International Association of Marine Aids to Navigation and Lighthouse Authorities

IALA

AISM Association Internationale de Signalisation Maritime

IALA Guideline No. 1078

On

The Use of Aids to Navigation in the Design of Fairways

Edition 1

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Document Revisions

Revisions to the IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision

Table of Contents

Index of Tables

Index of Figures

1 INTRODUCTION

The purpose of this Guideline is to give guidance for AtoN providers and competent authorities on the:

- use of AtoN in the design of fairways, including dredged channels and canals; and,
- review of existing AtoN for fairways including dredged channels and canals.

The objective is to define a suitable AtoN mix that enables safe and efficient vessel passage in the most cost effective way for AtoN providers.

This Guideline shall be used as a general overview. For more detailed AtoN planning, this document should be used in conjunction with other IALA documentation, especially the Maritime Buoyage System (MBS).

1.1 Background

The art of navigation has evolved over many hundreds of years, as well as the design of vessels. For instance, vessels are bigger and faster; vessel equipage has become much more complex.

In principle, navigation comprises:

- Planning a safe passage for a vessel, through the use of nautical charts and relevant publications;
- Monitoring or establishing a vessel's position or movement along a planned passage; and,
- Controlling a vessel, to ensure that it follows a planned passage.

The navigation process is normally performed by the vessel's navigator. The navigator will normally combine the chart and navigational information whilst at the same time controlling the vessel. In some vessels, for some of the time, this process is fully automated, using electronic tools. This places great demand on the accuracy of the chart, the navigation system and the vessel's control systems. Complete automation cannot be fulfilled under all circumstances with today's technology. In general, it is considered that proper marking of waterways/fairways, dredged channels and canals by visual and radar aids remains important to mitigate risk.

Until recently, mariners have used radionavigation systems (also referred as electronic AtoN) and short range visual systems, in two distinct ways. Short range visual AtoN were mostly used close to shore and in restricted waterways. Utilising radionavigation systems, vessels were able to navigate offshore safely using less accurate radionavigation systems. However, considering the availability, reliability and relatively low cost of high precision electronic position fixing systems (e.g. GPS/DGPS and electronic charting programs) available today, these two areas of navigation have become less distinct. This is especially true in those transitional areas where mariners shift from the low accuracy requirements of ocean navigation, to the high accuracy needs of coastal and inshore piloting. As electronic aids continue to improve, their use will increase in areas where short range aids were previously used. This evolutionary change must be considered when conducting waterway analysis and designing AtoN systems for fairways.

1.2 Future Development

In future, e-Navigation will have a considerable impact on the mix of AtoN for an existing or a planned fairway. e-Navigation will help to improve the efficiency of fairway marking with AtoN by integrating the elements of information. Further on it will provide:

- improved safety, through promotion of standards in safe navigation;
- better protection of the marine environment;
- the potential for higher efficiency and reduced costs; and,
- a potential reduction in bureaucracy - e.g. standardised reporting requirements.

Elements of e-Navigation, which are currently limited by availability of equipment and training of personnel, will be available in the future. Issues relating to the presentation of information still remain to be addressed.

2 DEFINITIONS

Table 1 Definitions

Term/Acronym	Definition/Expansion
Absolute Accuracy	The accuracy of a position estimate with respect to the geographic or geodetic co-ordinates of the Earth
Absolute Position	A position estimate with respect to the geographic or geodetic co-ordinates of the Earth
AtoN	Aid(s) to Navigation
AtoN Provider	Any organisation, public or private, which is required to deploy AtoN as part of its duties
Availability	The percentage of time that an aid, or system of aids, is performing a required function under stated conditions. Non-availability can be caused by scheduled and/or unscheduled interruptions
Canal	A narrow stretch of inland waterway created artificially to facilitate navigation
Channel	Part of an (otherwise shallow) water having sufficient depth for vessels and designated or customarily used for vessels. The borders of the channel may be defined by natural or artificial banks or by AtoN
Conspicuity	The ability of an object to stand out from its surroundings
Continuity	The probability that, assuming a fault-free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within a limited part of the coverage area
e-Navigation	The harmonised collection, integration, exchange, presentation and analysis of maritime information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment
ENC	Electronic Navigation Chart
Fairway	A charted and marked waterway recommended by a competent authority
High Speed Craft (HSC)	Craft capable of maximum speed equal to or exceeding $3.7\nabla^{0.1667}$ ms^{-1} where: ∇ = volume of displacement corresponding to the design waterline (m^3) This excludes WIG vessels
IHO	International Hydrographic Organisation
IMO	International Maritime Organisation
Integrity	The ability to provide users with warnings within a specified time when a system should not be used for navigation
Luminous range	The distance from which, under defined conditions, the user can identify the light

Nominal range	Luminous range in a homogeneous atmosphere in which the meteorological visibility is 10nm
Radionavigation	Radiodetermination used for the purpose of navigation, including obstruction warning
Radionavigation system	Navigational system that uses radiofrequencies to determine a position
Relative Accuracy	The accuracy with which a user can determine position relative to that of another user of the same navigation system at the same time
Reliability	Ability of a device, or system, to satisfy the requirements of its intended use within defined limits, and for a stated period of time
SOLAS	International convention for the Safety of Life at Sea
Useful range	The practical convenient range for a mariner to identify an AtoN
Waterways	Navigable waters
Wing in Ground (WIG)	Vessels, the hull of which is supported completely clear above the water surface in non-displacement mode, by aerodynamic forces generated by ground effect

3 USER REQUIREMENTS

3.1 General

According to SOLAS, Chapter V, regulation 13, each of the Contracting Governments is required to provide, as it deems practical and necessary, AtoN, as the density of traffic and the level of risk requires. IMO member states commit themselves to take into account international recommendations and guidelines when establishing such aids.

3.2 Accuracy

The required navigation accuracy for a vessel depends on the beam of the vessel, the draft of the vessel, the under keel clearance and the bathymetry and many other factors in the waterway. The position accuracy of the vessel should meet the required navigation accuracy. However, as there are many interacting variable properties of vessels and waterways, there will be a situation, where the navigation accuracy cannot be improved further by improving the position accuracy.

The mariner needs to be able to determine exactly the distance from the vessel to certain points or lines; for instance, a critical hazard or the limitation of the fairway. This distance can then be calculated as the difference between two absolute positions. This distance is therefore dependent upon both the absolute position accuracy of the vessel and the relevant object.

The distance can also be found directly, if there is a visual aid, or a radar target, or any other device indicating the relevant point or line. This is described by the relative accuracy. .The principle of relative accuracy is often used for the layout of visual AtoN systems.

The requirement for the position accuracy for radionavigation systems for general navigation is 10m for most of the different types of waterways[1]. Position accuracies of radionavigation systems are considered as absolute.

The position of the AtoN should be accurate and in accordance with IHO standards, in order that a vessel can establish its position sufficiently and follow a route in the fairway by visual or radionavigation means.

1 IMO Resolution A.915(22) ‘Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS)’, adopted on 29 November 2001; and, A.953(23), ‘World-Wide Radionavigation System’, adopted on 5 December 2003

The AtoN should be surveyed and positioned with at least the same accuracy as the nautical chart. This is determined in the IHO Standards for Hydrographic Surveys (S-44) 5th Edition February 2008 with accuracies of:

- 2 m for fixed aids (5 m when water depth more than 100 m);
- 10 m for floating aids (20 m when water depth more than 100 m).

In many cases, these minimum requirements will not be accurate enough because of the specific layout of the system and its components.

3.3 Reliability

In determining AtoN Reliability, such issues as Integrity, Availability, Continuity and mean time to repair (MTTR) need to be taken into account.

The required level of AtoN Reliability is determined by the level of risks to the mariner, the vessel and the marine environment that are mitigated through the use of a particular AtoN. In those areas in which the level of risk has been determined to be high, the use of certain types of AtoN may prove to provide greater risk mitigation.

The planner must consider availability objectives. AtoN providers should refer to IALA Recommendation O-130 'on Categorisation and Availability Objectives for Short Range AtoN' for additional information related to the categorization of individual AtoN, the calculation of availability targets, and recommended availability objectives.

If continuity is used for defining the requirements for a specific system, it has to be calculated for the time that a vessel takes to pass through the fairway or area.

3.4 Special Requirements for different user groups

The level of on-board navigational equipment can vary significantly on different types of vessels. SOLAS vessels are equipped with certified on-board navigational equipment. This is suitable to support long-range and/or low visibility navigation. These vessels are operated by professionally trained and certified personnel. For these vessels, visual AtoN are used as a back-up-system if radionavigation systems or on-board equipment fail. However, for vessels that are not SOLAS equipped[2], visual AtoN are more important.

For High Speed Craft and other fast vessels in coastal areas, using visual AtoN for a safe passage, the speed of these vessels can be the defining factor for the AtoN system[3]. The reaction time in these situations can be short, so the information provided by the AtoN needs to be quick and has to be unambiguous.

2 For instance, fishing vessels and leisure craft

3 IALA Guideline No. 1033 'on the provision of AtoN for different classes of vessels, including high speed craft' addresses the specific AtoN requirements of HSC.

4 PERFORMANCE PARAMETERS OF AtoN SYSTEMS

4.1 Positioning Accuracy

4.1.1 Radionavigation Systems

The position accuracy (95%) for a vessel using radionavigation systems – augmented by differential systems[4] where appropriate – can be assumed to be 10m. These systems provide absolute accuracy and absolute position information which should be used in conjunction with chart information. The accuracy of the chart has to be taken into account when using radionavigation systems.

4.1.2 Visual AtoN

Generally, visual AtoN do not provide absolute accuracies of 10 m or less as presented to the user. However, and importantly, they provide a good *relative accuracy*. Thus, they are a good tool to determine the vessel's position relative to relevant objects, such as fairway boundaries and hazards.

Due to differing mooring arrangements, the position accuracy of floating short range AtoN is sometimes difficult to define. Floating AtoN positions are subject to variation because of water depth, tides, current, mooring type and the capabilities of the servicing vessel in positioning the AtoN anchoring device.

4.1.3 Drift Detection

There is not an internationally agreed method for calculating vessel positioning accuracy in a fairway that uses buoys and other AtoN. Research in the calculation and presentation of drift detection is currently taking place. For instance, a new drift detection method for vessels in a channel has been developed in Japan. Details of this method can be found at ANNEX B.

4.2 Redundancy

Reliance upon a single AtoN may result in a higher availability requirement which may prove difficult for the provider to meet. Therefore, implementation of multiple aids should be considered to provide redundancy.

Duplication of the navigational functions of a single AtoN may be appropriate to provide a degree of redundancy to avoid the excessive cost of emergency repairs. Moreover, temporary duplication may be provided when new or alternative types of aids are being introduced in order to allow a safe transition period.

4.3 Perception

4.3.1 General

When designing a fairway, the distance from which the AtoN can be detected, recognised and identified by the mariner, is a critical consideration. For visual perception, this is called the useful range.

The useful range does not only depend upon the properties of the AtoN itself. The atmosphere and the human eye are the other determining factors. Therefore, useful range can be calculated using characteristics of the AtoN, atmosphere and the human eye (this is further determined by the experience of the observer). The conspicuity of an object is also relevant. An object is conspicuous if it appears outstanding in a complex visual scene. IALA guidance on this issue is included in certain IALA documents.

To identify an AtoN, it is important that the visual information provided by the AtoN is verified. The mariner achieves this task by comparing the characteristics of the AtoN (e.g. shape, colour, daymark, lettering and light character.) This process can take time due to interference by intermittent influences such as wave movement and visibility.

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[4] IMO Resolutions A.915(22) and A.953(23)

4.3.2 Lights

An AtoN light can be defined by its intensity, colour and divergence. When this light is measured in its practical application a further parameter is derived; the luminous range. The luminous range is the distance from which, under defined conditions, the user can identify the light. To identify the light, the mariner must be able to confirm its colour and character.

The prevailing visibility conditions will vary for different geographical locations. Therefore, when selecting an AtoN light, these conditions should be taken into consideration. The nominal range will be promulgated in nautical charts and publications for mariners, lists of lights etc.

The IALA E-200 series of Recommendations provides further information on the determination and measurement of marine signal lights.

4.3.3 Daymarks

The distance at which a daymark can be identified depends on size, shape, colour, contrast to the background, environmental conditions, background and geographical range. The object can be normally identified when it subtends, at the eye, an angle of more than 3' (three minutes of arc).

