FM FM-RDS is used as a data channel on the FM band. Spot-FM was terminated in 2004.
Both services use the three permanent reference stations to calculate the corrections. In this way, Denmark is covered so that the maximum distance to a reference station is 150 km, no matter where you are in the country.

Chapter 10.

10.0 Charts and Navigation

As mentioned in the introduction the publication of charts today takes place in an international environment where, for the construction of international databases, digital data of charts are exchanged between the Hydrographic offices. This work is carried out under the auspices of the International Hydrographic Organization, IHO. Denmark has been a member since 1921. As IHO has members from all over the world, regional committees are established for solving of local hydrographic and cartographic questions and tasks. The main aim of the international cooperation is standardization of charts and nautical publications concerning content, presentation and accuracy.

10.1 Projection and Datum

The navigator has to ascertain if the geodetically datum of the chart agrees with the datum used in the navigation system. If this is not the case, the navigator has to correct the difference between the used references systems, to avoid a considerable error.

One of the most essential geodetic tasks is to describe the shape of the earth. In simple terms a geodetically datum is a coordinate system, where positions are indicated as latitude, longitude and height. It should always be stated which datum is used together with the coordinates for a position.

In terrestrial navigation, that which the navigator has been using for several hundred years, it has not been necessary to know anything about the used geodetic system in the chart. A position in relative to the coast or to buoys in combination with bearing and distance indicated the position.

The navigator knows the importance of using charts in the best possible scale and to control the scale on two adjacent charts before distances are taken from the charts. In the same way as for charts in different scales charts are produced in different datum and it is important to be careful with references from one chart to an adjacent chart.

10.1.1 Projections

One can use different projections in a given datum. A projection is the method, which is used to depict the three-dimensional surface on a two-dimensional chart. In charts the most common one is the Mercator projection.
To summarize:
A chart can be in WGS84 Datum and produced in Mercator projection, whereas the GPS receiver is able to present Mercator coordinates in ED50 datum. If one uses the coordinates on a chart uncritically, the position can be several hundred metres wrong. The reason for this is the considerable difference in the way different data are positioned in relation to the centre of the earth.

10.1.2 Horizontal datum

With the use of the recent navigation systems such as GPS the navigator must know more about and be more observant to the geodetic datum, than earlier. With radio navigation systems such as Decca it was not possible to encode parameters for datum because you did not receive an absolute geographic position, but a relative one with reference to the station.

This means that you must know the datum as well as the projection and you may need accurate tools of transformation between different datum and different projections.

Most modern radio navigation systems do not state distances or values of hyperbola, but a position related to an encoded or installed geodetically system. WGS84 is the reference system used by GPS[11].

In Denmark a huge amount of positions are measured in WGS84 with very high accuracy. This is called the realization of WGS84 in Denmark. In other words it is the concrete manifestation of this datum, which otherwise would have been a more or less abstract concept. The realization of WGS84 in Denmark is also called EUREF89[12]. The navigator will not observe any changes, and in the chart the indication WGS84 will be stated, even though the correct indication is EUREF89.

11 The reference system takes the form of an ellipsoid and normally it is defined in a general geocentric three-dimensional coordinate system. WGS84 can be used all over the world because the centre of the ellipsoid is in the gravity centre of the earth. This is the opposite of the European reference ellipsoid (ED50) used in Denmark, which has its centre approximately 150 metres from the centre of the earth.

12 The deviation between EUREF89 and WGS84 is about 1 metre. The reason for using EUREF89 is that the earth crust is divided into big areas, which are moving relatively to each other. These movements are determined from the WGS84 coordinates, when one compares coordinates for the same point measured with GPS in 1984 and 1995. The EUREF89 datum is determined so that the ellipsoid follows the European movements of the plate. Coordinates in EUREF89 will not be subjected to movements determined by the movement of the European plate.

The navigator must make sure that the geodetic datum of the chart is in accordance with the datum used in the radio navigational system. If this is not the case, the navigator has to make corrections for the difference between the used reference systems.

10.1.3 Vertical datum

The height of the tide is defined as the vertical distance between the chart datum and the sea level. Most often the value is positive and should be added to the soundings on the chart to find the present depth at a given place.

Internationally it is resolved that heights on shore shall be referred to mean sea level (MSL) and that mean sea level shall be retained as the datum above which light heights shall be given.

Internationally it is resolved that the datum of tidal predictions shall be the same as the chart datum (datum for sounding reduction). It is further resolved that the Lowest Astronomical Tide (LAT) should be adopted as chart datum where tides have a considerable effect on the water level. Alternatively the differences between LAT and the national chart datum may be specified in the nautical documents. If low water levels in a specific area frequently deviate from LAT, the chart datum may be adapted accordingly.

Internationally it is resolved that Highest Astronomical Tide (HAT) should be adopted as the datum for vertical clearances where tides have a considerable effect on the water level. Alternatively the differences between HAT and national datum for vertical clearances may be specified in the nautical documents. If high water levels in a specific area frequently deviate from HAT, the datum for vertical clearances may be adapted accordingly.
Off Skagen[13] Mean Low Water Springs (MLWS) is used, as chart datum, but gradually the chart datum off Skagen will be related to LAT (HAT).

The definition of LAT (HAT) is:
The lowest (highest) tide level, which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.

In the Danish internal waters, the Danish Vertical Reference abbreviated DVR90[14] datum (which is close to mean sea level) is used as chart datum, and when using this datum the tide

13 Off Skagen is defined by a line which connects the Skagen Lighthouse at the position 57° 45,0’N – 10°35,8’E alongside the latitude 57°45’N to the Swedish coast.

14 At Århus Cathedral there is a physically marked fix point, which represents a zero value for height measurements in Denmark. The fix point is related to the Danish Meteorological Institutes’ 10 self-recording water gauges spread all over Denmark. Based on the levelling and water gauges registrations the Danish Vertical Reference 90 has been determined.

table values might have minus values, which means a lower depth than shown on the chart, typically 0,3-0,5 meter and in extreme conditions in some areas up to 1 meter. In charts Mean Sea Level (MSL) is stated as chart datum but in reality, DVR90 is the chart datum.

10.1.4 Tides

The navigator should plan his course with a view to the uncertainty of predicting the Astronomical Tide as well as the at times dominating meteorological influence.

Estimation of the tidal correction causes the most common error of the soundings. Systematic tide measurements and publication of tide tables were not established until 1966 in relation to the Greenland waters and in 1977 in relation to the Danish waters.

The origin of the calculated tides is the astronomy, and calculations of tides should be made over a period of 19 years by using harmonic tide constants, deduced from minimum of one year of observations. However, this is not always the case.

Average values of the meteorological influence should be added to the Astronomical Tide. Therefore, the accuracy of the data of the tide tables is approx. 0,3 meter.

The tide tables, issued by the Danish Meteorological Institute, for Greenland, the Faroe Islands and Denmark only describe the changes of the sea level influenced by the Moon and Sun, i.e. the Astronomical Tide. The often-dominating changes of the sea level due to meteorological and oceanographic circumstances are not taken into
account. The atmospheric field of pressure with parameters like wind power and direction define the meteorological influence. The barometer pressure also influences the sea level. A change of 10 hectopascal (hPa) in the barometer pressure may, theoretically, cause a change in the sea level of about 0,1 meter.

Tidal stream charts showing tidal streams and the range of the tide, can only give approximate values, due to the number of observations and methods of calculation. In areas with great geographical variations and changes to the character of the sea floor, the use of these charts may lead to a deviation of the soundings of up to 1 meter.

The tide in Kattegat, The Sound (Sundet), Great Belt (Storebælt) and Little Belt (Lillebælt) is caused by the tidal wave from The North Sea. Spring tides occur 1-2 days before new moon or full moon. The variation of the Mean Spring tide is only 0.1-0.4 metres.
Regular tidal currents cannot be expected since the currents are caused by meteorological

conditions. Within Skagen the currents are partly created by the admission of water from The Baltic Sea and partly by meteorological conditions.

