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FACTORS RELATING TO THE PASSAGE OF DEEP DRAUGHT SHIPS THROUGH THE BALTIC APPROACHES

by Milan THAMSBORG
The Royal Danish Administration of Navigation and Hydrography

ABSTRACT

To a still increasing extent maritime authorities of coastal states all over the world are faced with a series of problems linked with the safe navigation of large and deep draught ships in their waters. In narrow and shallow fairways this is of particular importance due to the additional risk of accidents and subsequent damage to the environment. To elucidate the situation from the point of view of the physiography of the surrounding waters the conditions pertaining to the Baltic Sea area in particular are examined in some detail.

The presentation takes its point of departure in a survey of the general topography of the deep water route(s) through Danish waters, followed by a statement on the various physiographic factors and their impact on shipping and the environment. Some countermeasures to the factors which limit the transit of deep draught ships through these waters are proposed and discussed.

The presentation of local problems in the Baltic Approaches leads to a general proposal on the formation of an *ad hoc* expert group under the IHO primarily to work out procedures, standards and codes on shipping-related oceanographic parameters.

INTRODUCTION

It is a well-known fact that global statistics on shipbuilding after the second world war show a rate of increase in the number and size of large ships, especially with emphasis on tankers and bulk carriers. For obvious reasons, the deep oceans carry the majority of these ships, but it is of interest to note that the above-mentioned trend is also reflected in the increased traffic seen in narrow and shallow waters such as the English Channel and the Baltic Approaches (the Kattegat, the Danish Sounds and Belts).

Evidently, from the point of view of width of traffic lanes and threshold depth in such waters, there exists a narrow upper limit of size and draught of ships which can safely navigate there. To improve cost-effectiveness shipowners are more or less inclined to urge masters and pilots to approach these known or unknown limits asymtotically with, of course, due regard to existing IMCO recommendations, national precautionary rules, etc. In logical reply to this, masters and pilots look for the best available information on the navigability and manœuvrability of the traffic lanes for the immediate or foreseeable future. Therefore, such factors as tolerance of charted soundings, instantaneous sea level, water buoyancy, current speed and direction, sea and swell conditions, etc., which at an earlier time were of only slight or academic interest, now become of real importance to the navigator aboard a deep draught ship transiting the Channel and the Baltic Approaches or calling at ports in the Baltic Sea area.

Procurement, handling and transmission of such data is of major concern to the maritime authorities of coastal states. Often they find themselves in a somewhat contradictory position. On the one hand, they are under an obligation to encourage, promote and facilitate navigation in their coastal waters according to international custom; on the other, they are held responsible by their government for the elimination, or at least the reduction to a minimum, of any potential risk of ship accidents, i.e., collisions, groundings, oil pollution, etc.

A discussion on the individual factors affecting navigability in the deep draught track(s) through the Baltic Approaches follows.

TOPOGRAPHY

General Bathymetry

Fig. 1 is a situation map of the Baltic Approaches with the approximate course of the main track and two secondary tracks indicated. Fig. 2 is a rough bathymetric profile of the track from the North Sea to the Bornholm area through the Great Belt (the deepwater route). It should be noted that small adjustments of the deepwater route in the Kattegat and the Great Belt are anticipated in the near future.

All soundings east of the Skaw are reduced to mean sea level of nearby ports or of fixed points on the coast as observed over a prolonged period. The reason for using mean sea level instead of a low water mark chart datum is that Danish waters, in general, are more influenced by aperiodic meteorological changes than by tidal effects.

