TRANSLATED VERSION OF THE ORIGINAL SPANISH TEXT

SERIES 3 Planning management and operation in port areas

RECOMMENDATIONS FOR MARITIME WORKS

ROM 3.1-99

Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins

GOBIERNO DE ESPAÑA
MINISTERIO DE FOMENTO
Puertos del Estado

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INDEX

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Recommendations for the Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins

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Foreword

With the publication of the «Recommendations for the Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins» (ROM 3.1-99), Puertos del Estado is materializing one of the Codes anticipated in 1987 when the ROM (Recommendations for Maritime Works) Programme was started by order of the former Directorate General for Ports and Coasts of the Ministry of Public Works and Urban Development.

These new recommendations strengthen the concept of port operability as a basis for laying down design criteria for the maritime configuration of ports, their approach channels and harbour basins. Therefore, ROM 3.1-99 does not just set mandatory maritime-port safety requirements but also seeks to guarantee minimum vessel navigation and manoeuvrability conditions in port waters and, finally, contribute to optimise the operating system of the different port areas attending to vessel traffic.

With this in mind, the main purpose of this ROM 3.1-99 is to design and build the maritime configuration of ports, their approache channels and harbour basins. Whilst not constituting a Regulation for Maritime Operation of these areas, the ROM 3.1-99 may easily be applied to this end, taking into account the fact that the maritime configuration of ports has to guarantee the limit operating conditions to be established for different vessel manoeuvring in port waters.

To this end, and within its scope of application, the ROM 3.1-99 echoes the major, methodological renewal effort that Puertos del Estado has addressed for the whole ROM Programme, one of whose supports is precisely to make safety requirements compatible with those of functionality. The design of the cross section and the layout of vessel navigation and manoeuvring areas in ports calls for the external actions envisaged during the service period of these areas to be taken into account as well as the predicted vessel traffic and types. This circumstance provides the content of this ROM 3.1-99 with a functional view more adaptable to the integral planning process of maritime-port construction.

These Recommendations reflect this modernizing effort and make use of the whole rich flow of technology currently existing in the field of vessel manoeuvrability and of the interaction of such vessels with their physical environment (wind, waves and current). To this effect, a suitable path is opened for the rational use of probabilistic methods, simulation techniques and scale model testing for full characterization of the most frequent manoeuvring of vessels operating in ports.

The use of the most advanced technology in the maritime-port field for designing approach channels and harbour basins allows the user of these Recommendations, whether a planner, designer or builder, to propose a calculation methodology adaptable to the targets and the available resources, without detriment to setting minimum general requirements. In this way, the ROM 3.1-99 is configured as an open instrument which proposes advanced calculation lines coherent with the general provisions of international organizations (IMO, IMMA, etc.) and committed to achieving a high standard of safety and operability in our port waters.

Madrid, June 2000

Introduction

The Recommendations for «Recommendations for the Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins» (ROM 3.1-99) are inscribed in the ROM, Recommendations for Maritime Works Programme as undertaken by Puertos del Estado. The Programme started in 1987 when the first Technical Commission was formed. Its mandate was to draw up a set of recommendations bringing together the most advanced technology in the field of maritime and port engineering, which would become a technical instrument for designers, supervisors and builders, whilst providing different State entities and private enterprises with authority or interests in maritime engineering with easy access to the specialized information necessary for undertaking their work.

Forming Technical Committees with some of the most acknowledged specialists in each field of maritime and port engineering guarantees the process as a mechanism for consolidating experience and technology in existing ports in Spain and as a starting point for future undertakings.

Up to the present time, the ROM has become an instrument of general use on the part of Port Authorities, Autonomous Region Gouvernments, official agencies and businesses with interests in Maritime Engineering, as well as Spanish Civil Engineering Schools. Its dissemination is currently international in scope, particularly in Europe and Latin America, as it serves some Port Authorities and Official Agencies with authority in port matters in other countries as a basic document for defining technical criteria and quality and safety levels as required in their infrastructure works.