The contrast between the background and the AtoN depends on the:

- chromaticity of the paint of the AtoN;
- specific meteorological visibility in the area;
- colour and illumination of the background;
- conspicuity.

Reflective sheets / retro-reflective material on the aid can be used at night to enhance the daymark in low visibility conditions.

4.3.4 Radar

The perception of an AtoN by a vessel borne radar is determined by the:

- height of the vessel's radar;
- height of AtoN above actual sea level;
- Radar Cross Section of the AtoN (including any radar reflector);
- environmental conditions:
  - radar clutter due to sea state and weather;
  - movement of AtoN due to environmental conditions;
- active radar devices on the AtoN.

4.3.5 Automatic Identification System (AIS)

Perception can be improved by means of AIS on AtoN, provided that the vessel's on-board equipment allows presentation of such information.

Some of the benefits of AIS include:

- unambiguous indication of AtoN identity;
- day/night and all weather operation;
- greater range than most visual signals;
- enhanced perception, showing the position on the vessel's electronic chart;
- verification of the integrity of the aid, including Off-Position and operational status indication / malfunction alert to the mariner and AtoN provider;

- additional broadcast of meteorological and hydrological data and safety related information in real time if suitable equipment is fitted to the AtoN.

More Details on AIS and its implementation as an AtoN can be found in IALA Recommendation A-126 on the use of AIS in Marine AtoN Services.

5 LAYOUT OF AtoN FOR MARKING A FAIRWAY

5.1 General

When considering the design of a system of AtoN, the IALA Maritime Buoyage System (MBS) must be adhered to. However, for inland waterways, there may be different legislation, rules and marking systems established by national authorities; for example, SIGNI (Signs and Signals on Inland Waterways).

The AtoN provider is responsible for ensuring that AtoN are identified and marked on nautical charts (ENC and paper charts).

In narrow, winding or meandering passages, it may be difficult for mariners to correlate the vessel's position with chart information in a timely manner. In these circumstances, visual AtoN will be the primary means of navigation.

5.2 AtoN Marking the Fairway Boundaries

The following *general* principles apply to the design of fairways:

1 A fairway shall be marked, in principle, by lateral marks.

2 There shall be AtoN at least at bends and junctions of the fairway.

3 Lit AtoN should be generally used for:

a the beginning and end of the fairway;

b changes of direction.

4 AtoN should be spaced evenly along the fairway, where practicable.

5 In general, the useful range of buoys at day and night should be greater than the distance between the buoys. The AtoN appearance on the vessel's radar screen should also be considered.

6 The distances between unlit AtoN are based on their size and daytime visibility.

7 In general, the AtoN on one or both sides of the fairway, should be positioned an equal distance from the central axis of the fairway.

8 If high navigational accuracy or a very clearly distinct fairway with continuous buoyage is required, ideally, the AtoN marking the fairway shall be established as pairs ('gates'); however, if this degree of accuracy is not required then a 'staggered' arrangement of AtoN could be considered. Moreover, AtoN could be positioned to one side of the fairway only.

9 If a fixed AtoN separation distance is required, then the appropriate mark and size has to be established. If a certain type of mark/size of AtoN is preferred for a particular purpose, then the separation distance of the AtoN has to be determined. Usually, this will be an iterative process. More than one option should be examined and assessed against the level of risk, from the navigational, economical, technical and operational perspectives.

10 In general, a high density of fairway AtoN ensures an easy and more accurate level of navigation. However, there is a saturation point where adding AtoN does not help positioning any further. To find the ideal AtoN density, simulation and risk assessment will be necessary, or at least very useful in fairway design.

11 To make AtoN service provision more economical, providers should consider defining a restricted number of various types and classes of AtoN (by size and shape) with certain

identification distances and useful ranges of the lights. Thus, the most suitable AtoN can be chosen from this 'toolbox' instead of designing a new one for each case.

5.3 Other AtoN Marks in the Fairway

In addition to marking the boundaries of the fairway, short range AtoN and electronic AtoN may be used in the right mix to indicate:

- critical points;
- the centre of the fairway;
- change of direction;
- marking of isolated dangers;
- marking of different areas.

The following marks can be used:

- Lateral, cardinal or safe water marks, which are physically deployed directly in the fairway, or on the point they indicate (or as close as possible to it). These can be floating (buoys) or fixed (beacons) aids.

5.4 Fixed visual AtoN Outside the Fairway

5.4.1 Leading lines

Leading lines (lit or unlit) generally provide high accuracy for the middle of the fairway. They can be established when there are straight stretches in the fairway Leading lines should be established if:

- the middle of a fairway needs to be indicated;
- other AtoN could be affected by ice, severe weather or tide;
- there is a channel inside the fairway, which has to be used by vessels with deep drafts;
- strong cross currents occur (for instance in harbour entrances);
- They can also be used to mark the boundaries of the fairway, provided this function is clearly shown in the relevant charts (see example in ANNEX G).

The preliminary decision in designing a leading line is to define length and breadth of the section of fairway to be defined by the leading line. Generally, it is costly to build a leading line to serve a long channel, as the rear leading light must be of sufficient height to be clearly visible above the front structure. Leading marks must also be large enough to be visible from the far end of the section of fairway marked. Both these conditions result in increases to the required height of the rear structure marking a long channel.

More Details can be found in IALA Guideline No. 1023 for the design of leading lines and in the IALA NAVGUIDE.

5.4.2 Sector lights

A sector light is an AtoN that displays different colours and/or rhythms over designated arcs. The colour of the light provides directional / positional information to the mariner.

A sector, or a limit between two sectors, may indicate a fairway, a turning point, a junction with other fairways, a hazard or something else of importance for the navigator.

When a fairway is covered by a sector light, colours indicating safe passage and danger areas are defined in the MBS.

A sector light may indicate one or more of the following boundaries and aspects of a fairway; for example:

- position at which a change of course should be made;

- location of shoals, banks, etc.;
- an area or position (e.g. an anchorage); and,
- the deepest part of a fairway.

More details can be found in IALA Guideline No. 1041 on Sector Lights.

New developments in optimizing sector lights have recently taken place. For example, sector lights with oscillating boundaries are a powerful tool for lateral positioning in the fairway and considerations for their use can be found in the IALA NAVGUIDE.

6 DESIGN METHODOLOGY/PROCEDURE

6.1 A simple procedure for the establishment of a Marked Fairway

The design of AtoN marking a fairway which is formed by straight lines and bends can be undertaken in three steps:

1 Establish a conspicuous AtoN, or pair of AtoN, at the beginning of the fairway.

2 Place AtoN at points where:

   a vessels have to alter their course;

   b the fairway boundary line or the middle line has a bend or curve;

   c critical shallows and rocks, or other hazards, form the boundary of the fairway;

   d fairways intersect.

3 Distribute buoys between these points with regard to the distance at which they can be detected and identified (refer to the section on perception of AtoN in this Guideline (section 4.3) and other relevant IALA documents).

   The distance, at which the marks should be detected and identified, may be different in relation to the length of the fairway for different cases as follows:

   a after the initial assumption of requirements made from section 4.3, the buoy separation distance should now be chosen as follows:

   b when the nearest buoy is being approached, the mariner should be able to see at least the next buoy along the fairway (the next two buoys in more accurate applications).

6.2 Channel Design and Maintenance

Fairway planners in the relevant authorities should consider AtoN solutions to minimise the amount of dredging and surveying that is required in fairway construction and maintenance. Further details on these matters can be found in the PIANC Guide 'Approach Channels.'

6.3 Risk assessment

Advice on risk assessment and risk management can be found in IALA Guideline 1018 on risk management and IALA Recommendation O-134 on the IALA risk management tool for ports and restricted waterways.

6.4 Simulation

Simulation can be used as a tool in the design and planning of fairways. Refer to IALA Recommendation O-138 on the Use of GIS and Simulation by AtoN Authorities and IALA Guideline 1058 on the use of simulation as a tool for waterway design and AtoN planning, for discussions on the use of simulation in fairway design and placement of AtoN.

7 EXAMPLES OF MARKING OF FAIRWAYS

Some examples for the marking of fairways are given in ANNEX C to ANNEX G.

8 CONCLUSION

When designing an AtoN system for an existing or a newly designed fairway, many considerations are necessary. The requirements can be defined in parameters such as accuracy, reliability and perception. The parameters vary depending on the type of fairway, the vessel traffic and on other factors. The design must include the considerations and requirements of international bodies such as the IMO, IHO, PIANC and IALA.

e-Navigation will integrate information on visual AtoN in the fairway with all the information available on the bridge of a vessel and thus contribute to the optimal use of the fairway. This is subject to further development, as currently many vessels are not equipped to use e-Navigation applications. A systematic approach to the design of AtoN systems and fairways is an initial step towards AtoN integration in e-Navigation.

Continuous improvement of marking principles and AtoN positioning will optimise the fairway design, drive efficiencies and protect the marine environment.

ANNEX A RELEVANT IALA DOCUMENTATION

1 IALA AtoN GUIDE (‘NAVGUIDE’)

This document provides overall guidance, in particular chapters on AtoN and Risk Management.

2 IALA RECOMMENDATIONS

1 R-101 on Maritime Radar Beacons

2 E-105 on the need to follow national and international standards

3 E-110 for the Rhythmic Characters of Lights on AtoN

4 E-111 for Port Traffic Signals

5 E-112 for Leading Lights

6 O-113 for the Marking of fixed bridges over navigable waters

7 A-126 on the use of AIS in Marine AtoN Services

8 O-130 on categorization and availability objectives for short range AtoN

9 O-138 on the Use of GIS and Simulation by AtoN Authorities

10 E-200-0 on Marine Signal Lights - Overview

11 E-200-1 on Marine Signal Lights - Colours

12 E-200-2 on Marine Signal Lights - Calculation, Definition and Notation of Luminous Range

13 E-200-4 on Marine Signal Lights - Determination and Calculation of Effective Intensity

14 E-200-5 on Marine Signal Lights - Estimation of the Performance of Optical Apparatus

3 IALA GUIDELINES

1 1010 on Racon range performance

2 1018 on Risk Management

3 1023 for the Design of Leading Lines

4 1033 on the Provision of AtoN for different classes of vessels, including high speed craft

5 1041 on Sector Lights

6 1046 on a Response Plan for the Marking of New Wrecks

7 1051 on the Provision of AtoN in Built-up Areas

8 1058 on the Use of Simulation as a Tool for Waterway Design and AtoN Planning

9 1061 on Light Application – Illumination of Structures

Other IALA Recommendations and Guidelines on VTS, AIS, Racons and DGPS should also be considered.

ANNEX B DRIFT DETECTION – JAPANESE METHOD

Extract from Japanese Method (contribution to Section 5 'Fairway Layout and Channel Width' to the Draft of the report of PIANC MARCOM Working Group 49 'Horizontal and vertical dimensions of channels').

1 CHANNEL CLASSIFICATION AND CHANNEL WIDTH ELEMENTS

Channel width can generally be assumed to consist of the following fundamental elements:

Width of basic manoeuvring lane: $W_{mi} \ \left(= W_m(\beta) + W_{my} + W_m(S)\right)$

where

$W_m(\beta)$: width needed against wind and current forces

W_{my} : width needed against yawing motion

$W_m(S)$: width needed for drift detection.

- Additional width needed against bank effect forces: W_{bi} ;
- Additional width needed against two-vessel interaction forces in passing condition: W_c ;
- Additional width needed against two-vessel interaction forces in overtaking condition: W_{ov} .

It is noted that the total channel width may be obtained by summing up necessary elements mentioned above, not necessarily all, according to design purposes and detailed conditions for the subject channel.

2 EQUIPMENT AND SYSTEMS OF NAVIGATION AIDS

A vessel sailing in a channel usually makes some amount of drift from its course line due to various causes together with external forces even if a vessel handler does believe that his vessel is running 'on track'. Drift detection may be impossible when the drift amount is small, but a vessel handler can recognize a drift when a vessel makes some considerable amount of lateral deviation from its course line as shown in Figure 1. The drift amount which a vessel handler can detect depends on the type of equipment and systems of navigation aids together with the way in which they are utilized. It should be noted that the drift quantity to be detected plays an important role in the design of channel width. A narrower width may generally be adopted for a channel with a higher level of equipment and systems where the drift detection can be made more easily. Moreover, a vessel of larger size may be allowed to sail by installing a higher level of equipment and systems even in an existing channel which cannot be widened due to some topographical limitations.