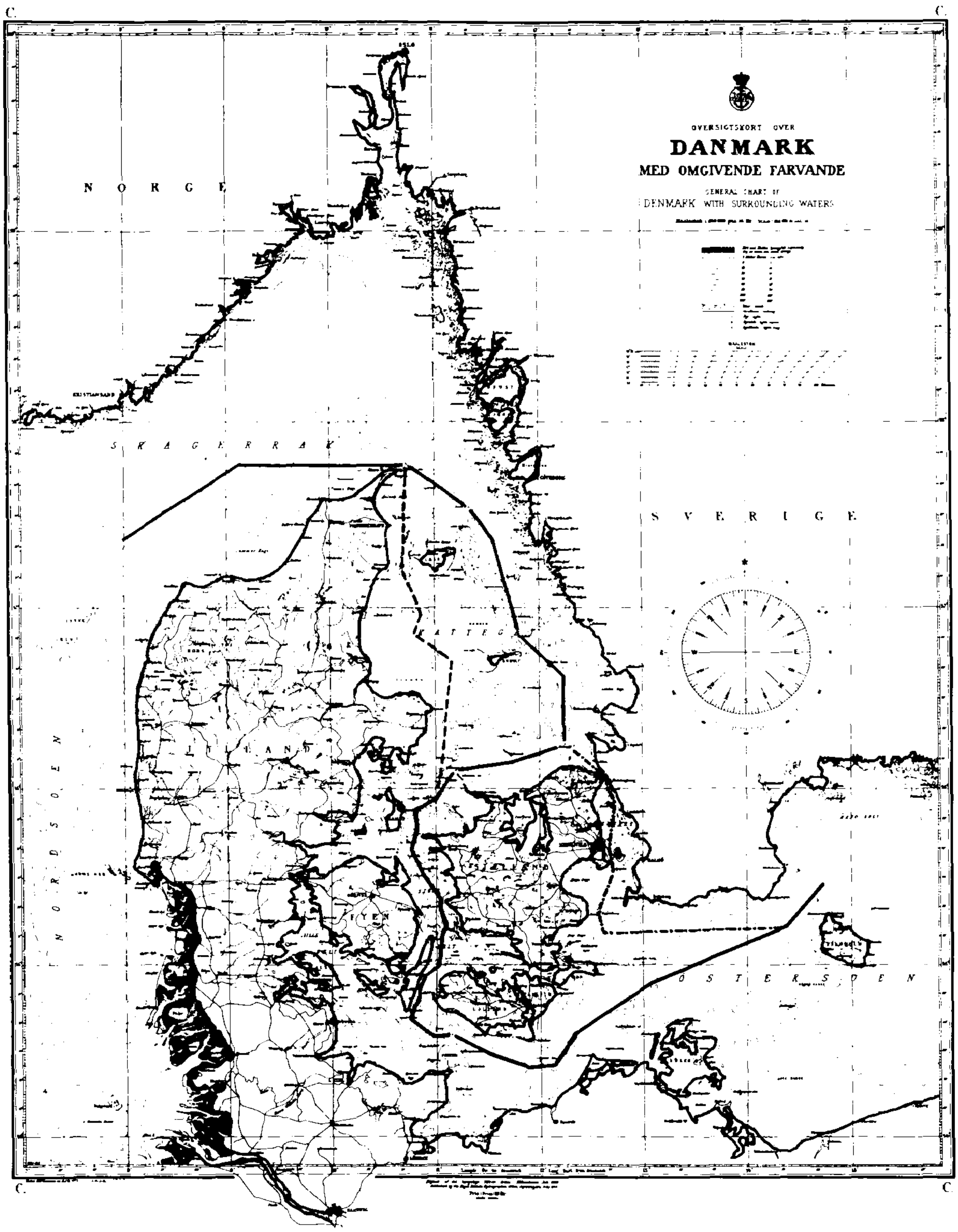


FIG. 1

A considerable portion of the bathymetry along the tracks is antiquated, with part of it dating as far back as the last century. Thus the survey tracks may be separated by several hundred metres and the depth figures vitiated by errors in position (mainly dead-reckoning positions) and depth (hand lead soundings). However, a major effort was initiated a few years ago, with the object of covering critical parts of the deepwater