When planning the navigation, the navigator should allow for the uncertainty of the prediction of astronomic tides and the, at times, dominating meteorological influence.

10.2 Source specifications

In all modern charts you will find an indication of sources either in the title or in a source diagram, indicating the periods of the years in which a certain area was surveyed. The source diagram is divided into: 1855-1952, 1953-1991 and 1992-2018. The source diagram is important for the navigator, because the uniform appearance of a modern chart might give the navigator a false sense of security. The nautical chart is uniform in its appearance, and areas of very old surveys exist close to areas of very recent surveys. This is the case of the map of the western part of The North Sea, where a majority of the soundings in the chart is taken from plum bob surveys dated around 1858. When reading the source diagrams, the navigator will know the quality of the surveys on which the chart is based, and he can ascertain the data quality and consequently plan a safe voyage. Fig. 19 shows a source diagram from chart 128. The extraction shown on fig. 6 is marked in the source diagram.

Generally, all charts are normally issued in a scale smaller than or equal to the one in which the survey has been done. The chosen line distance depends on the scale as well as the nature of the water, whereas the surveying technique has been varied, as described previously. The correlation between the scale and the time of the survey is essential, but it is the year of the survey, which is even more important. It indicates the technical methods of the survey and thereby the degree of coverage.

The coastline in the nautical chart is not necessarily updated in recent time, and a certain amount of inaccuracy is to be expected, especially when using modern navigational tools such as DGPS. The accuracy of the Danish coastline is generally better than 20-30 metres and with FOT data the accuracy is better than 10 metres.

The application of a source diagram was not common until in 1985 and many charts, like most of the Faroese and Greenland charts, does not contain information about the age of the survey data used. New Faroese and Greenland charts contain source diagram. The only way to assess the data quality of the chart is by reading the notes of the chart, if any.

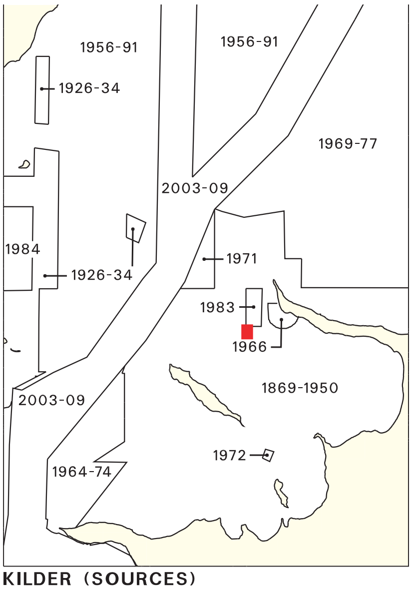

Fig. 19 Source diagram from chart No. 128. The extract in fig. 6 is marked with a red square.

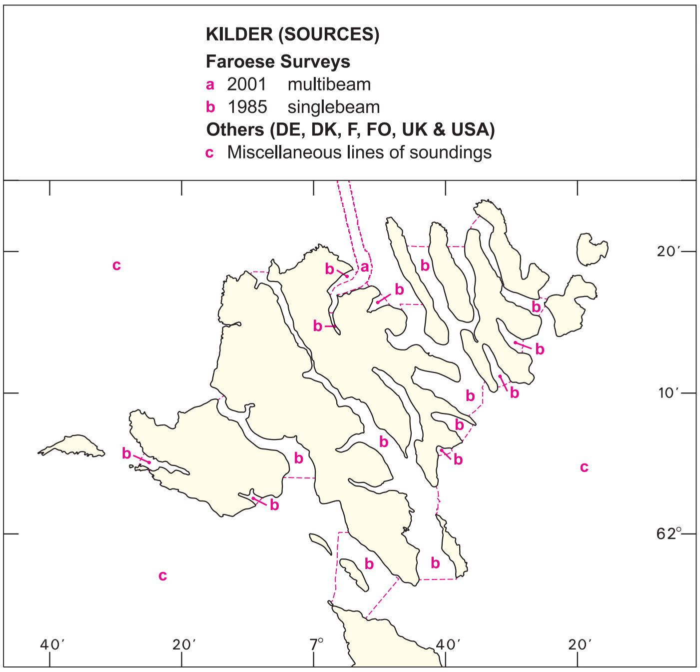

Fig. 20 Source diagram from Faroese chart No. 82.

Zone of Confidence (ZOC) categories
(For details see "Behind the Nautical Chart")

ZOC	POSITION ACCURACY	DEPTH ACCURACY	SEAFLOOR COVERAGE
A1	± 5m	= 0.50m + 1%d	All significant seafloor features detected.
A2	± 20m	= 1.00m + 2%d	All significant seafloor features detected.
B	± 50m	= 1.00m + 2%d	Uncharted features hazardous to surface navigation are not expected but may exist.
C	± 500m	= 2.00m + 5%d	Depth anomalies may be expected.
D	Worse than ZOC C	Worse than ZOC C	Large depth anomalies may be expected.
U	Unassessed - The quality of the bathymetric data has yet to be assessed.		

Fig. 21a Zone of Confidence (ZOC) categories from chart No. 123

Zone of Confidence (ZOC) diagram

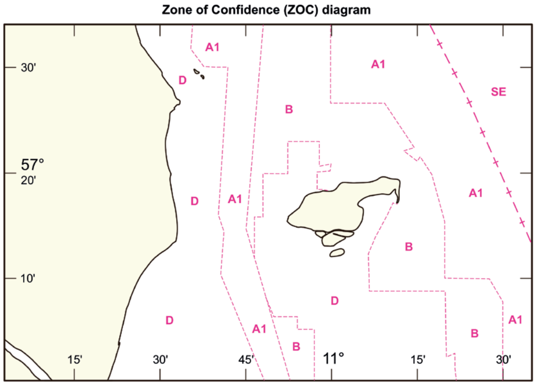

Fig. 21b Zone of Confidence (ZOC) diagram from chart No. 123

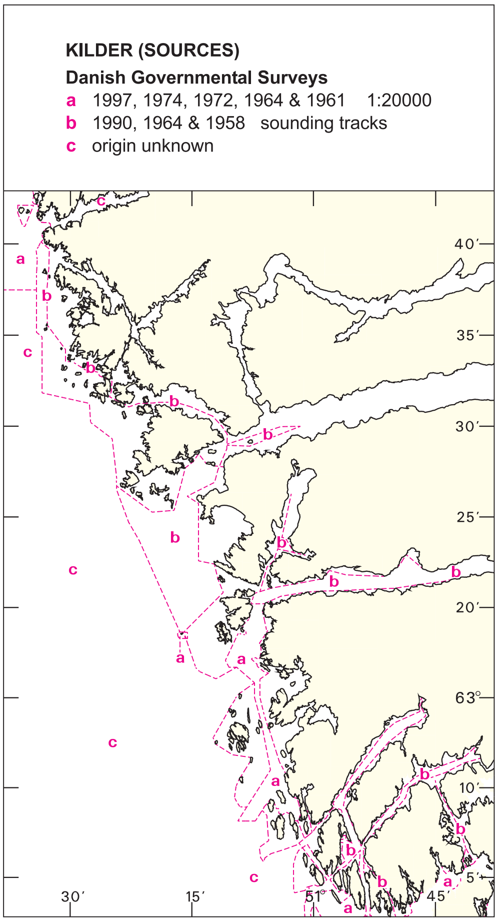

Fig. 21 Source diagram from Greenland chart No. 1213.

10.2.1 Zones of Confidence (ZOC) categories and diagrams

To create consistency in viewing source data between electronic and paper charts the ”Zones of Confidence (ZOC) Diagram” has been introduced.

When using ZOC, the quality of the hydrographic data used to compile the chart is divided into 6 categories. This categorization is called ‘Category Zone of Confidence’ (CATZOC). There are five categories (A1, A2, B, C and D) describing eva¬luated hydrographic data based on a minimum set of position, depth, and seafloor criteria. The last category (U) (unassessed) is assigned to areas where data exists but has not been evaluated (e.g. when older charts are used as source information, but have not had their data quality established). CATZOC is assigned to geographic areas to indicate whether data complies with a minimum set of position, depth, and seafloor criteria.