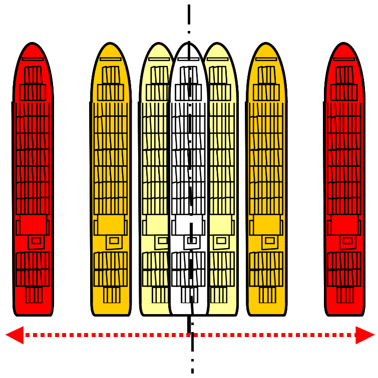


Figure 1 Undetectable zone

As for the drift detection, in general, three types of equipment and systems of navigation aids are available as follows.

- Drift detection by observing light buoys ahead on both sides of channel with the naked eye.
- Drift detection by observing light buoys ahead on both sides of channel with RADAR.
- Drift detection by GPS or D-GPS.

The channel width needed for the drift detection can be estimated with a detectable deviation from a course line with the use of the equipment and systems of navigation aids, as above, in each channel to be designed.

3 WIDTH NEEDED FOR DRIFT DETECTION

As for the drift detection means by observing light buoys ahead on both sides of channel either with the naked eye or with RADAR, the channel width needed for the drift detection may be estimated on the basis of an angle made by two lines from a vessel to two buoys ahead on both sides θ shown in Figure 2, which is defined as:

$$\theta = 2\arctan\left(\frac{W_{buoy}}{2L_F}\right) \qquad \text{(equation 1)}$$

where

W_{buoy} : clearance between two buoys

L_F : distance along channel centre line form vessel to light buoys ahead.

In equation 1, amounts of W_{buoy} and L_F are given in the following manner according to the subject channel of a newly designed channel or an existing channel.

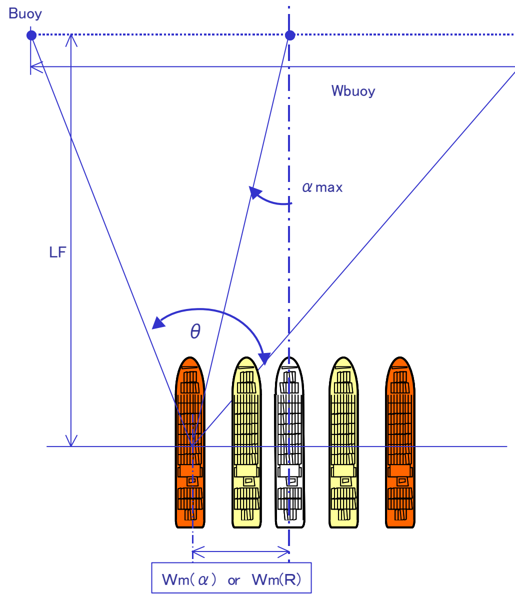


Figure 2 Detectable manoeuvring lane for light buoys on the both sides of fairway

3.1 Newly designed channel

In this case, W_{buoy} is to be the channel width finally determined which is unknown in the beginning of channel width design. Therefore an iteration technique as described in 5.3.6 is employed where assuming some amount of W_{buoy} iterations are made until computed value is to be finally identical to the assumed one. Amounts of L_F may be set empirically to be $7L_{OA}$ for a one-way channel and $(3.5-7)L_{OA}$ for a both-way channel. Moreover, L_F may be set with a value of $(0.5-1.0)$ times of the distance between two successive buoys along a channel when buoy locations are given.

3.2 Existing channel

W_{buoy} is set with a clearance between two buoys on both sides of the channel, and L_F is set with a distance between two successive buoys along a channel. However, when the distance between two successive buoys is thought to be somewhat long or more, L_F may be set, in a similar way to the case of newly designed channel, to be $7L_{OA}$ for a one-way channel and $(3.5-7)L_{OA}$ for a both-way channel.

3.3 Drift Detection by Observing Light Buoys with Naked Eyes

As shown in Figure 2, an angle made by two lines of a channel centre line and a line from a vessel to a midpoint of two buoys is denoted with α. A concept of the maximum deviation is introduced which is defined that almost all vessel handlers are able to recognize a drift from its course line. Corresponding to this maximum deviation, the angle of α is denoted with $\alpha_{\max}$ as shown in Figure 2. Making use of the above concept of $\alpha_{\max}$, the channel width needed for the drift detection by observing light buoys with the naked eye can be calculated by:

$$W_m(\alpha) = L_F \tan(\alpha_{\max}) \qquad \text{(equation 2)}$$

where $\alpha_{\max}$ may practically be estimated with an empirical formula developed on the basis of statistical data by full scale experiments, which is given by:

$$\alpha_{\max} = 0.00176\theta^2 + 0.008\theta + 2.21372. \qquad \text{(equation 3)}$$

3.4 Drift Detection by Observing Light Buoys with RADAR

The channel width needed for the drift detection by observing light buoys with RADAR can be calculated by:

$$W_m(R) = \frac{W_{buoy}}{\sin\theta}\sin\gamma \qquad \text{(equation 4)}$$

where

γ : error of direction observation by RADAR.

The following expressions are easily written from equation 4 for two cases of γ = 2deg. and 1 deg. respectively.

$$W_m(R) = 0.0349\frac{W_{buoy}}{\sin\theta} \ (\gamma : 2 \text{ deg.}) \qquad \text{(equation 5)}$$

$$W_m(R) = 0.0175\frac{W_{buoy}}{\sin\theta} \ (\gamma : 1 \text{ deg.}). \qquad \text{(equation 6)}$$

3.5 Drift detection by GPS

In vessel manoeuvring operations with the utilization of GPS, a vessel handler may judge and recognize the vessel position by an image of GPS information displayed on an electric chart. Although image information on the electric chart is sufficiently accurate, the drift detection is made solely by perceiving a vessel movement on the display with the naked eye, and some amount of perception error should be taken into account. As for drift detection by means of GPS, an assumption is made for the above perception error to be a half of the vessel's breadth. In addition, the margin of error for GPS information error is assumed to be 30 meters for a standard GPS and none for a D-GPS. Therefore the channel width needed for drift detection by GPS and D- GPS can be calculated by the following equations, respectively:

$W_m(GPS) = 0.5B + 30$ (unit: meter) (equation 7)

$W_m(D - GPS) = 0.5B$ (unit: meter). (equation 8)

In addition, it is noted that the channel width needed for drift detection by GPS should be designed with careful consideration of the risks involved in using GPS and GPS-related equipment.

4 REFERENCES

[1] Ohtsu,K., Yoshimura,Y., Hirano,M., Tsugane,M.and Takahashi,H.: Design standard for fairway in next generation. Asia Navigation Conference 2006, No.26, 2006.

[2] The Japan Port and Harbour Association: Technical Standards and Commentaries of Port and Harbour Facilities in Japan,2007.(in Japanese)

ANNEX C AtoN DESIGN FOR THE RIO DE LA PLATA NAVIGATION CHANNEL

The Rio de La Plata Navigation Channel is a partly straight and partly curved channel with buoys from a position of 129.1 miles seawards of the harbour entrance of Buenos Aires.

More data can be seen on the following chart.

1 SOME BASIC DATA

Waterway in analysis	
Length:	63.8 M
Width:	100 m (one way channel) (there is a two way channel sector of 160 m)
Design Depth:	34 feet
Tidal range	0.60 m

2 THE VESSEL TRAFFIC

Total Traffic in the Area in 2006: including	7.760 vessels
Container vessels:	1,726
Bulk Carriers:	3,134
General cargo:	962
Oil Tanker:	1,386
Other:	552

3 MAXIMUM SIZE OF VESSELS DIMENSIONS:

	Length BP	Beam	Design Draught
Container vessel	261 m	40 m	41 feet
Bulk carrier	260 m	42 m	42 feet
Tanker	241 m	32.2 m	49 feet

4 AtoN

The buoyage system is designed as 'paired buoys' with the following parameters:

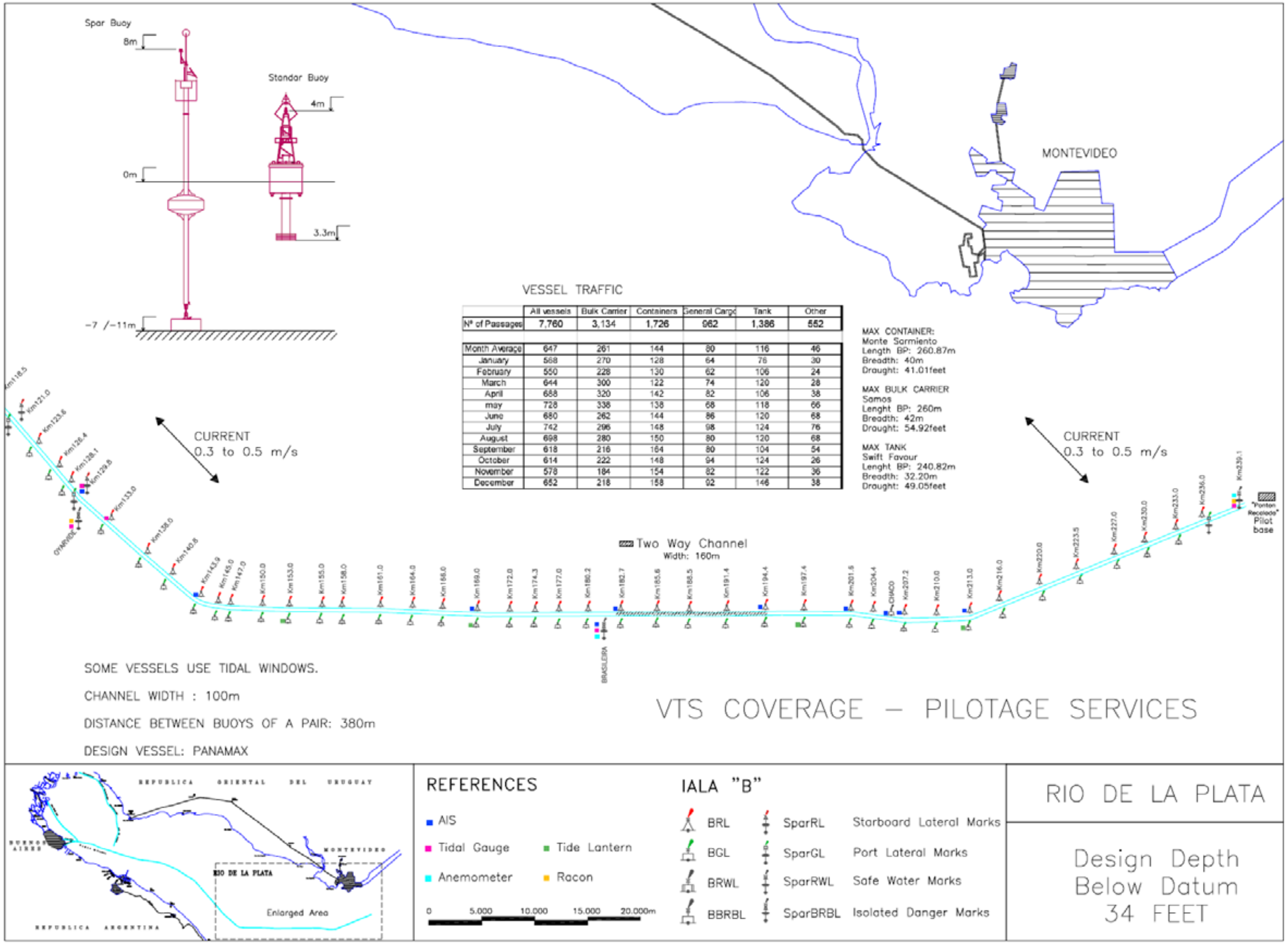
Buoy separation distance	average 3000 m (max 5.000 m, min 1.100 m)
Buoy types	Floating buoys and Spar Buoys
Floating Buoy size above water level	4 m
Spar Buoys size above water level:	8 m

Additionally there are the following AtoN:

DGPS coverage (on demand- private service)

VTS and AIS control by Prefectura Naval Argentina (National Coast Guard)

Mandatory Pilotage services



	All vessels	Bulk Carrier	Containers	General Cargo	Tank	Other
Nº of Passages	7,760	3,134	1,726	962	1,386	552
Month Average	647	261	144	80	116	46
January	568	270	128	64	76	30
February	550	228	130	62	106	24
March	644	300	122	74	120	28
April	688	320	142	82	106	38
may	728	338	138	68	118	66
June	680	262	144	86	120	68
July	742	296	148	98	124	76
August	698	280	150	80	120	68
September	618	216	164	80	104	54
October	614	222	148	94	124	26
November	578	184	154	82	122	36
December	652	218	158	92	146	38