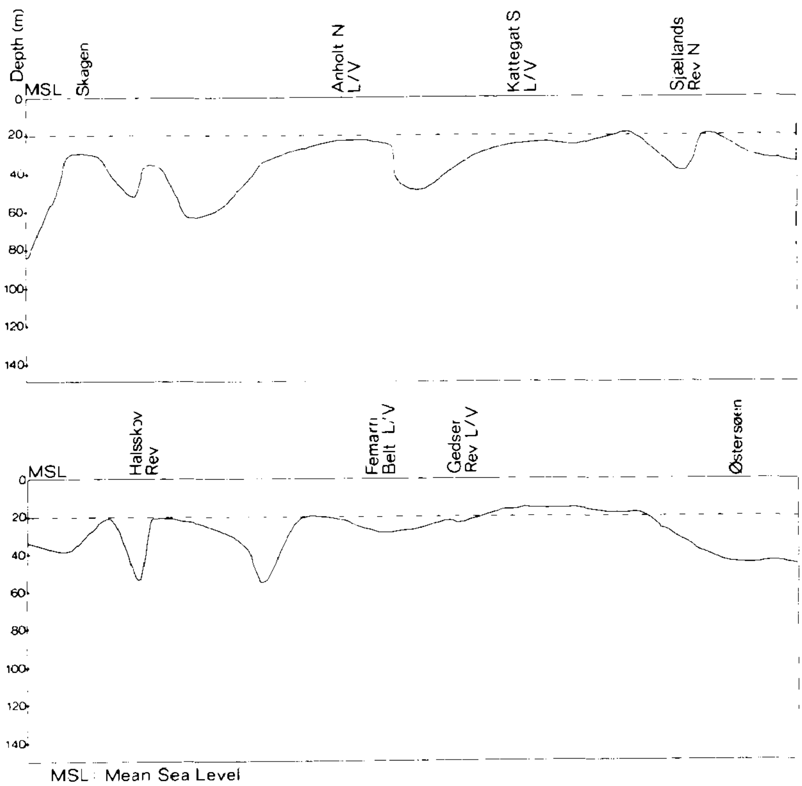


FIG. 2

route with adequate data. This will be accomplished using precision electronic position systems and advanced echosounding equipment.

As can be seen from Fig. 2, depth figures along the deepwater track are for the most part greater than 20.0 metres. But at a few localities the course of the track is rather intricate (e.g. east of Samsø and east of Langeland) and the depth is shallower than 20.0 metres (e.g. in the Sound area, in Læsø Rende, off Sjællands Rev and in the Gedser-Darsser area). The threshold depth of the Sound is approximately 8.0 metres (in the dredged channel of Drogden), that of Læsø Rende is 11.0 metres and the threshold depths of Sjællands Rev and Gedser-Darsser are 19.0 and 17 metres respectively, according to the latest available information. A discussion on the reliability of charted data is presented later on in this article.

SEA LEVEL

Apart from sea and swell the actual sea level at a given place is a function of the following meteorological/oceanographic elements :

— Mean sea level (or average condition).

— Tides (standing waves).
— Actual and historic wind and atmospheric pressure.
— Fresh water run-off from rivers and precipitation.
— Composition of watermass.
— Other physiographic factors — e.g. land up-lift and changes in total amount of water in the oceans (eustatic changes).

Mean Sea Level (local)

The average water level condition at a given place over a period of several years is the local mean sea level. Data used for the calculation of mean sea level are only available at certain ports or at fixed installations mounted in the sea bed where precision tide gauges have been installed and observed during a prolonged period. In the open sea the hydrographic surveyor as well as the navigator is normally limited to using the mean sea level as computed for one or more nearby ports, thereby being forced to accept an error of unknown magnitude.

Tides

In the Baltic Approaches inside the Skaw the tides (level changes) are of only minor importance. Going southwards from the Skaw towards the Baltic Sea the tidal range decreases from approx. 0.4 m (Frederikshavn) to 0.2 m (Korsør) and further to practically 0 m (Gedser). Eastwards of the Gedser-Darsser threshold the tidal range is of no practical importance. The predominant tidal harmonic constant is the semidiurnal moon component M_2 (or M_4 and M_6).

Sometimes, as in the case of rapidly increasing or decreasing winds or during the passage of a low pressure, a periodic east-west oriented change of the sea level in the Baltic Sea can be observed. This phenomenon, however, has nothing to do with normal lunar tides, but should merely be considered as standing waves (seiches) generated by other forces such as atmospheric disturbances. The range of such waves does not normally exceed 0.8 m, and the periods of the waves seem to vary between a few hours and 72 hours.

Wind and Atmospheric Pressure

The Baltic Sea and the Approaches are situated within the wind regime of the northern westerlies, yet the easternmost part is somewhat influenced by the topography of the East European continent. Due to the land and undersea topography the effect of wind and atmospheric pressure on the actual sea level is of major significance.

The piling-up (stow) effect created by the windstress on the surface layer is very complex. Besides wind force and direction, such components as coastal configuration, depth of water and fetch also play a major role. Generally speaking, persistent wind from a westerly direction forces water from the North Sea into the Kattegat and further down through the Approaches into the Baltic Sea, resulting in a general rise of the sea level. Under extreme conditions, up to 2.0 m above mean sea level has been registered at several locations in Danish waters. Strong easterly winds normally have the opposite effect (negative stow), showing pronounced variations from one part to another. Local topographical conditions, however, may completely change the overall picture and reverse the effect in certain areas.

Historic winds in this context should be understood to mean the average windfield which existed during the immediately preceding period. In cases of strong and persistent winds from a given direction the accompanying piling-up of water may be of such an order that the equalization process may dominate or interfere with the actual wind effects for several days afterwards.

It is a well known fact that atmospheric pressure alone may affect the average sea level, but usually to a lesser degree than the accompanying wind (a difference of 1 decibar in pressure equals about 13 cm column of water). Yet, the passage of a low pressure centre or trough can easily bring about a rise and subsequent fall of the sea level of the order of a few decimetres.