The ZOC diagram outlines the positional accuracy, depth accuracy and seafloor coverage for each of these values to allow for risk assessment in connection with navigating in a particular area.

The ZOC diagram allows the mariner to assess the data quality of the hydrographic data on which the chart is based.

By understanding the accurate limits of the underlying data in more detail, the mariner can use this in the risk assessment associated with navigation in a particular area.

ECDIS display these CATZOC values in ENCs using a triangular or lozenge shaped symbol pattern. The number of stars contained within these symbols denotes the CATZOC value. For example six stars are given to the highest level of data quality (A1) and two stars to the lowest (D). A single star is not used to avoid possible confusion with a rock symbol. Areas that have not been assessed for CATZOC are shown as the symbol (U) for unassessed.

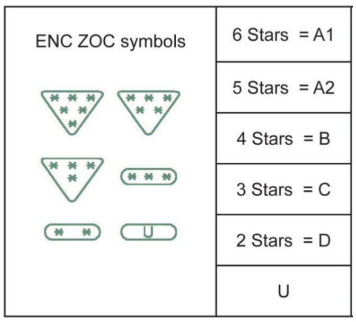

Fig. 21c Category Zone of Confidence (CATZOC) symbols used in ECDIS

The paper chart displays the information as a diagram and a category, respectively. See Fig. 21a and 21b

Read more about Zones of Confidence (ZOC) at the International Hydrographic Organization (IHO) website www.iho.int

10.2.2 No source diagram

When planning the navigation while using a chart without a source diagram, the navigator should interpret the accuracy and the completeness from the presentation of the chart and its possible notes.

Soundings evenly scattered in the chart and continuous depth contours indicate a regular collection of soundings. However, evenly dispersed soundings per area unit do not indicate reliability whereas the application of depth contours might give some idea of how regularly the sea bottom has been surveyed. In areas with rare or broken depth contours or where soundings are shown in an uneven way and possible hints that soundings should be considered as reconnaissance or that the positions are unreliable, no regular surveying has been done.

Soundings shown as sounding lines most often originate from known surveying or from vessels in ordinary transit. In this case, the navigator should be very cautious and avoid the large, white areas, which you can find in the Greenland charts. This white area indicates lack of information and not lack of danger.

The description of areas named "urene" on the Greenland charts does not refer to an uneven sea bottom, but the fact that information about the area is missing. It can also indicate that the area is so full of rocks and shallow waters that generally the navigator is advised not to enter the area or that navigation in the area is impossible.

The accuracy that ships can achieve these days by the use of the satellite based navigation systems is not in harmony with the drawing accuracy of the Greenland coastline. There can be inaccuracies of up to several nautical miles in the Greenland coastline relative to GPS position fixing.

Because of this, at Greenland a GPS should be used with great care. When navigating in coastal areas near shore the position has to be controlled by the use of relative navigation using radar or terrestrial navigation combined with the use of classical tools such as gyro, log and dead reckoning. It is not advisable to use GPS as the only navigational tool when navigating in the waters around Greenland. The passage of shoals has to be done with sufficient distance depending upon the circumstances.

The discrepancy between the coastline and positions taken by means of GPS is largest at the east coast of Greenland, but discrepancies can also be found in the Danish waters.

Fig. 22 outlines an example of the above description of a chart without a source diagram. Here the navigator is able to gather much information from the presentation of the chart.

The navigator is advised to use the source diagram when planning his navigation or if this does not exist, to interpret the accuracy and completeness of the chart and its notes, if any.

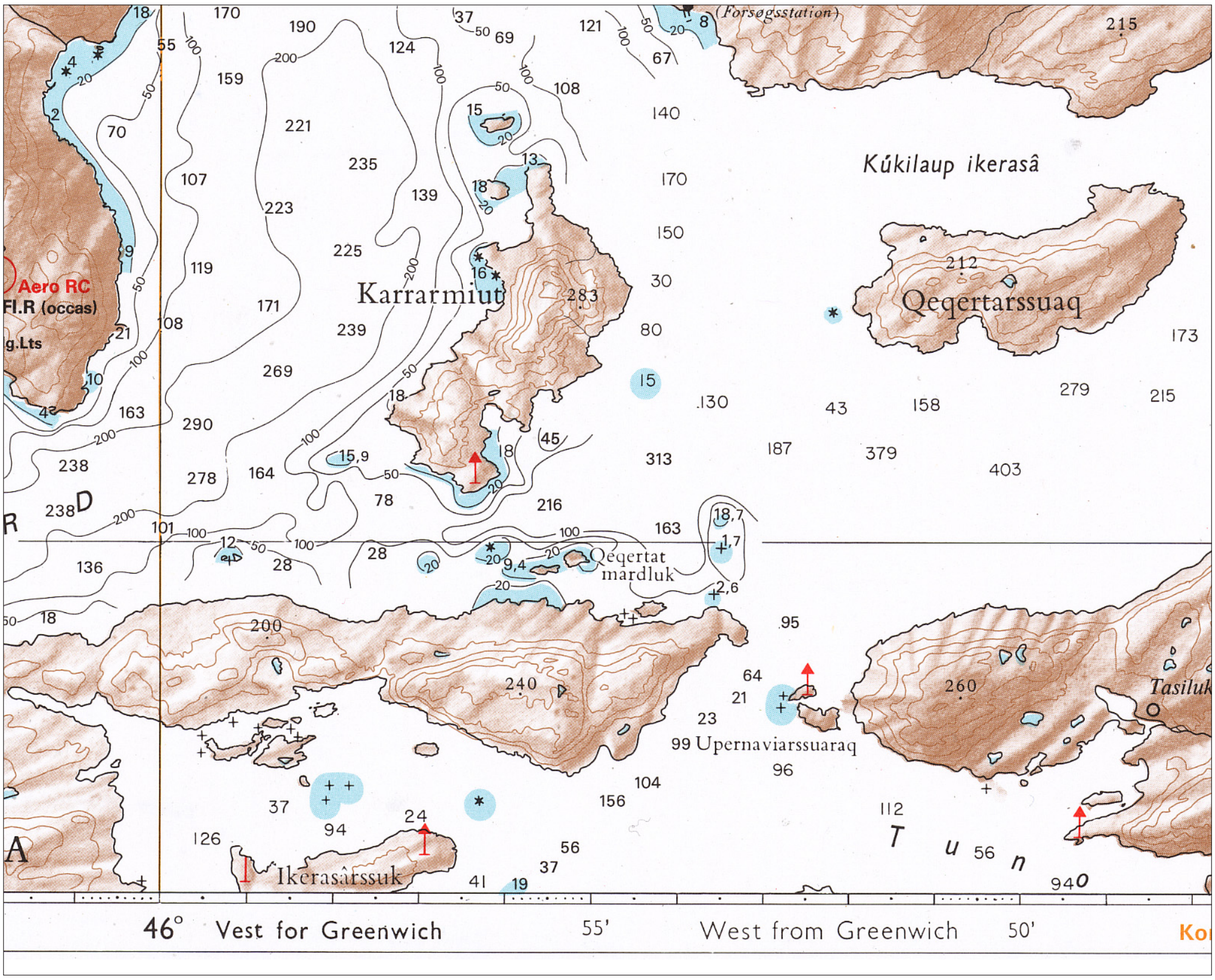

Fig. 22 Extract of Greenland chart No.1115.

10.3 Dynamic sea floor

The navigator should be cautious and contact the local harbour authorities to get information about the sea floor and currents, when sailing in areas where the charts and the pilots have notes about depth variation.

In areas with sand, sand waves corresponding to dunes at land are formed, owing to strong currents and waves. The extent of these sand waves can be several metres from top to bottom and the length of the sand waves several hundred metres. The height can change several metres within a few years, but the waves might also move horizontally with or without any modification of the height. Due to a long period of sanding up, the track through Østre Mærke to Nysted with a promised depth of 2.2 meter was moved eastwards more than 2 km. In this area, the chart indicates 0.3 meter but a new survey of the depth showed around 3 metres.