Figure 3 AtoN design on the Rio de la Plata

ANNEX D AtoN DESIGN - FINLAND

1 MUSSALO

FAIRWAY DATA Alignment and buoyage: The channel starts SW of Kotka Lighthouse and runs in a NE direction. E of the edge mark Kaakkoniemi it turns northwards towards the Deep Harbour of Kotka. Length 51 km/28 nm. 5 navigation lines, marked by boards and sector lights. Cardinal marks in the channel, lateral marks in the harbour. Lit. Dimensions: Design vessel: bulk carrier 125 000 DWT, l = 300 m, b = 48 m, t = 15.3 m. Authorised draught 15.3 m, safe clearance depths (MW 90) 18.4 m, along the navigation line in the harbour 17.5 m. Minimum width 200 m. Anchorage areas etc.: Anchorage NE of Kaunissaari, close to crossroads. Safe clearance depth - 18.4 m.
NAVIGABILITY Navigational conditions: The approach as far as the island Viikarinsaari consists of open sea, unsheltered against E–S–SW winds. Navigation may be hampered by strong winds and sea state. The channel is at its narrowest at the edge mark Elo 2, where it is only 510 m wide. Along the navigation line in the harbour the width is 200 m. RECOMMENDATIONS (channel) Speed: Vessels sailing at maximum draught should take the squat effect into account; design speed 16.5 knots (Sc 18.4) in the approach, 13 knots (Sc 17.5 m) in the harbour.
TRAFFIC SERVICE Pilotage: Pilot order, tel. +358 204 48 5604. Pilot boarding position 60°07.49\, 26°29.65\. Pilotage distance 25 nm. VTS: Kotka VTS, VHF Channel 67. Tugs: Provided by Alfons Håkans Ltd. Ordered by pilot, if required.
PORT Quays: A Quay: length 609 m, safe clearance depth 15.0 - 17.5 m; B Quay: length 500 m, safe clearance depth 11.7 m; C Quay: length 936 m, safe clearance depth 11.7 m; Liquid Bulk Terminal, berth N 1: length 69 m, safe clearance depth 15.0 m; Liquid Bulk Terminal, berth N 2: length 60 m, safe clearance depth 11.5 m. Cargo handling: A Quay – four cranes (40 t), B Quay – two cranes (40 t) and a mobile crane, C Quay – four cranes (50 t). Harbour basin: Speed of vessel to be regulated to ensure that no harm or damage is caused.
CONTACTS VTS: Kotka VTS tel. +358 204 48 5604 fax +358 204 48 5600 Port: Port of Kotka tel. +358 5 2344 280 fax +358 5 2181 375