Fresh Water Run-off

The rivers and streams emptying into the Baltic Sea drain a hinterland several times the surface area of the Baltic itself. Therefore, comparison of the average sea level and the geodetic level (equipotential surface) shows a decrease from the eastern part of the Baltic Sea towards the North Sea, with the local gradient approximately inversely proportional to the local cross-sectional area. The total difference in sea level between the end positions of the route is of the order of a few decimetres, with high seasonal variability. In the spring time, melting ice in the hinterland and in the sea itself will bring about a relatively steep total gradient. During winter when the Gulfs of Bothnia and Finland are ice covered the overall gradient reaches a minimum of about zero.

Composition of Watermass

The fact that the composition of the vertical water column varies considerably from the eastern Baltic Sea to the North Sea also affects the sea level. As the salinity of the water column decreases from west to east a gradient will build up similar to that mentioned above. Also, there are frequent changes in the composition of the local water column with time, thus the local gradient will vary accordingly and in a very complex manner.

Other Physiographic Factors

Land up-lift or subsidence, variation in the total amount of water in the oceans, nodal tides, are important considerations in connection with the precise determination of mean sea level (chart datum inside the Skaw) for geodetic purposes, but they are usually of only slight importance to the navigator due to the fact that changes in sea level produced by these factors take place very slowly. In this context it should be mentioned that the Coriolis force associated with currents in the narrow straits may lead to differences in sea level in a direction perpendicular to that of the individual strait e.g. in the Great Belt the transversal difference is of the order of 0.7 m max.

As can be seen from the foregoing, determination and/or prediction of the actual sea level at a given time and place is rather complex, and is presently beyond our actual capability. However, the simultaneous combined effect of all the afore-mentioned parameters is significant in cases when the navigator of a deep draught ship intends to pass the critical localities en route to or from the Baltic Sea.

Effect of Composition of Watermasses along the Track

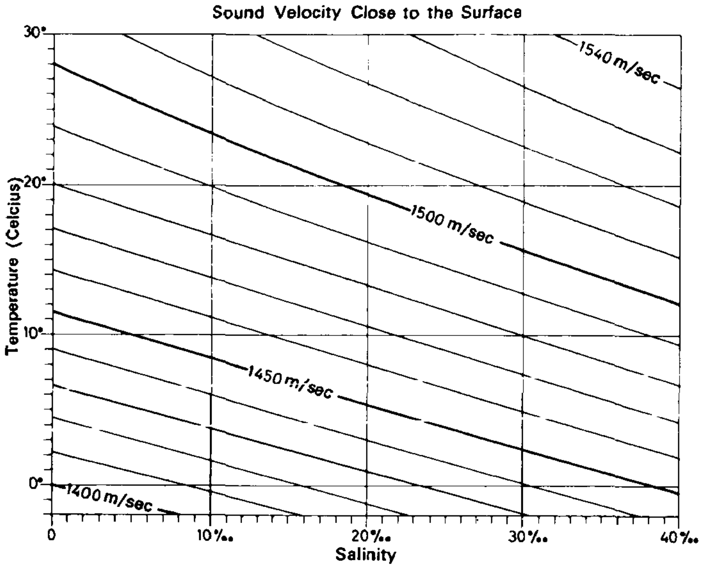
Besides the aforementioned influence of water composition on the actual sea level, there are two more separate effects which vary with the changes in the density of the vertical water column:

— Speed and propagation of sound;
— Changes in buoyancy.

As a third factor could be mentioned formation of ice, although this is related to temperature, salinity and sea state in a different way.

The speed of sound in sea water varies considerably with the density of water. The surface layer extremes are about 1400 m/sec for cold fresh water and 1550 m/sec for warm ocean water. Figure 3 showing the speed of sound in water as a function of temperature, salinity and pressure gives an idea of the variability of the parameter.

Sound propagation conditions on the whole are highly intricate, especially in the Baltic area. In general, the salinity as already stated decreases eastward from the North Sea (sal. = approx. 32 ‰) to the Baltic Sea (sal. = 10 ‰), but the most complicating factor is the local change in the composition of the water column with time. As the echosounder is based on sound wave propagation, the measured distance to the reflecting bottom is a function of the average speed of sound in the water column in question. Both the surveyor and the navigator are much affected by this fact. According to IHO standards the sounded depth, before being entered on the chart, should be reduced to a propagation speed of 1500 m/sec or be converted to geometric depth. As the surveyor has means of determining the local average speed of sound down to a depth of about 10 metres (bar-check method) or right down to the bottom by *in-situ* measurements