When navigating in Danish waters, the navigator should pay attention to the dynamic sea bottom. The Danish Coastal Authority is carrying out surveys repeatedly within areas of the west coast of Jylland. After strong storms, sand hills will change position, direction and depth in an unforeseeable way. Local sand hills are found at the entrances to harbours, and here the navigator should be particularly cautious. Artificially made tracks have a tendency to sand up, due to the currents made by ferries. Development work in connection with extension of harbours or bridge building might cause considerable changes of currents, and consequently the transportation and depositing of sediment.

When sailing in areas where charts and sailing directions indicate varying depths, the navigator without local knowledge is advised to be cautious and to contact the local harbour authorities to get information about the sea bottom and the currents.

10.4 Wrecks

The maintenance of registers of wrecks is a dynamic process and an everlasting work for all hydrographic organizations.

The navigator should beware of wreck data, because measuring the position of the wreck or the minimum depth is a difficult process and might be temporary. The navigator should take the same precautions near wrecks as recommended for shoals (chapter 5.5).
Every year vessels are lost and most likely they sink. Surveyors have to locate the wrecks and determine their positions. The wrecks move and fall apart due to the constant currents in the sea, and you cannot be sure that the danger they might constitute for the navigation will diminish systematically throughout the years. Some wrecks buried in sand might reappear, move position, change location or rise and thus become a danger for navigation. New and unknown wrecks are found every year when surveying and numerous changes of the known wrecks are added to the register. Better and more precise positions and minimum depths above the wrecks might be found. Some old wrecks might not be rediscovered at all and therefore deleted from the register.

As mentioned before, it can be difficult to measure the minimum depth above a wreck, especially if the mast of the ship is the shallowest depth above the wreck. The surveyor must be able to find an object with a radius of down to a few centimetres. If the ship is situated in an area with currents, the minimum depth might have changed for the worse or the better, and after some time the ship may have changed position. If the ship constitutes a danger for the safety at sea; it might be necessary to blast off the wreck or perform a salvage operation.

As shown above, the navigator should beware of wreck data as the measuring of the position of the wreck or the minimum depth is a difficult process and might be temporary. The navigator should take the same precautions near wrecks as recommended for shoals.

10.5 Recommended routes

Ships of a certain size and especially the tankers should always navigate through the recommended routes wherever these routes are established.

Recommended routes are routes that have been intensively surveyed. They are marked with buoys and lights to obtain a greater safety at sea for navigation, and to minimize the risk of environmental disasters. It can be main routes like Route T, which was established in 1976 from Skagen in the north to an area north east of Gedser in the south, or it can be entrances to harbour areas, harbours and anchorages. In these routes, the authorities will guarantee a minimum depth (in Route T a depth of 17 metres is guaranteed) within a certain width as all shoals and wrecks have been examined with closely surveyed lines completed by the use of Side Scan Sonar.

The Helsinki Commission, HELCOM, works to protect the environment in The Baltic Sea (Østersøen) from all kinds of pollution by coordination and cooperation at government level of all of the Baltic States.
A direct consequence of the extraordinary HELCOM ministers meeting in Copenhagen 2001 and the following meeting in Helsinki 2002, Denmark has in the period 2003-2007 planned a complete hydrographic resurvey of the main shipping routes (Route T and B) in a width of 4 kilometres, where possible.

Leading lines where 2 lights/beacons are seen in line are often used for the recommended routes. Besides being very well surveyed, the routes are also subject to "hydrography on keel" implying that experience has been gathered by numerous vessels. When using the safety of the leading lines, the navigator should follow the lines very carefully. It is not as safe and as accurate to take bearing of a single light or beacon, as it is to use leading lines. This method should therefore be used with caution.

If natural marks are used leading lines in old charts they might be obsolete because of forestation, redevelopment. If the pilot and the chart are not concordant or if natural marks like trees, bushes and the like have been used, it would be better to contact the local harbour authorities for advice.
Vessels of a certain size, and especially tankers should always navigate in the re-

commended routes wherever these have been established.

10.6 Safety at Sea

The Danish Maritime Authority takes care of the international coordination and rules of safety in the UN International Maritime Administration Organization (IMO), including the international convention of "Safety of Life At Sea", SOLAS. Chapter V of the convention, the safety of navigation, demands that the coastal states should initiate a number of initiatives in promoting safety of navigation and prevention of accidents at sea.

Several Danish shipping routes systems have been established, like the Traffic Separation Theme South of Gedser and the Deep Water Route Kadetrenden (north east of Gedser).

In order to assist ships passing the Great Belt Bridge and Hatter Barn areas, a VTS mandatory Ship Reporting System, BELTREP, operated by Great Belt VTS "Great Belt Traffic" with a radio reporting system has been established. Reporting to the Great Belt VTS is mandatory under the SOLAS convention. The VTS-system carries out its duty in accordance with the International Maritime Organization (IMO) Resolution "Guidelines for Vessel Traffic Services".

In order to improve the safety and efficiency of navigation and to increase the protection of the maritime environment in the Sound between Denmark and Sweden a mandatory ship reporting system, SOUNDREP, has been established. The ship reporting system is operated by a Vessel Traffic Service, Sound VTS.

AIS (Automatic Identification System) is a digital system also known from air traffic, which ships uses to avoid collisions. For ships bigger than 300 gross register tonnes, the system is compulsory. Within the limit of the VHF communications range, the system transmits data like identity of ship, course, speed and other information to other ships and coastal stations with an interval of a few seconds.

AIS are also used on important special marking in fairways and at production platforms. The Danish Maritime Authority can on short notice lay out so-called virtual buoyage for example, impaired depth or dangerous wreck in fairways.

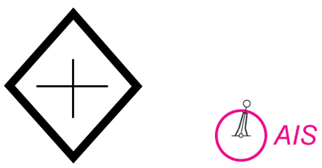

Fig. 23 Virtual AIS symbol and symbol shown on charts.

10.6.1 Examples of accidents at sea

It is always dangerous to deviate considerably from a recommended route. Accidents cannot be avoided, but the numbers can be reduced if the navigator is aware of the importance and considerations behind always using safety margin of minimum depth under keel and a horizontal margin by passing objects with sufficient distance.

The Danish Maritime Accident Investigation Board, which was founded in June 2011, is an independent institution. The Investigation Board is responsible for investigating accidents and deaths at sea and to determine the cause. By doing this, measures can be taken to seek to prevent similar accidents from happening again.

Accidents in merchant ships caused by navigational errors, manoeuvring errors and errors in operation of the equipment carry great weight in the statistics of accidents at sea, but a certain decrease is noticed in 2001 compared with the period 1996-2000.

The reason for these accidents may be many, but misjudgement of the radar picture, erroneous manoeuvre at turning points, miscalculation of positioning etc. are among them. In the period 1994-2001 a total of 129 merchant ships and 67 fishing vessels grounded. In the period 1994-2001 an average of 17 fishing vessels were lost each year.

The following is a small extract from published statistics by Danish Maritime Authority "Accidents at sea 2001".

A coaster was lost when sailing on the wrong side of a rock marked by light because the captain tried to shorten the route. The chart was not updated and the captain failed to see a general warning about rocks in the area. The engine room was filled with water at the grounding and because of an illegal door between the engine rooms and cargo room water penetrated into the hold. The crew was rescued by helicopter.

Another accident concerned a coaster, which collided with a lighthouse and shortly afterwards sank. Both the captain and mate died when the ship was lost. At the time of the accident, nobody else was on the bridge of the ship. Therefore it has not been possible to explain why the ship did not turn in time.

A 22 BT trawler took a wrong course on its way into harbour and with full speed ahead it hit the breakwater and grounded south of the harbour. The skipper, who had been on duty for 7 hours only realized that something was wrong when the ship stopped. The 2 men on board jumped to a life raft and they were rescued to the beach. Afterwards the trawler was brought afloat.

When sailing in a traffic separation zone an oil tanker had to change course to avoid a tugboat,

which suddenly changed course, and sailed in the "wrong" side of the separation, in front of the oncoming tanker.
According to the Danish tanker they had paid attention to the oncoming ship, and the passage distance was 0,3 nm.