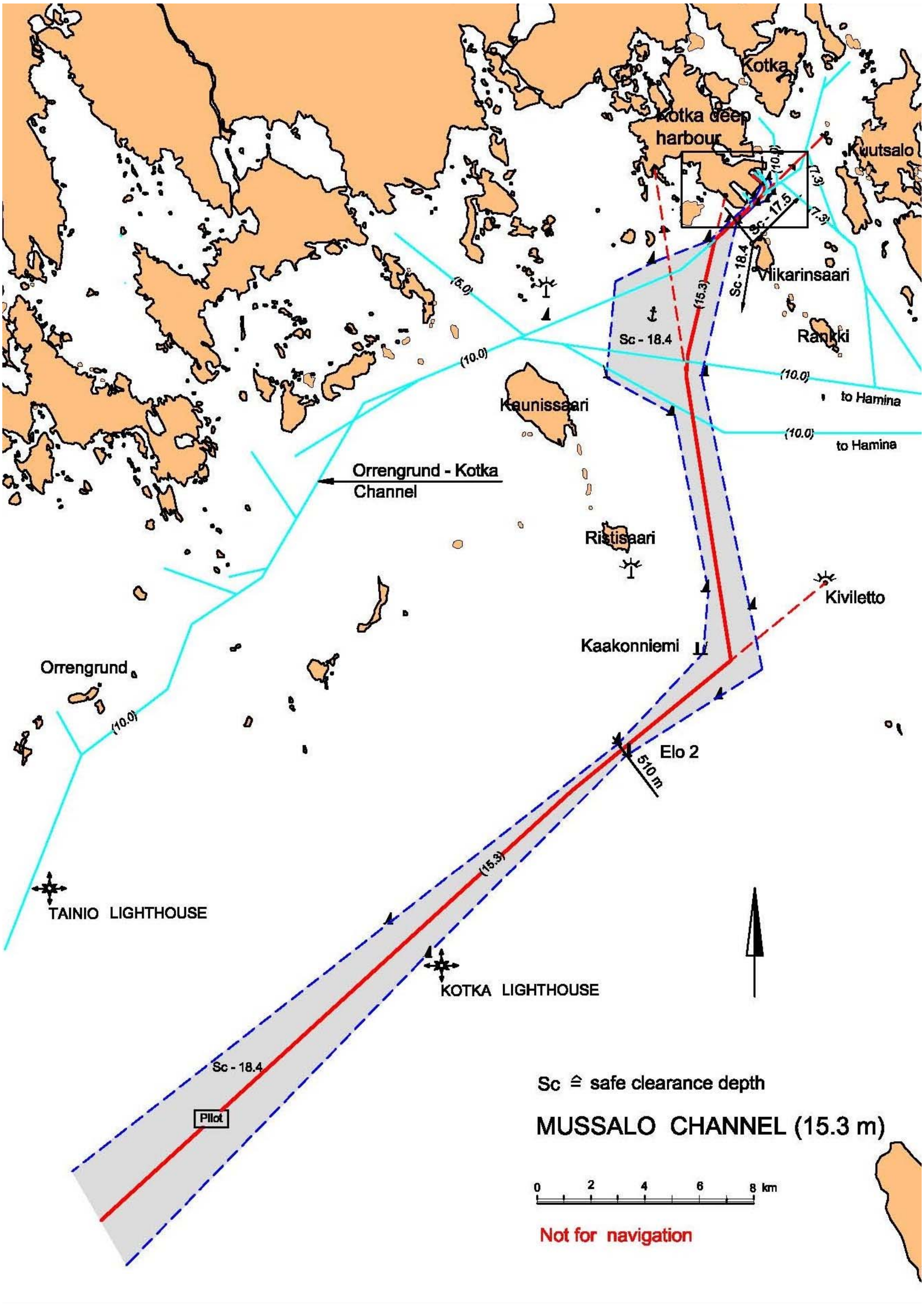


Figure 4 Mussalo Channel

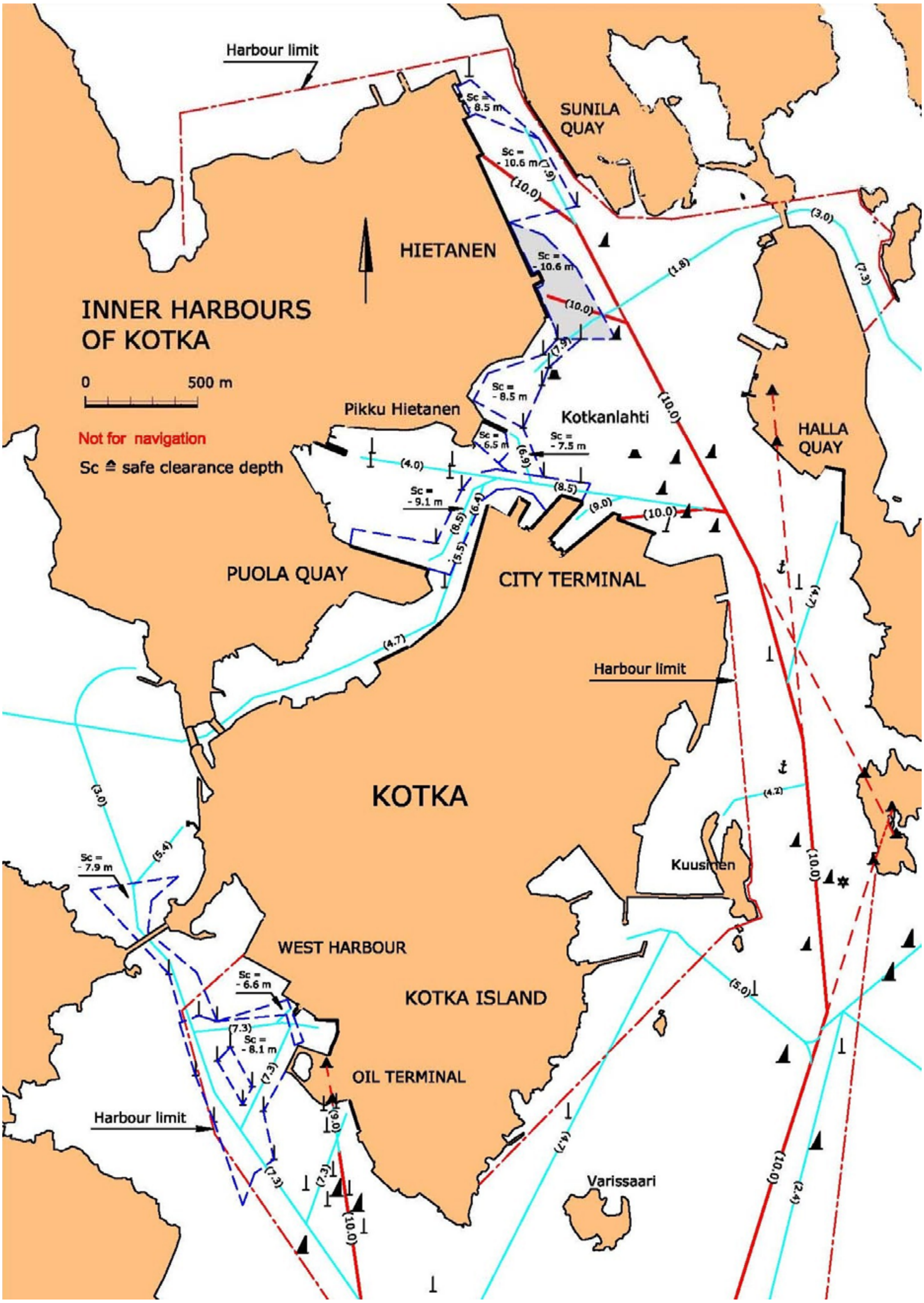


Figure 5 Kotka inner harbours

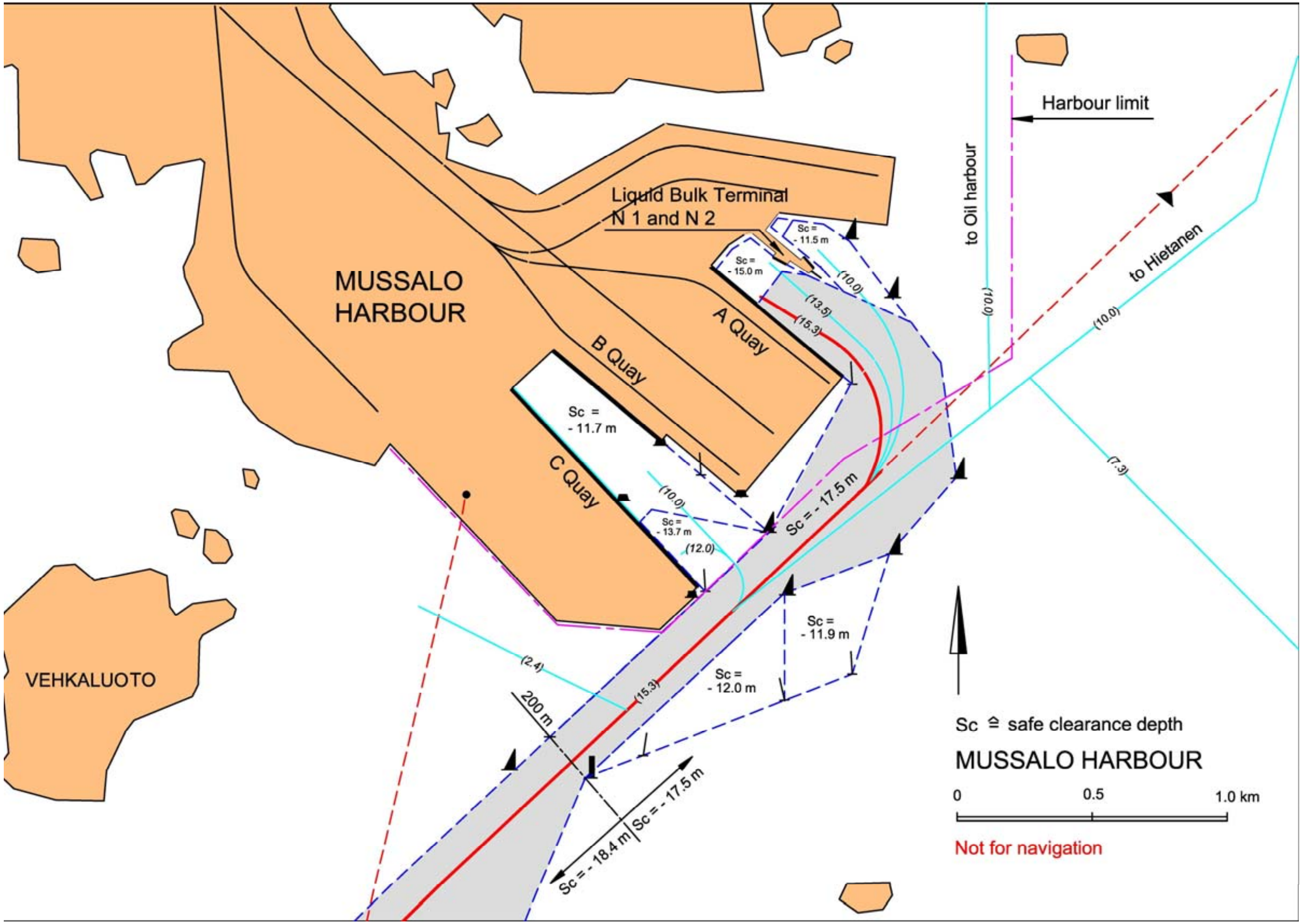


Figure 6 Mussalo Harbour

2 RAUMA

2.1 Rauma Channel

CHANNEL DATA

Alignment and buoyage: V of Rauma Lighthouse – port. Four lines. Length approx. 26 km/14 nautical miles. Lateral marks. Lit.

Dimensions: Design vessel: Ro-Ro vessel, L = 210 m, B = 30 m, T = 10.0 m. Maximum authorised draught 10.0 m, safe clearance depth (MW95) in the outer channel -12.0 m, in the inner channel -11.5 m. Minimum width 120 m, in the passage of Kovankivet 160 m; minimum bend radius 1000 m; design speed in dredged passages 12 knots.

Anchorage and other special areas: In the outer channel, anchorage W of Rauma Lighthouse; beware of cable S of lighthouse. In the inner channel, anchorage and passage either in the widened area N of Rihtniemi or SW of Iso Järviluoto, approx. 1.5 km before arrival into port.

NAVIGABILITY

Navigational conditions: The outer channel to Rihtniemi is unsheltered and open to S-W-N winds. From Rihtniemi on, the channel continues as a narrow and densely marked channel, sheltered by isles, islands and mainland. Cross currents, which make the manoeuvring of large vessels more difficult, may occur when navigating the Urmluoto line in the passage of Kovankivet. Strong side winds also aggravate the side drift.

Ice conditions: In winter ice fields tend to move in the channel, outside Hylkikarta. Ice movement may cause buoys to be pressed beneath the surface and their lighting devices may be damaged.

OPERATIONAL RECOMMENDATIONS (channel and harbour)

Wind: Max. speed of drifting wind gusts 18 m/s in daytime and 15 m/s at night. Limits lower for Ro-Ro vessels and vessels in ballast. Max. wind gusts 11 m/s for vessels in ballast, larger than the design vessel. Drifting wind means a wind which differs from the Urmluoto line by more than 30°. Pilotage is discontinued when the wind speed exceeds 20 m/s.

Visibility: The Urmluoto lines should be visible at night.

Vessel-specific recommendations: Vessels larger than the design vessel and vessels with poor manoeuvrability are piloted only in daytime.

New authorised channel draught practice applied in the channel as from July 15th, 2005 (NtM 17/2005, 20.6.2005).

TRAFFIC SERVICE

Pilotage: Pilot order, tel. +358 204 48 6645. Pilot boarding position 61°07,5', 21°10,4'. Pilotage distance 10 nautical miles.

VTS: West Coast VTS, Channel 67

PORT

Quays: Petäjäs: length 445 m, safe clearance depth -11.0 m; Iso-Hakuni: 6 berths alongside/Ro-Ro berths, safe clearance depth -11.0 m; Oil harbour: safe clearance depth -9.15 m; Central harbour: length 665 m, Ro-Ro berth, safe clearance depth -6.70..-7.30 m; Laitsaari: length 246 m, safe clearance depth - 9.05 m; Inner harbour: 2 chemical piers, safe clearance depth -5.10..-7.05 m.

Cargo handling: Petäjäs: cranes 40 t, 45 t and 16 t, pneumatic grain suction device; Iso-Hakuni: cranes and reach stackers; Oil harbour: piping, pumping power 1000 t; Central harbour: crane 6 t. Vehicle mounted cranes (50 and 100 t) used in all parts of the port.

CONTACT INFORMATION

VTS: West Coast VTS, Pori	Tel. +358 204 48 6645 Fax +358 204 48 6646
Port: Port of Rauma, Rauma	Tel. +358 2 83 44 710 Fax +358 2 822 63 69 Port Director Hannu Asumalahti

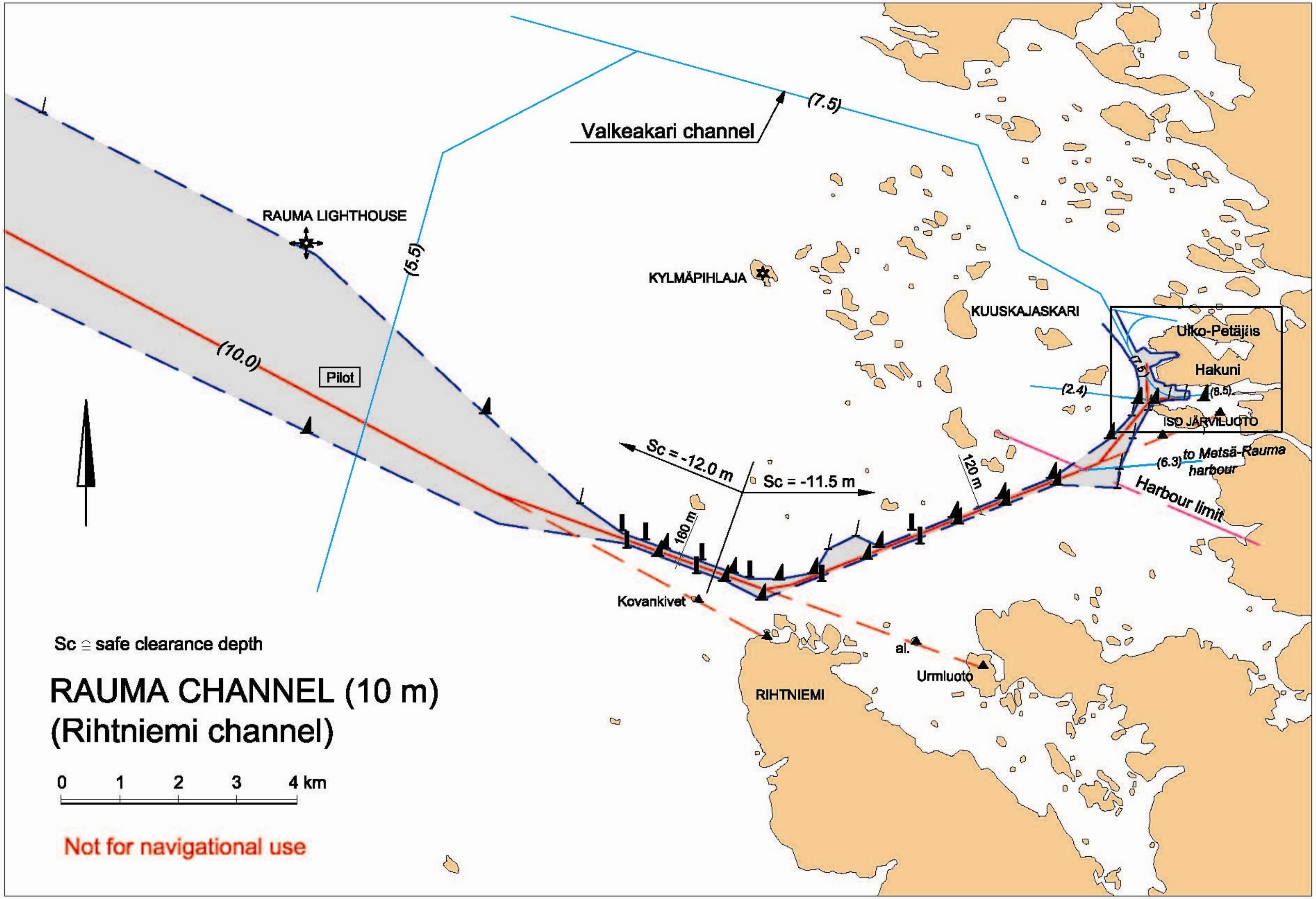


Figure 7 Rauma Channel

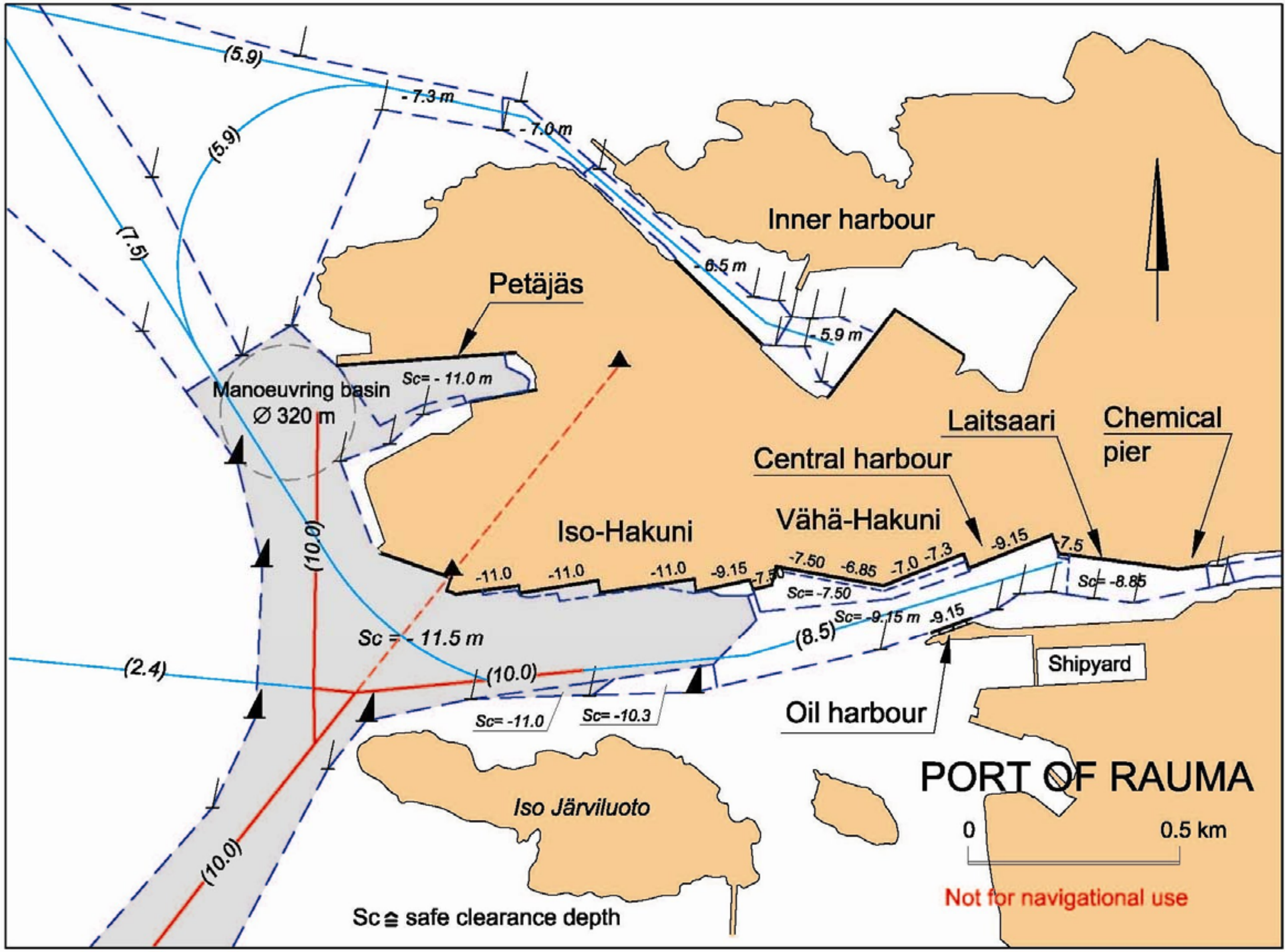


Figure 8 Port of Rauma

ANNEX E ATON DESIGN FOR LE HAVRE AND PORT 2000, FRANCE

Le Havre (1st port in France) is a deep-water port with day and night access for the largest container carriers (10,000 TEUs and more).