Sound Vel. at 0° and 35 ‰	
Depth m	m/sec
0	1445
1000	1464
2000	1482
3000	1500
4000	1518
5000	1536
6000	1554
7000	1571
8000	1588
9000	1605
10000	1622

FIG. 3. — (From G. DIETRICH : General Oceanography, 1965).

of salinity and temperature, he is usually able to make the reduction with a fairly high degree of accuracy. The navigator, however, ordinarily has no means of determining the actual speed of sound, therefore he is precluded from making a proper comparison between the measured depth and the corresponding charted depth, even if the equipment is tuned to 1500 m/sec. It should be noted that depth figures in the majority of, if not in all, charts covering the Baltic Sea area are supposed to be geometric depths.

The error arising from the lack of comparability amounts to a few per cent (max.) of the measured depth, which is by no means negligible at critical points of the fairway,depending of course to a high degree on the type and draught of the ship. As 1500 m/sec corresponds to a fairly high salinity at normal oceanic temperatures, the navigator will usually register greater depths than indicated on the chart. This deviation will increase as the ship moves eastwards. Figs 4-7 are examples of salinity. temperature and sound speed profiles in or close to the Approaches.

Other aspects of water density, in relation to shipping, affect buoyancy. En route from the North Sea south through the Approaches, ships, under normal conditions, will continue to lose buoyancy, and the draught will increase roughly proportionally. A total increase of about 3 % of the actual draught is not unusual.

Another factor emanating from changes in buoyancy is the trim factor, which is dealt with in detail in the German periodical *Der Seewart*, 1973 [3].

Finally, formation of ice along or close to the route may, on special occasions, hamper the traffic to a high degree, partly by reducing the manœuvrability, and partly by unintended displacement or removal of markers and buoys.