Unfortunately many examples exist. The following two foreign groundings will be described in more detail, because they contain several of those circumstances, which are described in this guide.

A large passenger ship grounded in 1992 in the US. The findings of the report are: The immediate causes of the accident were, therefore, the presence of significantly shallower depths than those charted, together with an overestimation of the height of the tide and a underestimation of the effect of squat. In regard to charted sounding data the report made comments as follows relating to hydrography:
The used chart over the area of grounding has no references to either chart data or to the date of the hydrographic surveying on which the chart is based.

Charted depths, located within 800 metres of the grounding position, were taken from a hydrographic survey conducted in 1939 and include a least depth of 11,8 metres in close proximity to the grounding position. The forward and aft draughts of the vessel before departure were 9,85 and 9,54 metres respectively. A previous hydrographic survey, which was conducted in 1887 using lead line soundings, recorded greater depths in the area.

In 1939 a line spacing of 400 metres was achieved. Soundings were acquired by means of a non-recording echo sounding machine providing an estimated vertical accuracy better than 30 cm and a sea floor coverage diameter of approximately 0,4 times the depth of water.

The charts concerned are in scale 1:100.000 and the standard for surveying for such a scale was for sounding lines to be spaced at a maximum of 500 metres and this standard was achieved. It is further noted that an area is usually surveyed at a larger scale than it is charted and an area such as this would today be surveyed at scale 1:25.000 with line spacing of 125 metres. Areas with depths less than 40 metres would be inter-lined at 62.5 metres spacing. Full side scan sonar coverage would be necessary to detect any dangers to navigation lying between sounding lines. Thus, the 1939 survey would not meet today’s standards.

Different international documents draw attention to "Under Keel Allowance". Many factors should be taken into account like the limitations of hydrographic surveying and the importance of considering the date of surveys rather than the expression of the chart in assessing the reliability of the charted information.
The navigator has to be critical and realistic in his confidence to the data of the chart by using

safety margins.

1) Vertically: As least depth under keel.
2) Horizontally: By passing objects with sufficient distance.

Two additional factors involved and cited in the report related to the calculation of the predicted height of the tide, which should have been calculated as 15 cm instead of 60 cm, and uncertainty as to the precise amount of squat. Attention is drawn to a warning for merchant ships about the danger of groundings due to squat because of high speeds in shallow water. It says that an increase in draught of well over 10% has been observed at speeds of about 10 knots, but when speed is reduced squat rapidly diminishes. In the actual case, the passenger ship had a speed of 25 knots and 10% would correspond to a squat of 1 meter.

The rocks on which the passenger ship grounded are located in an area between adjacent sounding lines from 1939, and they were not indicated on the charts in use on board the ship.

The charts used do not indicate the dates of the surveys. In the absence of such survey meta data the report states that the Master was restricted in his ability to assess the reliability of the charts. It is considered that the Master was deceived by the look of charts in use and placed undue reliance upon the information presented. The report also states that a crucial factor is the age and nature of the surveying on which the chart is based and this information is not provided on charts, which were in use. It is recommended that the responsible authorities should seek to remedy this deficiency.

The other foreign example is a large oil tanker, which in 1977 sailed aground at the east coast of Sweden. The ship sailed in a natural and not a dredged fairway in the Swedish archipelago. The mean draught of the ship was 8,65 metres. The recommended maximum draught for the passage in the fairway was 9 metres.

The ship ran aground slightly less than one hundred metres west of a small skerry, about ten metres outside a ten-metres contour of the chart. The depth over the sunken rock was about 6 metres.

The chart of the area in which the rock is located was first published in 1932 and is on scale 1:50.000. On the chart it is stated that it is based on hydrographic surveying performed from 1911-32, but for less important areas from 1845-73.

The area around the sherry was first surveyed between 1812-1849. During these surveys a rock with a depth of 7,5 metres was discovered SSW of the skerry. When the area was again surveyed in 1918, the rock was probably not found again. In 1921 the area was once again surveyed, presumably as a check on the surveying of 1918 to see whether there was a rock at a depth of 7,5 metres or not. As far as can be ascertained, the rock was not found. These surveying were made utilizing lead and line surveying.

The area was surveyed once again in 1969 utilizing echo sounders. This surveying revealed a rock with a depth of 6 metres. Afterwards this rock was not marked in the chart, because the position of the rock was estimated to be in the area between the depth contours 6 and 10 metres (closest to the 10 metres) and therefore regarded as covered by these contour lines.

After the grounding, an extremely thorough surveying was made of the rock and the area in its proximity. The result of the surveying showed that the distance between the top of the rock and the shore is 106-108 metres.

A comparison between the surveying of 1969 and 1977 shows a difference in the position of the rock of some 6-8 metres. The 10 metres contour was placed wrongly in the chart by about 20 metres and the contour should have been drawn in a somewhat more northerly direction. Due to the scale of the chart this means 0,12 – 0,16 mm and 0,4 mm respectively.
The inquiry showed that because the navigator on the tanker, who sailed through the fairway, made a S-curve manoeuvre to save time he sailed 120 metres closer to the skerry compared to ships, which follow the normal route.

The example illustrates the importance of careful adherence to the recommended routes, which are well surveyed and proved by the number of ship passages. The relatively small deviation in the route of the tanker combined with small uncertainty of the 10 metres contour resulted in the unfortunate consequence that a large tanker grounded.

It is always dangerous to deviate considerably from a recommended route. Accidents cannot be avoided, but numbers can be reduced if the navigator knows about the importance and considerations behind using safety margin. A vertical margin as a minimum depth under keel and a horizontal margin by passing objects with sufficient distance.

10.6.2 Observed discrepancies between charts and reality

Finally situations where the reason for the grounding is discrepancies between chart and reality, concerning depths, stones, buoys etc. are given. The cargo ship "Rocknes" grounded 19. January 2004 in Vatlestraumen, Norway and was lost with loss of human life. In addition to paper charts "Rocknes" had on board an electronic chart ARCS (Admiralty Raster Chart Service).

Generally, the surveys in the area date back to 1941, but a few years before "RocknesV grounded an unknown extended ridge with approximately 9.7 metres of depth was found 55 metres from a lighthouse in a 300-400 metres narrow sound. Previous depth on the chart was 29 metres. New charts were published the year before and they showed the changed depth conditions, but these charts were not in use on "Rocknes". About the used chart material, the following is concluded:

1) The buoys at Revskolten are placed 25 metres wrong compared with Norwegian charts. The lighthouse has been moved further out in Vatlestraumen than in reality.
2) The white light from Hilleren Lighthouse, which is the light ships are using for navigation passing Revskolten Lighthouse, has a white sector more than shown on Norwegian charts. Looking at ARCS charts it apparently looks like the white sector is just at Revskolten Lighthouse. For navigation in daylight without the use of leading lines from the lighthouse and by the use of the ARCS chart the waterway into Revskolten Lighthouse looks unproblematic.

If the official electronic navigational chart (ENC) from Norway, to be used in ECDIS systems had been in use, the recently discovered shoals would have been shown. If the alarm were activated, a warning would have been given about the danger of grounding in Vatlestraumen. A chart is a navigational tool and not a precision instrument. This guidance contains information about the inaccuracies and the uncertainty, which exist in the chart concerning surveying data. The local precautions are mentioned as notes, which the navigator has to be aware of in the charts. The importance of consulting the nautical publications and the local harbour authorities for information about dynamical sand banks, current conditions, water depths, buoyage etc. have been described. Furthermore, the problem concerning the very accurate satellite navigational systems has been addressed.

Ships sometimes indicate grounding positions, where further investigations in the area shows that the ships grounding is unlikely to have happened there, but nearby shoals exist, which would be the possible position for the grounding. Furthermore, positions with reference to the floating buoyage are reported, which the navigator should never used for position fixing.
The positions of buoys can be wrong for several reasons.