Located at the south end of the port, the facilities of the Le Havre oil port are made up of 8 specialised berths, including two for the reception of 230- 280,000dwt tankers.

Recently, a new external port (Port 2000 terminals) able to welcome and rapidly handle the largest container carriers in the world in optimal logistic and nautical conditions has been created.

The area is also one of the major places for pleasure and fishing craft in the region.

1 THE VESSEL TRAFFIC (PER YEAR)

Total traffic flow:	80 million tons
Container traffic flow:	2.5 million TEUs
Oil:	40 millions tons
Roll-on/roll-off services:	472 000 vehicles
Passengers:	355 000
About 7 500 vessel calls	

2 MAIN WATERWAY IN ANALYSIS

Length:	12 nautical miles from the landfall buoy to the main entrance
Width:	450 metres (two-ways channel)

3 PORT 2000 WATERWAY

Lenght:	3 nautical milles
Width:	350 metres (two-ways channel for vessels up to 55 m beam)
Design Depth:	15 meters + tide
Tidal range:	8,00 metres

4 AtoN

The buoyage system is designed as ‘paired buoys’ with the following parameters:

- Buoy separation distance average 1400 m (max 2 000 m in the entrance , minimum 1.000 m at Port 2000);
- Buoy types: 18 Floating buoys and 3 fixed beacons (LH 17, 18 & 21) for the marking of the effective width of the fairway (EWF);
- Floating Buoy size above water level: 3,5 m with a luminous range of 3 miles by night;
- Beacons size above the highest water level: 5 m.

All the lights are synchronised by paired buoys and sequenced (timing method GPS)

Additionally there are the following AtoN:

- Leading lines covering the main channel up to the landfall buoy (front light height 36 meters and range 25 Miles by night rear light height 78meters and range 25 miles by night) operated night and day;
- A very precise PEL Sector light with oscillating boundary for the Port 2000 channel (5 sectors in 5°) operated night and day;
- Various Sector lights in the port;

- DGPS coverage;
- VTS and AIS control by The port of Le Havre Authority;
- AIS Aton on the landfall buoy;
- Mandatory pilotage services.

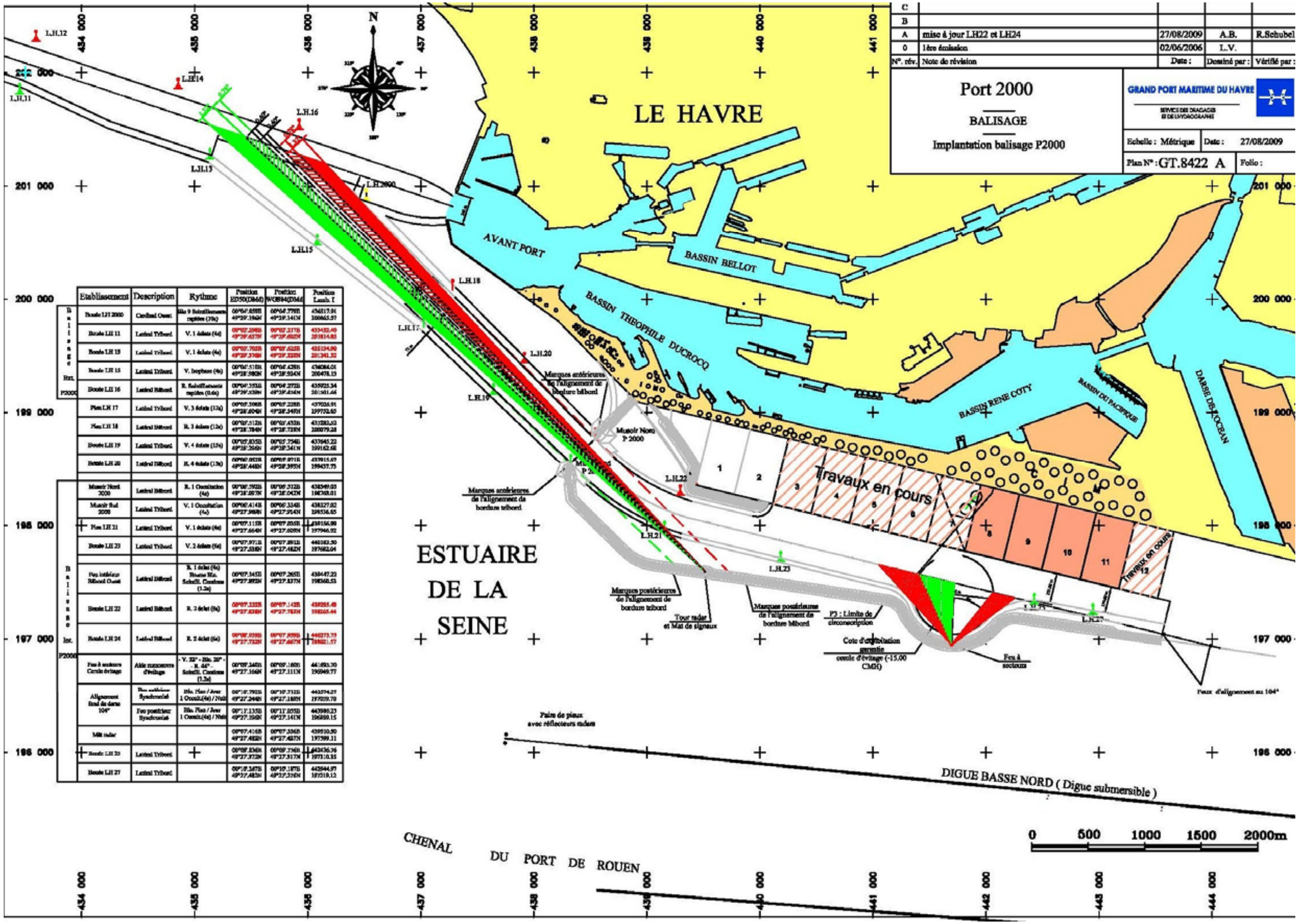


Figure 9 Port of Le Havre

ANNEX F AtoN DESIGN FOR THE 'SEEKANAL ROSTOCK'

The Seekanal Rostock is a straight channel with buoys from a position 6 miles seawards of the harbour entrance of Rostock/ Warnemünde leading into the mouth of the river Warnow with following design data:

1 WATERWAY

Outer part:

Length:	5.7 M
Width:	225 … 120 m
Depth:	≥ 14.5 m

Inner part:

Length:	1.5 M
Width:	120 m
Depth:	≥ 14.5 m

2 VESSEL TRAFFIC

Total Traffic in the Area in 2006:	25.200 vessels
including	
Passenger- and Ro/Ro Ferries:	13,000
Cargo vessels:	4,500
Oil Tanker:	1,800

The area is also one of the major places for pleasure and fishing craft in the region.

3 VESSELS DIMENSIONS

Terms for two lane traffic passing 120 m width area:

1 Beam < 40 m – sum of both passing vessels and

Draught < 8.5 m

2 If wind < 6 Bft and both captains accept a two lane traffic passing and

Beam < 60 m – sum of both passing vessels beams and

Draught < 8.5 m

3 vessel with draft > 8,5 m and using the leading line

X = 60 m – 0.5 * beam of this vessel

MAX beam of the meeting vessel X/5 (opposite direction)

All other vessels have to pass by 'one lane traffic' under the responsibility of the captain with assistance of VTS.

4 MAXIMUM SIZE OF VESSEL IN 'SEEKANAL ROSTOCK'

Length	296.0 m
Beam	32.0 m
Draft	10.5 m

The channel is narrow in relation to the vessels dimensions.

5 AtoN

The buoyage system is designed as ‘paired buoys’ with the following parameters:

Buoy separation distance	Outer Part	1500 … 1000 m
	Inner Part	600 m

Buoy type Outer Part: deep water light buoy ‘LT 81’, steel mooring chains

Inner Part: hinge beacon with steel tube, with a minimal swinging circle radius, synchronised lights

Buoy size above water level	Outer Part:	2.5 x 5 m
	Inner Part:	1 x 4 m

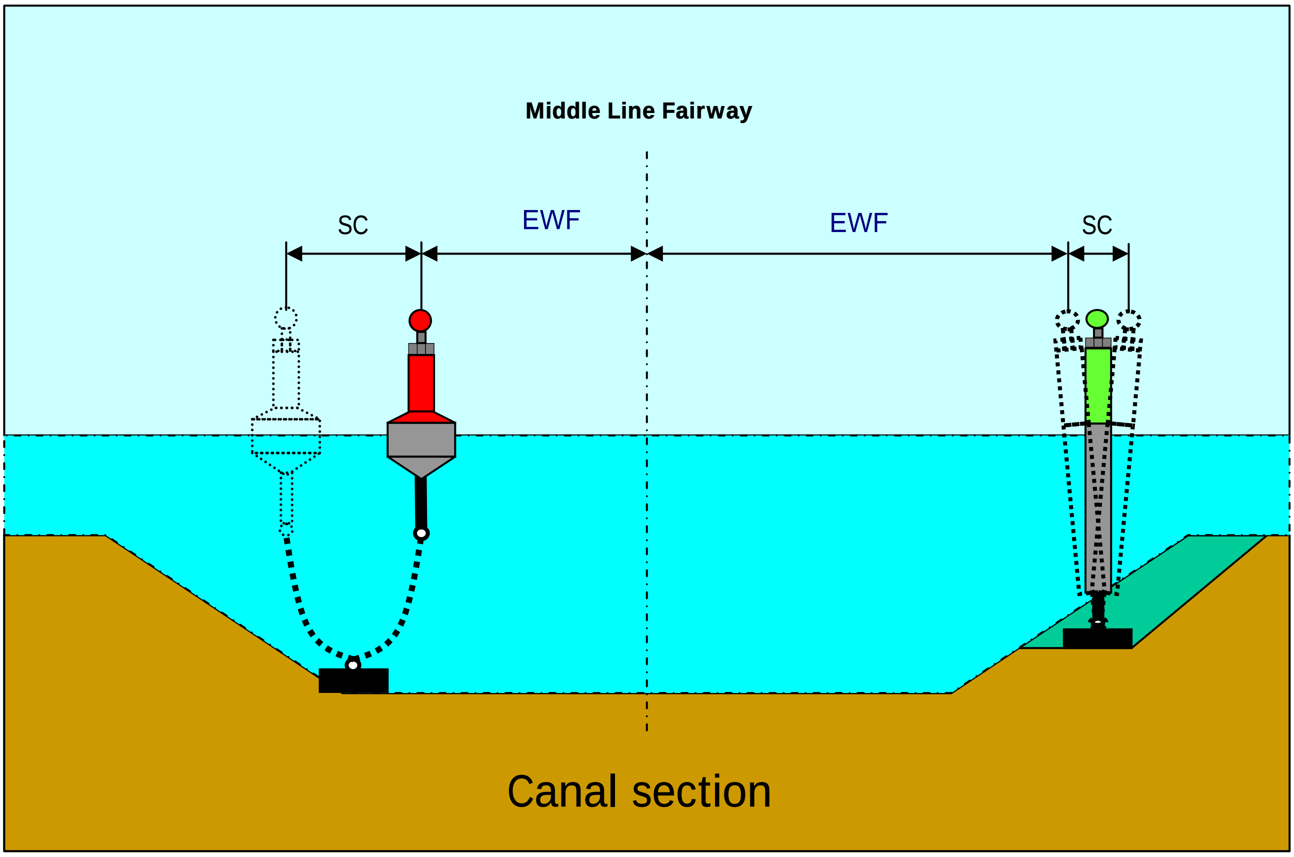


Figure 11 Seekanal Rostock – canal section

The inner part of the canal is designed with Hinge Beacons because they have a smaller swinging circle and thus cause less reduction of the effective width of fairway.