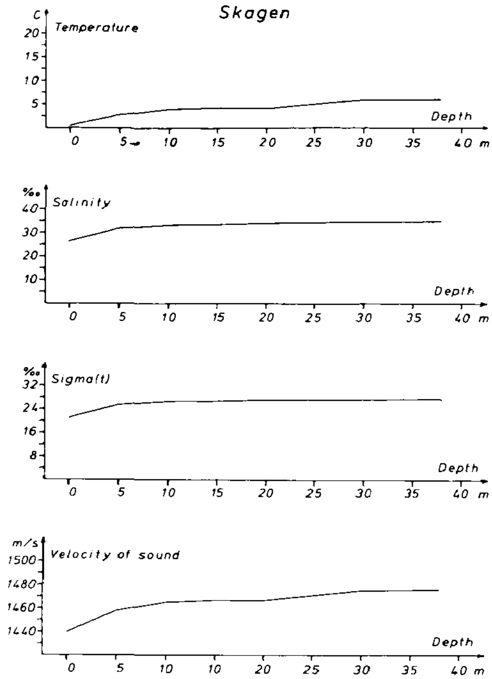


FIG. 4

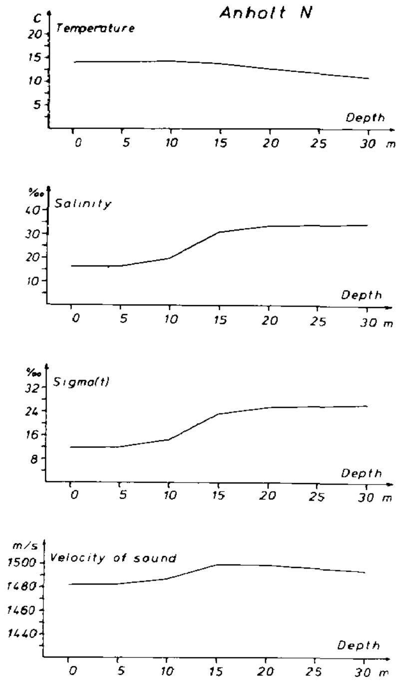


FIG. 5

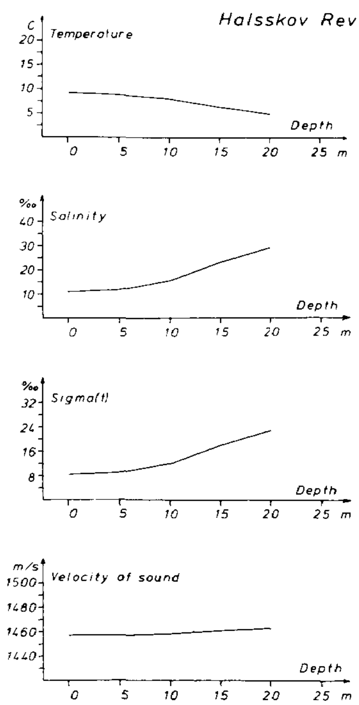


FIG. 6

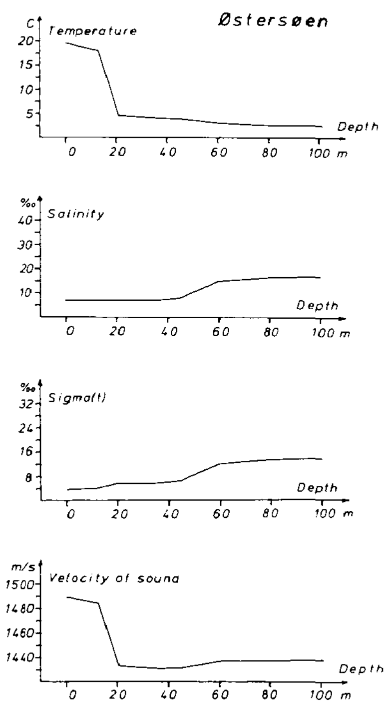


FIG. 7

CURRENTS

The total current occurring in the Baltic Sea area consists of the following main components:

— Tidal current.
— Wind generated current.
— Surface gradient current.
— Internal pressure (hydrostatic) current.

Corresponding to sea level the actual current speed and direction is highly dependent on the physical geography. Generally speaking, the current speed at a given time reaches a maximum in the most constricted parts of the route.

Tidal Current

At most places in the Kattegat and the Baltic Sea tidal current is of only minor importance. In narrow passages connecting large water areas, however, the tidal component may reach several knots, thereby constituting a potential risk to shipping. The Little Belt is a good example of this situation.

Wind Generated Current

This kind of current occurs frequently in the Baltic Sea area, although separation from other components is often very difficult. The surface current (speed and direction) is primarily dependent on wind force and local topography, i.e. depth of water, position of coastline relative to the wind, etc. Secondary effects are the earlier mentioned piling-up of water against windward coasts as well as compensation currents in the water layers below the surface.

Surface Gradient Current

This is the component resulting from the level difference between the Baltic Sea and the North Sea. It is created by the fresh water run-off from North European rivers and forms the major part of the total current during spring and early summer. The remainder of the year, and especially during winter time, the surface gradient component is usually of only slight importance.

Internal Pressure Current

Due to the fact that two watermasses of different density are present at a specific locality during most of the year, the internal pressure field will normally create an outgoing surface current carrying brackish water and an incoming deep current with high salinity water of oceanic origin. The internal face (front) between the two watermasses can be well developed in calm periods during spring and summer. However, in the case of strong persistent winds a nearly homogeneous watermass from surface to bottom will form, so that the internal pressure field and the accompanying current will vanish.

Thus the total current through the Approaches may, at certain localities, reach a maximum of several knots, especially during or shortly after rough weather conditions. Since deep draught ships have to pass points of critical depth or turning points at reduced speed (steerage speed), the existence of following or contrary currents may affect the manœuvrability of ships to such an extent that the increased risk of groundings or collisions is unacceptable.

Sea and Swell

The effect of waves may be of importance in the case of ships approaching a shallow area facing open water exposed to strong onshore winds or swell. However, in the deep draught track through the Approaches, sea and swell do not usually create a major problem to shipping, because the wave lengths are relatively small compared to the length of large ships. But, one cannot ignore that pitching and rolling of the ship caused by sea and swell under unfavourable circumstances may bring about a critical increase of draught.

Accuracy of Charted Data

In addition to the limitations in accuracy of the soundings and positions mentioned earlier, it must be kept in mind that the depth data utilized in constructing the chart are selected from, and are representative of, a large number of primary data, i.e. the total amount of data collected by the survey ship. The shallowest depth figure within a specified area is normally selected as the figure to be put on the chart as representative of that area. These areas are not determined geometrically, but are merely based on an estimate which incorporates components such as traffic intensity, general character of the waters, density of symbols, scale, etc.

As a consequence of the above-mentioned selection process, the position of the chosen depth figures do not always correspond to the actual depth of that position. According to IHO standards, the depth figures up to 20 m should normally be rounded off to the nearest lower decimal point, but not all member nations strictly follow that recommendation.