1) The buoy is badly placed relative to the danger it is marking, but the location in the chart is correct.
2) The buoy is well placed relative to the danger it is marking, but the cartographical placement in the chart disagrees with the reality.
3) The buoy is badly placed relative to the danger it is marking, and the location in the chart disagrees with the reality.

When a position of a buoy deviates from the chart, the reasons can be because the buoy is drifting or that the buoy has been pulled away from the position by ice or because it has been hit by a ship. It can also happen because the buoy is not anchored in the right way at the right place, due to lack of accurate position fixing.

The navigator is recommended not to base position fixing of his ship relative to a buoy. Buoys are to be passed with "safe" distance and never between the buoy and the danger it is marking.

When charts are published, the known and the important navigational information is up to date, but normally the survey data is the same as in the earlier chart, which can be more than 100 years old.

The charts are published as new editions when major additions or complex changes of the chart content exist. The former edition is then cancelled.

New charts are only produced for areas, where special conditions as for example changing in navigational pattern, international interest and the like are estimated appropriate or necessary from a social point of view.

10.7 ENC and DGPS

There is a difference in the definition of a digital and an electronic navigational chart. A digital chart is a paper chart, which has been scanned into a raster picture. Afterwards the chart is built up in points, lines and areas, then every point is assigned a code and the chart is vectorized. According to the standard data format S-57 the vector chart is afterwards changed and adapted, and it becomes an "Electronic Navigational Chart" (ENC) ready for use in "Electronic Chart Display and Information System" (ECDIS)[15].
The difference between ENC and ECDIS is that ECDIS is an integration of all the navigational tools of the ship as radar, echo sounder, DGPS etc., while ENC is the actual electronic chart used in ECDIS system.

The navigator has to be very careful when DGPS and electronic nautical charts are used as the accuracy in depth, position fixing and the coverage of the sea floor in many areas does not live up to modern standards. In the meantime until a resurvey has been carried out the navigator must use a safety margin when navigation is planned and carried out.

GPS has accuracy better than 20 metres (95%) without the deliberate noise emissions (SA), which was stopped in year 2000. DGPS has, depending upon the distance to the reference station an accuracy of 10 metres. With European Geostationary Navigation Overlay System EGNOS, the accuracy reduced to 2-5 metres. The system consists of land based stations,

15 ENC is the official electronic chart from the Hydrographic Offices, but there are other available digital charts to be used in the electronic Chart Systems (ECS), which are not in S57-format and they are not distributed from the official institutions. Updating and responsibility for these electronic products is not vested with the Hydrographic Institutions.

which cooperate with a system of satellites.

Even though the navigator makes corrections for the difference between a DGPS position in WGS84 and the datum of the chart used, the accuracy of data in the chart will not be better than the accuracy in which the original surveying was carried out. If a shoal shown on a chart was measured and positioned in 1869, and the navigator plans his DGPS route close to this shoal; the confidence in the accuracy of the chart data is too great, and the risk of grounding exists.

The depth as well as the position can be of guidance to the navigator, but it is realistic to consider an uncertainty of more than 300 metres in the position when the survey is of an older date.

The advantage of using ECDIS is that the position of the ship is shown in real time and continuously on the electronic display. It is no longer necessary for the navigator to fix the position of the ship and subsequently to plot a track on the chart. The navigation system used is in most cases is a Differential GPS (DGPS) in WGS84 with an accuracy of about 10 metres.

The danger is that the navigator may be navigating too close to shoals, which were surveyed more than 100 years ago, and where the survey could have been carried out in a scale smaller than it is possible for the electronic navigational chart to reproduce.

It will probably take many years to resurvey the areas that do not meet the modern day expectations to a survey, with respect to 100% coverage and an accuracy of equal to or better than that of DGPS. Until then there will exist an accuracy mismatch when using the ECDIS system. The user will have to use caution when looking at the presented chart data.

It is not only the data from the sea floor, but also the coastline data that the navigator will experience as inaccurate, when the position fixing the ship is within a few metres.

As mentioned earlier the error of the coastline is greatest in Greenland waters, but the inaccuracy can also be seen in the Danish coastline data.

Fig. 26 shows a paper extract of the southern part of the Great Belt (Storebælt) and fig. 27 shows the same area as it looks on an ENC. As it can be seen the presentation of the two charts are quite different, and the navigator needs to get accustomed to the use of electronic navigational charts.

By using the source diagram in fig. 19 it is evident that great deals of then surveys in the extract shown were carried out between 1889-1900.

Fig. 25 is an example of an ECS product named "Det levende Søkort". It was issued on CD-rom for the first time in November 2000 and later fased out. The product was a result of a maritime cooperation between the Danish Maritime Authority, the Danish Meteorological Institute, the Danish Pleasure Sailing Safety Board, the Danish Sailing Association and Geodatastyrelsen. It was via the Internet it is possible to update "Det levende Søkort" with new charts, themes, software updates etc.

The navigator must be very careful when using DGPS and electronic navigational charts, because the accuracy in depth, position fixing and the coverage of the sea floor in many areas do not live up to modern standard. In the meantime, until a resurvey has been carried out, the navigator must use a safety margin, vertically in the form of under keel clearance, and horizontally by passing underwater obstacles with sufficient clearance.

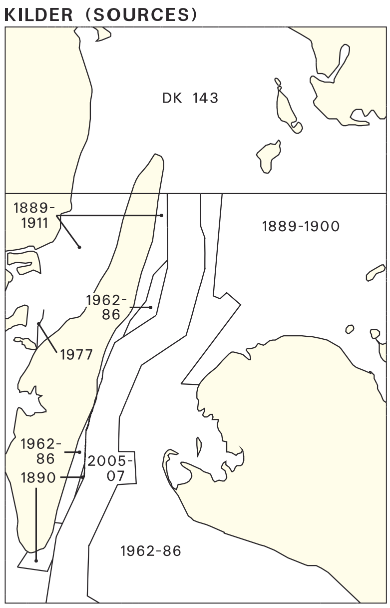

Fig. 24 Source diagram for the southern part of Great Belt (Storebælt).