Additionally there are the following AtoN:

- Leading Lights over 4 miles, DGPS coverage, VTS coverage, AIS coverage;
- The Leading Lights are synchronized (same character for front light and rear light).

To avoid misleading information in case of failure of one of the lights by mirroring a light with the same character on the water surface and be interpreted as a front light in the wrong place, in case of failure of either the front light or the rear light the other one will also be switched off. This is ensured by connecting the remote control devices of the front light and the rear light.

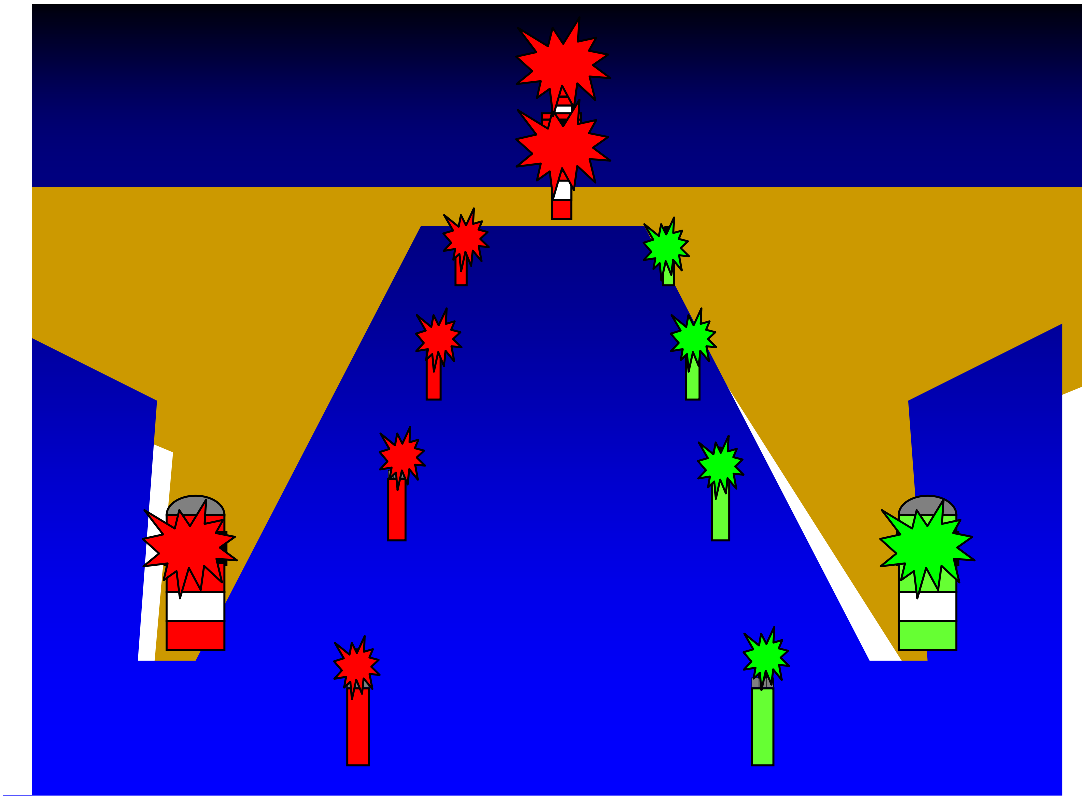


Figure 12 Example for synchronized AtoN : Inner part of 'Seekanal Rostock'

The Leading Lights are synchronized with the mole lights and the buoys as shown in Table 2.

Table 2 Synchronization of AtoN

	1s	2s	3s	4s	Flash code
Leading lights	X	On	On	On	Occ. 4s
Mole lights at canal entrance	X	X	On	On	Iso. 4s
Articulated lights on buoys	X	X	X	On	Fl. 4s

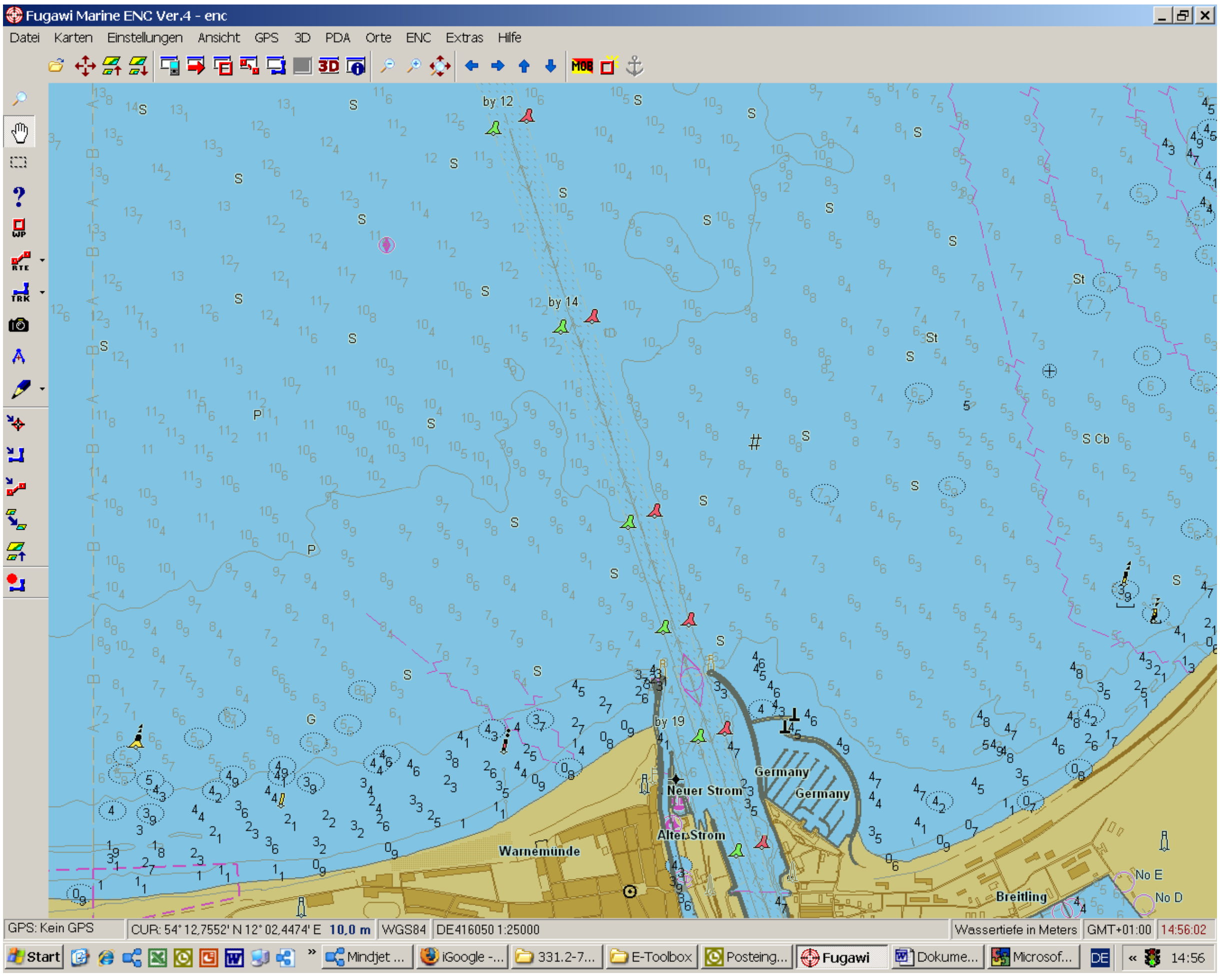


Figure 13 Sea Chart of a part of the outer and inner channel 'Seekanal Rostock'

ANNEX G ATON DESIGN FOR THE APPROACH TO MALMÖ, SWEDEN

The Port of Malmö is located on the west coast of the southern part of Sweden. The port is approached from the sea through a channel marked by buoys, light buoys, lights and beacon, on the alignment of leading lights. The channel layout is based on a simulation that was carried out in November 2006 in order to evaluate risk and conditions in terms of vessels types and sizes, tug capacity, port and channel layout.

Waterway

Outer part
Length: 3.9 nm
Width: The channel has been widened to 162 m for its full length.
Depth: 13.5 m

Inner part
Length: 0.6 nm
Width:
Depth: 13.5 m

Vessel Traffic
Total Traffic in 2008: 1102 arr/dep

Vessel Dimensions: 260 x 40 x 12.5 m

AtoN

The buoyage system is designed as ‘paired buoys’.

Buoy separation distance Outer part: 0.3 nm
Inner part: 0.1 nm

All buoys in the channel have synchronized lights with the same frequency at the same time. The light rhythm for the buoys in the channel is Q (0,2s + (0,8s) = 1s) on both sides of the channel. The buoys are of type ‘S-7’ (light is 4 m above surface of water). The placement and the synchronised flash on the buoys in the layout is an advantage for safe navigation during darkness as it is much easier to see as the darkness period is very short.

The position of the leading light has been optimized according to new channel layout and the blink rate has changed to Oc 6s. There are two lights in line, marking the sides of the channel with the light rhythm Q. The quality of the centre line has improved with a modern high visible light. This improves safety for navigation in restricted visibility.

These improvements have made navigation in darkness much safer.

Additionally

DGPS coverage, VTS, Mandatory pilotage services etc.