Depending upon the character of the area in question the distance between survey tracks varies from several nautical miles up to a few metres. However, it is a well-known fact that even if the distance between lines is determined to be so small that a certain overlap will result, it might still be difficult to guarantee that the shallowest depth actually has been found, e.g. in the case of a sloping sea bed with its crest parallel to the survey lines. And even if modern surveying techniques are used, it is likewise not possible to guarantee that there are no obstructions on the sea bed. Part of wrecks, boulders, objects thrown over-board, etc. may be overlooked, even if the surveying pattern is very dense and wiredrag, sonarscanner or the like have been used. A safety margin based on experience must therefore be introduced. As boulders of a diameter of 2 m are not uncommon in the Danish area a margin of that order for the time being is recommended for ships passing the Approaches.

Although the above explanatory notes on the various physiographic factors which affect the safe passage of deep draught ships through the Baltic Approaches do not pretend to be complete, it is believed that the most important elements relating to navigability and manœuvrability have been outlined.

DISCUSSION

As previously mentioned, the responsibility of the coastal state for the safe passage of ships through its waters necessitates the issuance of restrictive regulations on size and draught of ships, onboard navigational equipment, use of sea pilots, etc. Concerning the draught limit, restrictions must necessarily be formulated in terms of minimum clearance under the keel. In so doing, however, the draught of the ship is automatically coupled to the instantaneous state of the surrounding waters and the estimated sea-state during the hours of passage.

From the foregoing pages it can be deduced that the combined influence of sea level and sound propagation, together with the limitations in the accuracy of charted data, can easily amount to a deviation of one metre or more from the "average" conditions.

Similarly, the "resultant" current speed at certain intricate points along the route may amount to two or more knots and the current direction may deviate considerably from that of the intended track. The impact of this factor on ship manœuvrability adds to the overall difficulties in the passage of large ships at critical points.

In general it may be maintained that even if the particular effect of each factor were known in detail, it would be extremely difficult, if not impossible, to forecast the total effect of all elements important to shipping at a given time and place.

However, considerations on how to provide shipping with at least some essential information on a real time basis or, if possible on a forecast basis, lead logically to the splitting up of all relevant data in two main categories: namely (1) static or quasistatic data, and (2) variable data. The latter being data of a rapidly changing nature, either periodic or aperiodic. To the first category could be assigned charted data (soundings and their positions, mean sea level or any other level selected as chart datum, etc.) and position data. Improvement of the accuracy of such data mainly follows conventional lines, i.e. refined resurveys of the routes with the emphasis on depths up to 40 metres. This in turn implies denser survey patterns (cross and overlapping tracks), use of high accuracy sounding equipment and local position systems, investigation of the sea bed by sonar, magnetometer, television scanning and/or wiredragging. Localization of dangerous obstructions should be followed up by actual clearance of the sea bed down to a certain minimum depth.

To improve and facilitate navigation aboard the individual transiting ship, high precision navigation systems should be provided, preferably on fixed, icesafe installations mounted on the sea bed close to the track. Also, dense sidemarking of lanes with moored buoys, etc. could contribute considerably to safe navigation along the route.

A significant step in the efforts of providing adequate and real time information to shipping would be to establish and operate meteo-oceanographic stations at locations sufficiently close to the intricate points with the primary object of minimizing a possible error of extrapolation and interpolation in time and space. Such stations should be equipped with automatic tidegauges; in addition to that, current meters, wave recorders, thermo- and salinometers, wind and visibility sensors would be useful.

In any case, there should be the necessary means of recording and transmitting data to the potential user either directly or via a navigational warning and information system.

While this first phase merely aims at the collection and transmission of data on a real time basis, the next phase which proposes itself when a network of operating stations is established, would be to investigate the feasibility of forecasting the oceanographic conditions a few hours ahead. To meet this requirement a set of hydrodynamic numerical models must be developed, the operation of which should be based on electronic computers with continuous input of instantaneous measurements from the oceanographic stations and other relevant data sources in- and outside the area. Since pilots onboard large ships are most anxious to be warned of the potential risk of negative surges (extreme low water conditions), the forecast of sea level should be given first priority. But also there are others interested in the establishment of an oceanographic recording and forecasting system, including those concerned with pollution control and monitoring, biologists and other marine scientists.

Contrary to the conditions in the English Channel area, the bottom relief along the deep draught route through the Baltic Approaches is fairly stable even though it consists of rather loose material. In other words, no significant current-generated movement of consolidated sediments (sand and gravel) has been so far observed close to the route. This fact may enhance consideration of making "short cuts" and of deepening the tracks by dredging at certain points along the route. A quick look at the chart to examine the constricted areas, brings one to focus on the area east of Samsø, the Great Belt and the Gedser-Darsser area. This shows further that it would not pay to deepen the adjusted route to more than approximately 20 m; this being more or less the overall minimum depth through the entire Approaches.