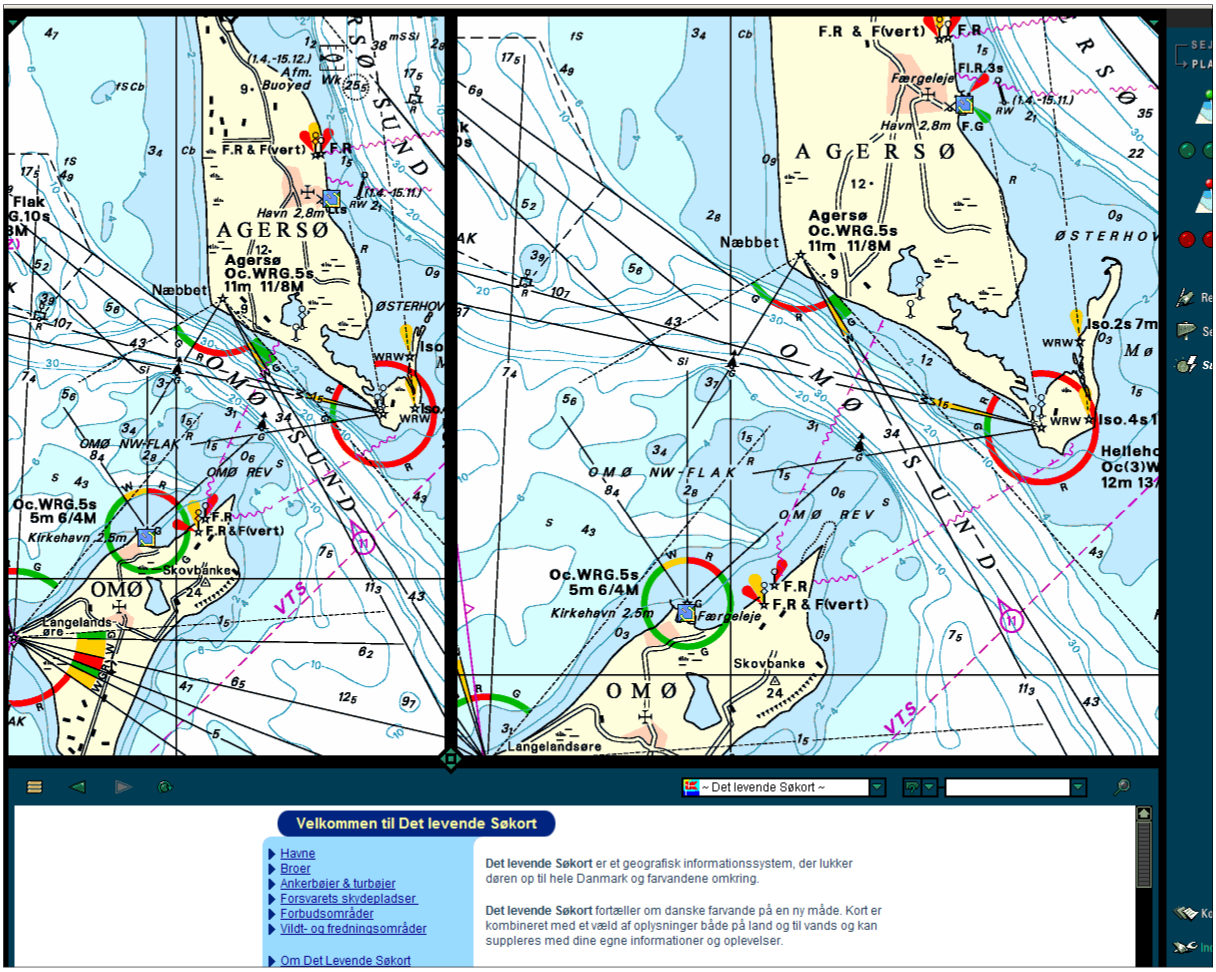

Fig. 25 "Det levende Søkort" is an example of an ECS product.

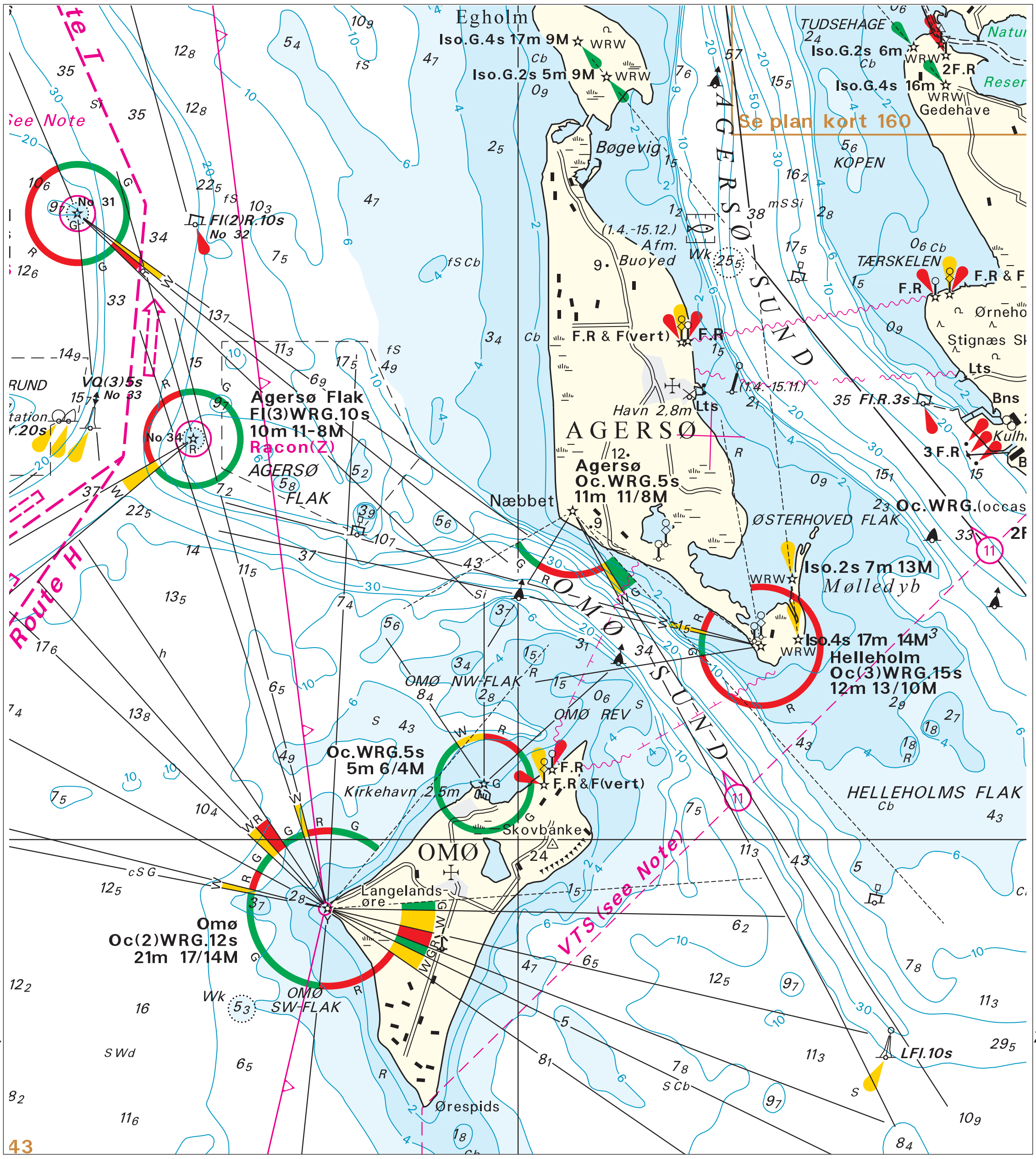

Fig. 26 Southern part of Great Belt (Storebælt). Chart 142 as seen on a paper chart.

10.8 ECDIS in Danish ships

In Copenhagen 2001, at the extraordinary HELCOM ministers meeting, the Baltic States agreed to promote the use of ECDIS, and to acknowledge this system as an alternative to paper charts.

In this context Denmark has informed IMO in the autumn 2001 that under certain conditions ECDIS is acknowledged as an equivalent to paper charts.