The following Recommendations have been published and have been in force since the first ROM Programme Recommendations were published in 1990:

- **ROM 0.2-90:** Actions for the Design of Maritime and Port Works*.
- **ROM 0.3-91:** Environmental Actions I: Annex I: Maritime Climate around the Spanish Coast*
- **ROM 0.4-95:** Environmental Actions II: Wind.
- **ROM 0.5-94:** Geotechnical Recommendations for the Design of Maritime and Port Works*
- **ROM 3.1-99:** Recommendations for the Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins.
- **ROM 4.1-94:** Recommendations for the Design and Construction of Port Pavements*

The ROM 3.1-99 for the «Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins» was drawn up by the Technical Commission appointed to the effect by the Presidency of Puertos del Estado under the organic responsibility of the Directorate for Planning and Management Control. The members of this Commission and the official agencies to which they belong are as follows:

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* Available in English (http://www.puertos.es/es/programa_rom/index.html)

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- ***Programme Secretary:***
  José Llorca Ortega, *Puertos del Estado.*

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  Javier Uzcanga, *Bilbao Port Authority*

ROM 3.1-99, Recommendations for the «Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins» strengthens port operating conditions as a basic reference element, together with safety, to establish design and construction criteria for maritime and port works. To this effect, the factors, actions and effects affecting vessel manoeuvrability in port waters are stressed from two sides:

- From the side of the vessel, the parameters necessary for defining the Design Vessel and factors affecting its manoeuvrability, in particular, its propulsion system, rudder actions, mooring lines, anchors and cable chains and other relevant factors related to mass and inertia.
- From the side of the physical environment, guidelines are established for determining the action of wind, current and waves and their effects, as well as the effects of storms, shallow waters, bank suction and rejection and passing vessels.

The importance of tug boats in port operating conditions and, consequently, in the design of layout and cross section of manoeuvring areas called for a specific chapter to be devoted thereto. Together with characteristic elements and propulsion systems of the tug boats, this chapter defines procedures for calculating towing forces and requirements of tug boats during the process of vessel arrival or departure as a function of the basin dimensions and the operating limit conditions adopted.

The joint action of the factors that characterize a vessel and its environment determines its turning circle and leads to a study of manoeuvring which this ROM 3.1-99 lays down in three phases: initial knowledge of the problem raised by the manoeuvring, selection of the most suitable manoeuvring and study of emergency situations. The consideration of this characterization process of the manoeuvrability is basic for setting the cross section and the layout requirements for maritime port configuration.

From the point of view of the cross section, the **ROM 3.1-99** lays down the basic requirements for water depths in Navigation Channels and Harbour Basins as a function of the factors related to the vessel, water level and seabed. Likewise, requirements are established for above water clearances over basins, determined so that they allow vessels to navigate or to stay in port under safe conditions taking into account the crown levels of the quay, and considering the water levels and vessel and port operation criteria.

The layout requirements show criteria for the geometric definition of the layout of the Navigation Channels, Harbour Basins and other port facilities, whether in maritime, river or lake areas. In particular, requirements for the following Navigation and Basins areas are set as a function of all factors, actions and effects considered, and taking into account the general provisions issued in this matter by the International Maritime Organization (IMO):

- Fairways, including shipping routes, approach channels and inland navigation canals.
- Harbour entrances.
- Manoeuvring areas, including zones necessary for vessel stopping and turning.
- Anchorages and outer harbours.
- Mooring berths and buoys systems.
- Basins and quays.
- Emergency areas.
- Special facilities (shipyards, locks, etc.).

In general terms, the line of modernity with which these Recommendations are directed is justified in the need to improve a model of safety-risk assessment for maritime-port works, which can contribute to fix more and more accurate criteria as a function of the available information. Specifically, the establishment of minimum safety requirements corresponds to a risk assessment which requires the progressive introduction of statistical models to analyse multivariate functions and the use of simulation models to represent with accuracy the real casuistic of the manoeuvrability of vessels as a function of their characteristics and the external actions on them.

In this direction, ROM 3.1-99 incorporates a chapter devoted to numerical models and simulators of vessel manoeuvring which presenting the state-of-the-art in this matter, analyses the field of applicability of each one and finally recommends a methodology for the use of simulators. Therefore, ROM 3.1-99 encourages technological development, whilst recommending the fulfilment of minimum general requirements which should be taken as a «Good Practice Guide». The fulfillment of these requirements does not exempt from fulfilling other official Standards or Codes which may be applicable.