Since many construction firms are actually looking for locations to dredge sand, gravel and stones, there appears to be a possibility of having the necessary work done at reasonable cost, i.e. a cost comparable to the profits gained by increased draught.

While an adjustment and deepening of the track through the Great Belt apparently will not modify the biologic environment to any high degree, the situation might be quite the contrary in the eastern Baltic if the Gedser-Darsser sill is deepened to 20 m over a width of several hundred metres. It is well-known that under average conditions the sill (min. depth approx. 17 m) acts as an effective barrier along the bottom. Partial removal of this barrier means that the North Sea water will penetrate further eastwards along the bottom of the Baltic and fill up the troughs in the central area. Scientists still disagree, but recently initiated investigations on the exchange of water between the North Sea and the Baltic Sea (sponsored by the Danish Government in collaboration with Germany and Sweden) may give the answer to this challenging question.

The above general discussion on the problems related to the safe passage of deep draught ships through the Baltic Approaches outlines a strategy aimed at alleviating the various restrictions.

The following is an enumeration of the proposed individual countermeasures which could be taken to meet the requirement of navigation security. The items are *not* set out in order of priority.

1. Establish regulation of traffic (means of navigation, allowed maximum draught, use of sea pilots, etc.).
2. Conduct refined resurveys with emphasis on depths up to 40 m, including sonar scanning, wiredragging, etc. Actual clearance of the sea bed.
3. Improve navigational facilities with installations mounted on the sea bed, lane-marking buoy systems, etc.
4. Establish and operate tide gauge stations close to the route, including real time transmission of sea level data.
5. Establish and operate oceanographic stations with real time transmission of meteo-oceanographic data (current, temperature, salinity, waves, wind, visibility, etc.).
6. Establish a prediction and warning centre system for extreme meteo-oceanographic situations.
7. Straighten and deepen shipping routes by dredging.

FINAL REMARKS

With a view to improving weather forecasting and developing predictions for storm surge and other factors important to shipping, fisheries, pollution monitoring, coastal engineering, etc., a number of European countries recently initiated a special project called COST 43 (European Cooperation in the Field of Scientific and Technical Research). This project implies the establishment of a telemetering ocean buoy network in European waters. The buoys of fixed platforms will be provided with meteorological and oceanographical instruments capable of recording, logging and transmitting data to local centres in the region for processing and further transmission to potential users. It is intended that COST 43 should form part of the Integrated Global Ocean Station System (IGOSS).

Danish authorities concerned with safe navigation of ships transiting the Baltic Approaches would, of course, be interested in having the North Sea - Baltic Sea part of COST 43 modified to fit the above discussed requirements. Due to the shallowness of these waters, fixed installations as substitutes for buoys will play an important role in this particular region. Such installations could be exploitation platforms, lighthouses or the like mounted on the sea bed close to the tracks; dependent on the degree of exposure to wind, waves and ice the various sensors may be mounted on the installation itself, suspended from a fixed boom, or alternatively from a minor buoy anchored in the vicinity with cable or acoustic link to the platform.

During the pilot phase of COST 43 it is only intended to gain experience as to the various sensors, their mounting, application and maintenance. The provision and preliminary operation of adequate transmission systems as well as data processing tests in local centres come also under the initial phase of the project. The entire meteo-oceanographic network is planned to be operational by the end of 1980.

Undoubtedly, current information systems based on real time data, transmitted and processed as indicated above, will be most useful to shipping in the future, especially in constricted waters all around the world. It is however felt that some sort of mutually agreed guidance (standards) for the sponsoring maritime authorities in the field of procedures for collection, processing and presentation of data is needed. Such guidance should include for instance the following elements : type of data needed, way and rate of collection, transmission procedures, interrogation mechanisms, predictions, etc.

For many years the IHO has played the important role of international coordinator in matters dealing with traditional hydrography. As oceanography and other sciences related to shipping now form part of the IHO activities, it seems quite natural that the organization also takes the leading position in this field. This could for instance be done by formation under the auspices of IHO of a small *ad hoc* expert group composed of nautical specialists, hydrographers and oceanographers; their primary task should be to work out procedures, standards and codes for the relevant parameters such as sea level, current speed and direction, temperature, salinity, sound propagation, buoyancy, wave spectra, visibility, physiography and changes of the seabed as related to surveying, etc. Later on the group could be asked to look more closely into the question of predictions, not only of the conventional type (like weather forecasting and tide prediction), but also of non-tidal sea level changes, current speed and direction, waves, visibility, etc.

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