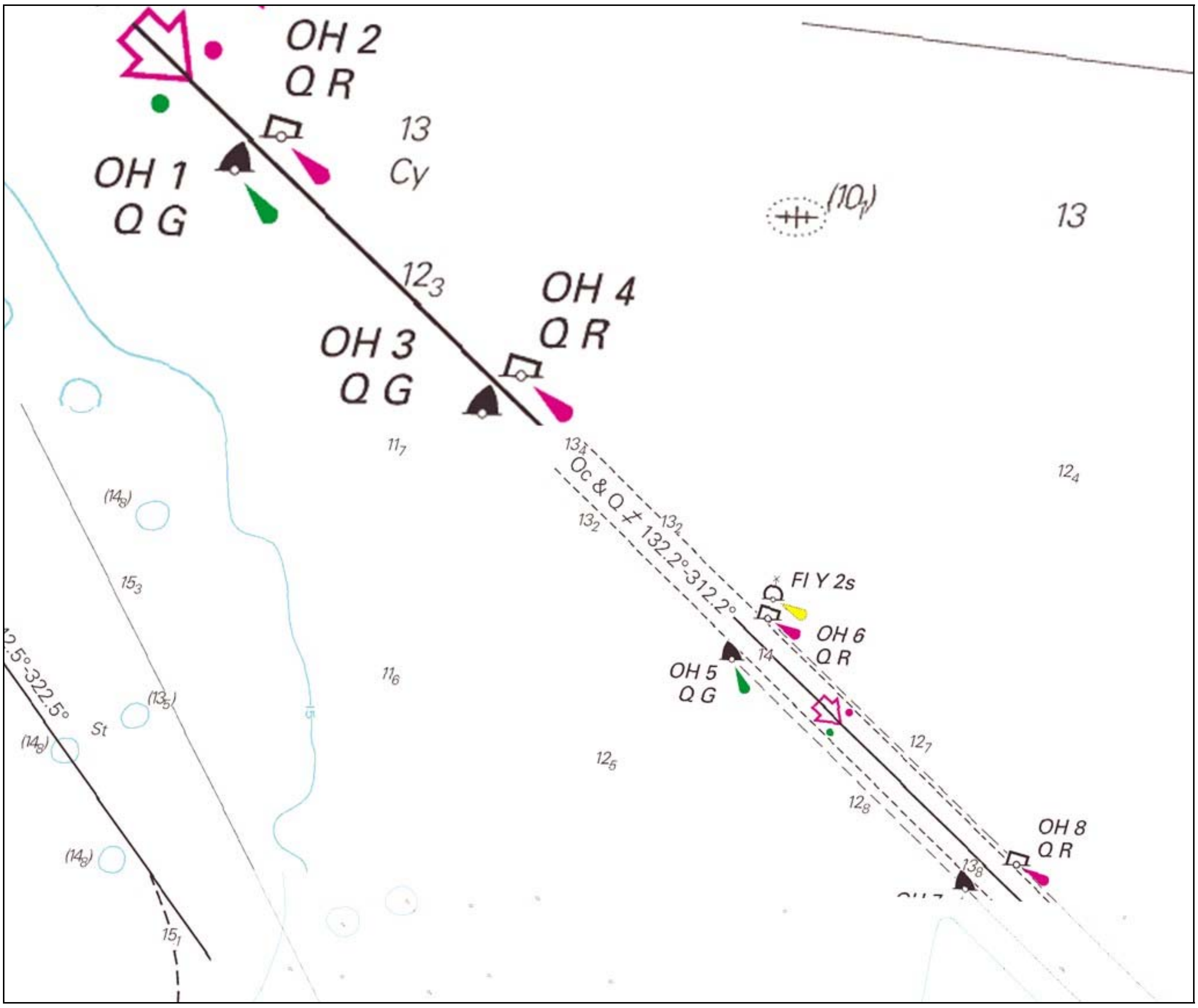


Figure 14 Outer part of channel - Malmo

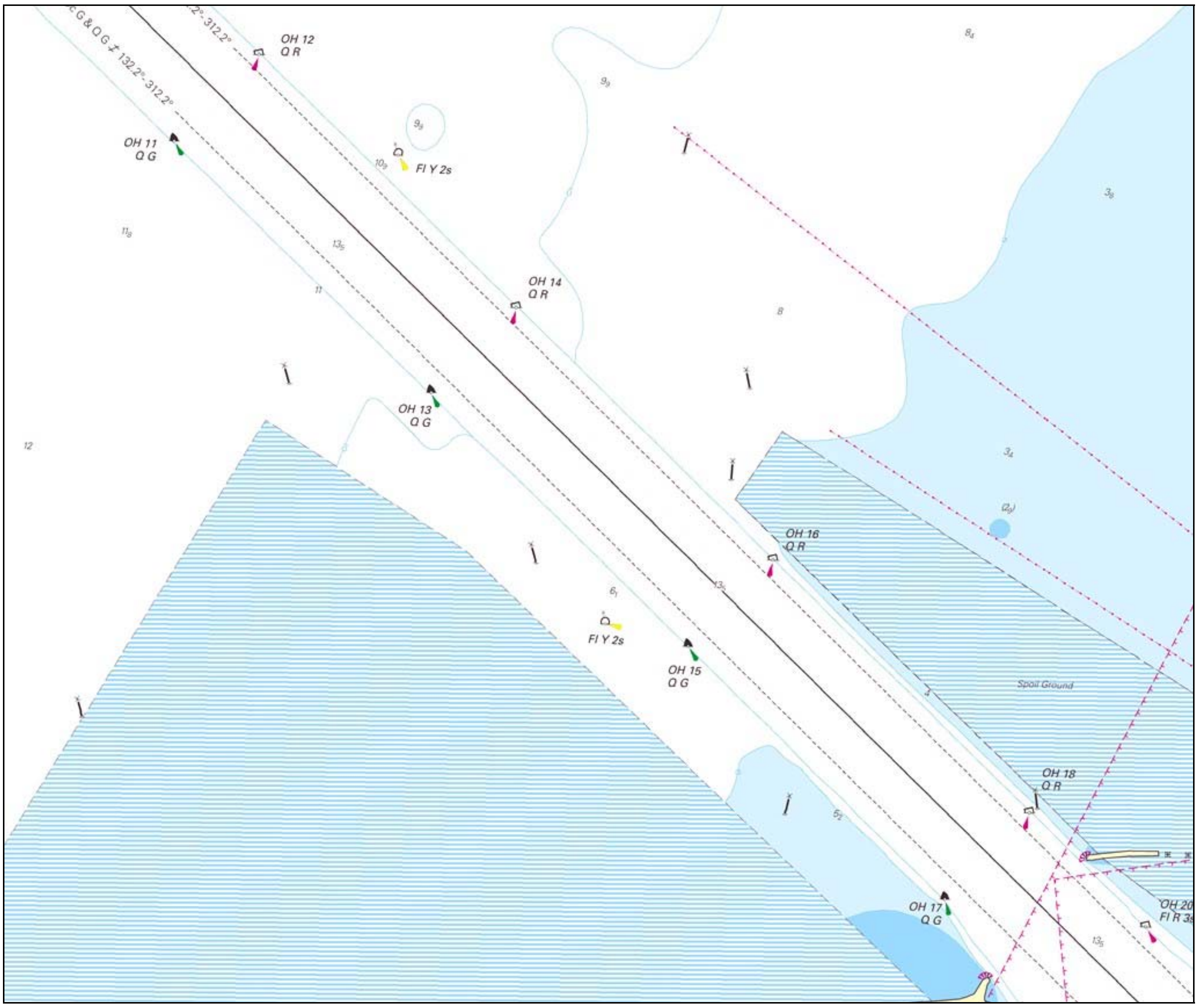


Figure 15 Inner part of channel - Malmo

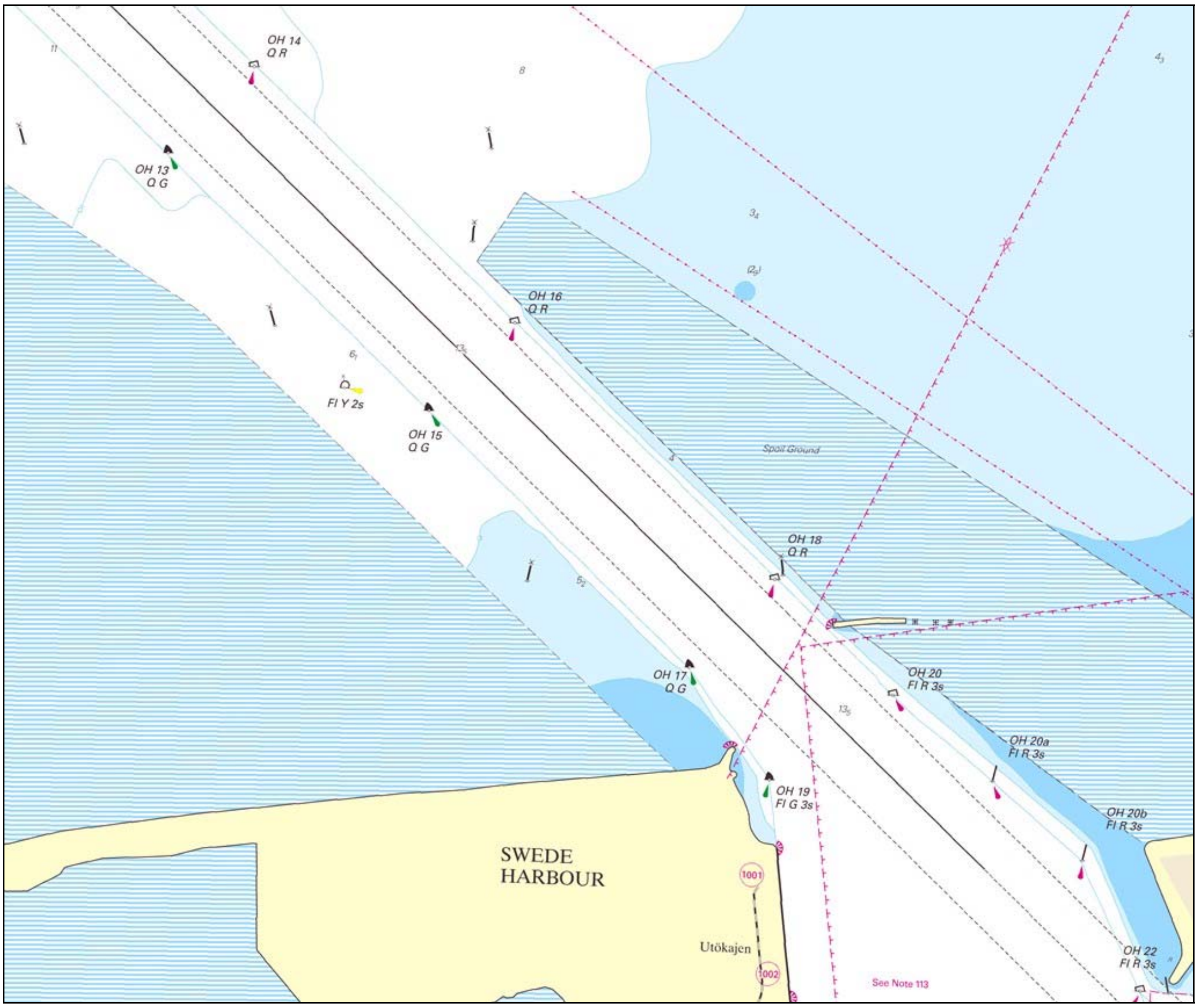


Figure 16 Entrance to Malmo Harbour

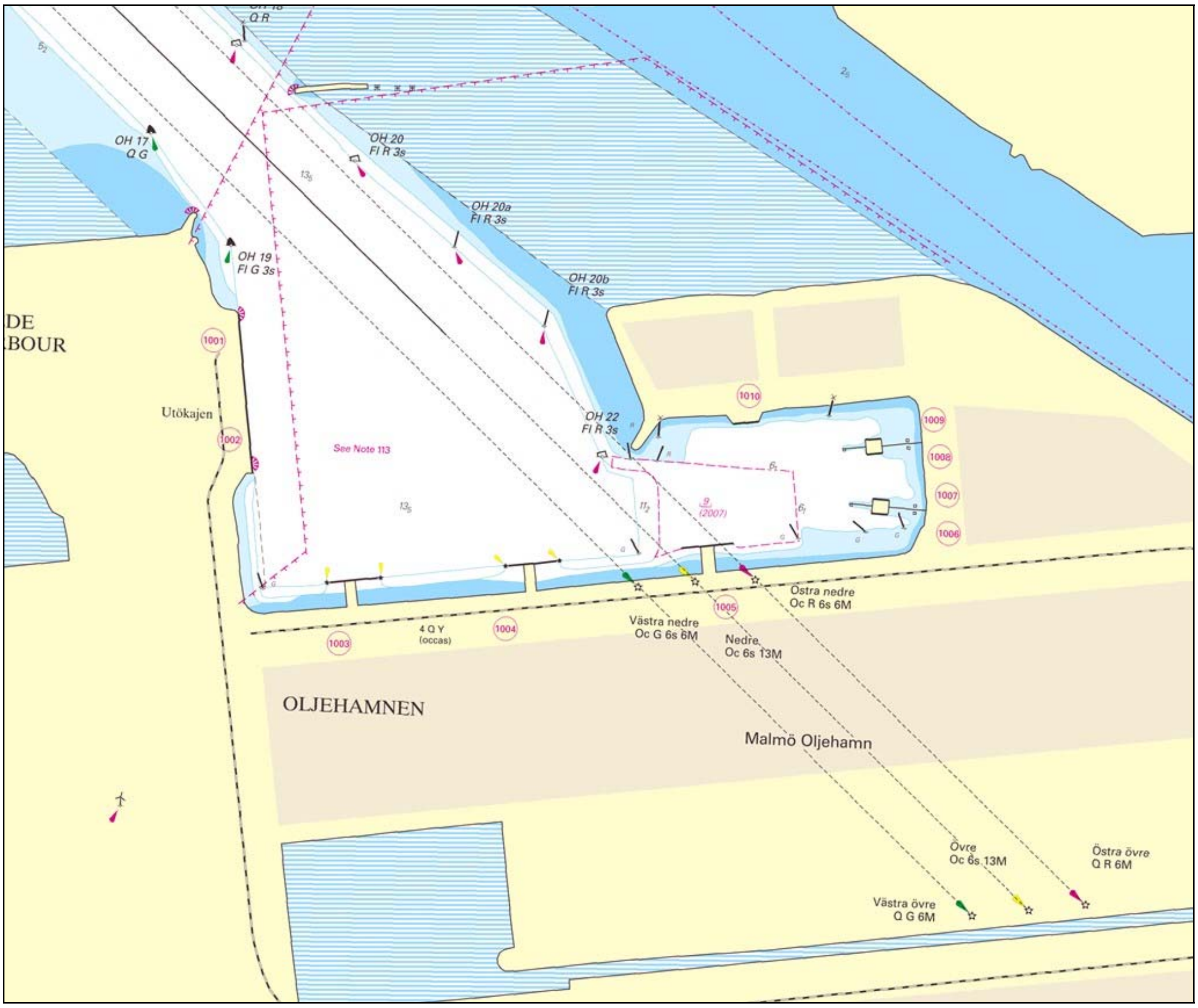


Figure 17 Malmo Harbour