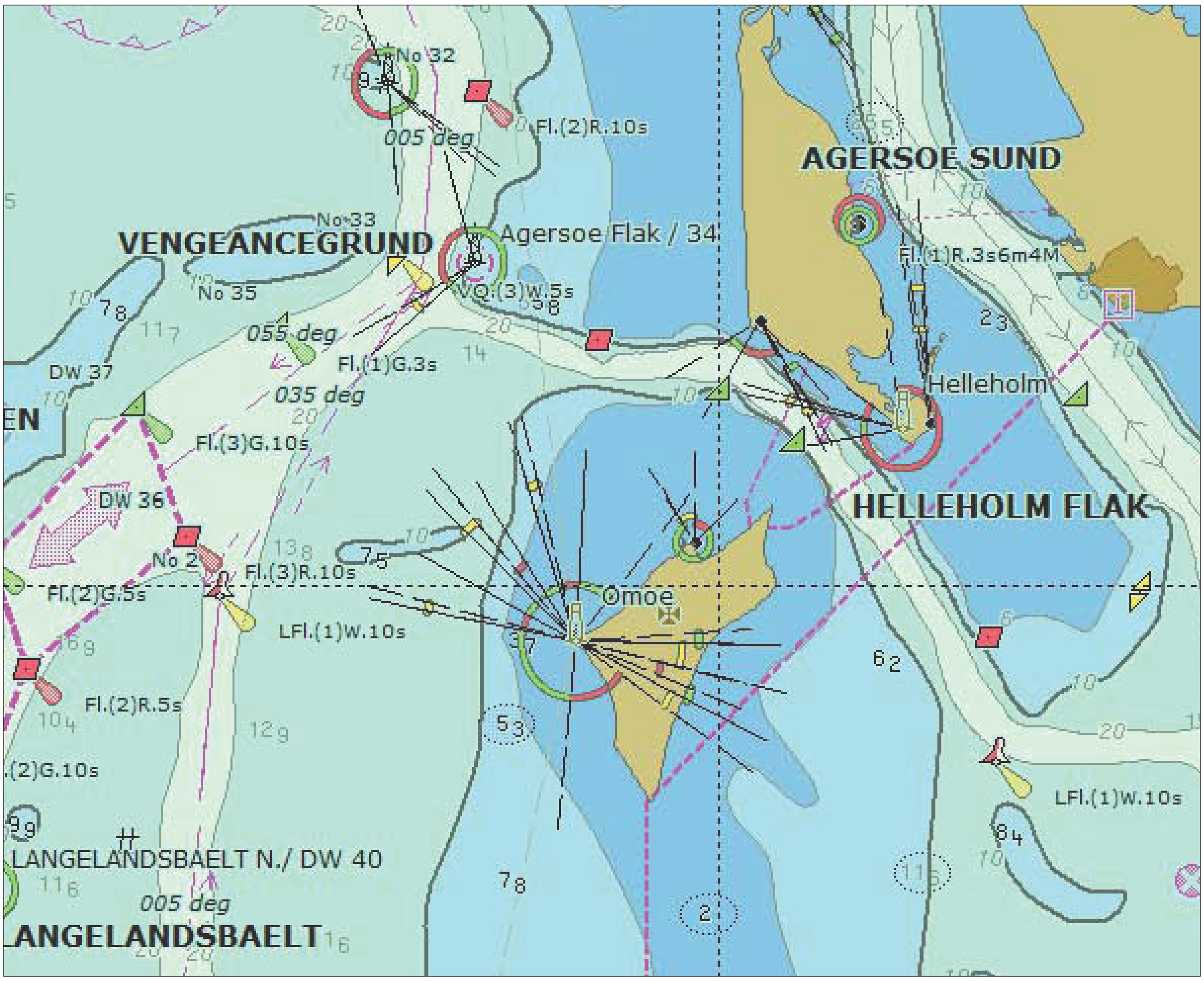

Fig. 27 Southern part of Great Belt (Storebælt). Chart 142 as seen on a ENC.

On the 1 July 2002 the revised IMO SOLAS chapter V was put into effect. Chapter V/2 describes nautical charts and nautical publications:
"A nautical chart or a nautical publication is a special-purpose map or book, or a specially compiled database from which such a map or book is derived, that is issued by or on the authority of a Government, authorized Hydrographic Office or other relevant Government institution and

is designed to meet the requirements of marine navigation."

With reference to IMO SOLAS V the requirements for charts and publications to be carried by ships can be fulfilled by:

Carriage of official and up-to-date paper charts, or Carriage of a type-approved ECDIS, using official and up-to-date Electronic Navigational Charts (ENC) together with an appropriate back-up arrangement.

The minimum carriage requirements for charts and publications are satisfied by the use of paper products. After the amendment of SOLAS regulations 1 July 2002 it is allowed to replace the paper charts and publications by electronic means if a suitable backup is provided. Paper charts and publications continue to be the minimum requirement for backup purposes.

The status for Denmark in accordance with the Danish Maritime Administration:
Chart requirement for navigation:

1) Up-to-date paper charts.
2) Up-to-date ENC's on ECDIS.

ECDIS requirement if use of ENS's:

1) ECDIS on the bridge of the ship with ECDIS as backup on independent energy source.
2) ECDIS on the bridge of the ship with an appropriate folio of up-to date paper charts as backup.

Use of private charts for navigation:
Use of private produced charts is not approved for navigation.

Use of official raster charts for navigation:
Official raster charts in ECDIS mode or other modes are not approved for navigation.

Chapter 11.

11.0 Final remarks

Shipping is being automated by using electronic navigational charts in integrated navigational systems with warnings to the navigator about possible collisions and groundings. Because of the increasing number of fast ferries, the risk analysis are generated for ships in the same way as it has been done in the air plane industry for many years.

The human factor is more important than ever as the general view and the responsibility for the automation lie with the navigator. The position of the ship is plotted in real time on the chart; time is made available for the navigator for other relevant work which has to do with the navigation and safety of the ship, including supervision of positions and equipment. When the automated systems fail, the navigator must retain the general view and use other ways of objectively judging the position and the navigation of the ship.
It is important to use all nautical publications when planning the route, as the navigators knowledge and judgement of the surveying data on the chart may be of crucial importance for the safety of the ship.

The hydrographical data is continuously improved with more accurate and adequate surveys regarding depths, tides, currents, and coastal data.
However, this work will never end because the technological possibilities continuously change. It will take many years to resurvey areas, which have not been surveyed up to the standard, which is possible with DGPS and multi beam echo sounder combined with Side Scan Sonar.

The aim of ECDIS is to achieve increased safety and ship efficiency in a maritime world, where time and safety are highly prioritized factors, but the most important factors are still the human resource and maritime judgement.

The advantage for safety and ship efficiency by using electronic navigational charts are only 100% achieved when the charts possess the same accuracy as differential GPS. Until then, the navigator using electronic navigational charts with the correct position of the vessel in the chart shown on a screen, must be informed about the uncertainty of data, which depends upon waterways, the time of the survey and the survey technique.

Chapter 12.

12.0 Summary

Surveying and reliability

The navigator should take great care when sailing close to shoals since the navigator must foresee a certain margin of the sounding shown on the chart depending on the area and year of survey.

An evaluation of the surveying from 1855 to 1952 in general shows that we are far from a full covering of the sea bottom and data accuracy, and the completeness is poor. Therefore, there might be objects on the seabed, which are not shown on the nautical charts, but nevertheless these objects might constitute a risk for the navigation in or through Danish waters.

An evaluation of the surveying from 1953 to 1991 in general will show, that without supplementary use of wire drag or Side Scan Sonar full covering of the sea bottom has not been achieved. Data accuracy and completeness are poor. Therefore, there might be objects on the sea bottom, which are not shown on the nautical charts, but nevertheless these objects might constitute a risk for the navigation in or through Danish and Greenland waters.

The navigator must never uncritically and without the necessary precautions base his navigation on (D)GPS in waterways, which are not surveyed with the same accuracy as that achieved with a DGPS system.
Furthermore the navigator should consult all available nautical publications for areas, which he passes or calls at.

Echo sounders, tides and satellite navigation

The navigator is advised to build up an experience with using an echo sounder since the measurements of depths depend on many factors. With larger ships and less under keel clearance an exact sounding can be of the utmost importance.

Charts and navigation

The navigator must make sure that the geodetic datum of the chart is in accordance with the datum used in the radio navigational system. If this is not the case, the navigator has to make corrections for the difference between the used reference systems.

When planning the navigation, the navigator should allow for the uncertainty of the prediction of astronomic tides and the, at times, dominating meteorological influence.

The navigator is advised to use the source diagram when planning his navigation or if this does not exist, to interpret the accuracy and completeness of the chart and its notes, if any.

When navigating in areas where charts and sailing directions indicate varying depths, the navigator without local knowledge is advised to be cautious and to contact the local harbour authorities to get information about the sea bottom and the currents.

The navigator should beware of wreck data as the measuring of the position of the wreck or the minimum depth is a difficult process and might be temporary. The navigator should take the same precautions near wrecks as recommended for shoals.

Vessels of a certain size, and especially tankers should always navigate in the recommended routes wherever these have been established.

It is always dangerous to deviate considerable from a recommended route. Accidents cannot be avoided, but numbers can be reduced if the navigator knows about the importance and considerations behind using safety margin. A vertical margin as a minimum depth under keel and a horizontal margin by passing objects with sufficient distance.

The navigator is recommended not to base position fixing of his ship relative to a buoy. Buoys are to be passed with "safe" distance and never between the buoy and the danger it is marking.

The navigator must be very careful when DGPS and electronic navigational charts are used, because the accuracy in depths, position fixing and the coverage of the sea bottom in many areas do not come up to a modern standard. In the meantime until resurveying has been carried out, the navigator must use a safety margin, vertically in the form of under keel clearance, and horizontally by passing underwater obstacles with sufficient distance.