Taking into account the high technological development particularly associated to the field of navigation and vessel manoeuvrability in port waters and, in general, to the construction of probabilistic and simulation models, this document is, from now on, open to all those revisions that can be necessary once the application experience, demonstrated and contrasted, or significant advances in the “State of the Art” are available. To this effect, PUERTOS DEL ESTADO offers the possibility to address it all those comments or suggestions about the content of these Recommendations through the EROM initiative, in force since 1998. The aim of this initiative is precisely to consolidate a biannual techno-scientific publication as an open and permanent forum for interchanging information and technical discussion about the contents, application experience and future development of the ROM documents published up till now. In any case, all remarks on the ROM programme should be addressed to:

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Part I

1.1. SCOPE OF APPLICATION

The Recommendations for the «Design of the Maritime Configuration of Ports, Approach Channels and Harbour Basins» (ROM 3.1) will be applicable in all maritime and port works whatever their type or the use they are designed for.

To these effects, Maritime and Port works will be taken as those works, structural elements or earth movements located in maritime or river port areas or in any other maritime-land public domain possession provided they are in a stationary situation when in service, whether fixed or floating, and Approach Channels and Harbour Basins of the said Maritime and Port works will be taken as all those spaces of water in which ship operations related to maritime or river traffic may be undertaken.

1.2. CONTENT

These Recommendations summarise the criteria necessary for defining, designing and establishing operating criteria for all Approach Channels and Harbour Basins related to maritime and port works and may be applied to any site regardless of what its local and weather conditions may be.

Recommendation 3.1 is structured into 9 parts to cover these aspects, each with the following content:

- **Part 1.** General. Includes the general aspects necessary for correct application and understanding of the recommendations: scope of application, general summary of their content, definitions, units used, notation, symbols and references.

- **Part 2.** General Design Criteria. The different design phases and working hypotheses to be considered in dimensioning Approach Channels and Harbour Basins, the criteria for determining the Useful Lifetime of the different phases, the identification of the elements defining a Navigation Channel or a Harbour Basin, dimensioning criteria, criteria for assessing the geometrical dimensions and assessment of Accident Cases are defined and delimited.

- **Part 3.** Vessel manoeuvrability characteristics. This chapter analyses all the vessel characteristics which influence their manoeuvrability, whether their geometrical and displacement dimensions or the propulsion systems, engines, propellers, rudders, mooring lines, anchors and cable chains. The mass and inertia characteristic affecting ship motions are also analised.

- **Part 4.** External actions on the vessel. This chapter analyses the effects of wind, waves and current on vessel manoeuvrability, as well as the effect of shallow waters, proximity of banks or interaction with other ships moored or in motion under these manoeuvring conditions. An assessment is also made of external actions produced by wind, waves and current on ships, following the basic criteria established in ROM 02 «Actions in the Design of Maritime and Port Works»

- **Part 5.** Tug Boats. This chapter defines the functions and types of tug boat and analyses their most usual propulsion and steering systems. The main characteristics of these ships are studied in terms of manoeuvrability, stability and horsepower. The ways in which tug boats operate and their action on a vessel are analysed and criteria for determining tug boat requirements are established. Finally, the main towing elements are analysed (winches, bitts, hooks, tow ropes, etc.).

- **Part 6.** Vessel underway and manoeuvring. This chapter analyses two fundamental ship manoeuvres on which the design of the Navigation Channels and Harbour Basins that are the subject of this ROM will be based: the vessel's turning circle or manoeuvre it makes under constant power and rudder angle and extinction of headway, which is the manoeuvre made to bring the vessel to a halt. The general methodology for analysing other type of manoeuvring is also introduced. It is described in greater detail in Annex 1 to this ROM in order to avoid giving this chapter a long, unbalanced treatment.

- **Part 7.** Cross section requirements. This chapter gives the criteria for determining water depths and above water clearances required in the different navigation channels and harbour basins, taking into account both factors related to the vessel (trim, clearance for vessel motions due to wind, waves, current and alterations in course, clearances for safety and control in navigation, etc.) and those related to the water level (astronomical and meteorological tides, long wave resonance phenomena, river regimes, etc.) and those depending on the sea bottom (bathymetry inaccuracies, deposits of sediments and dredging tolerance). This chapter also includes recommendations on the quay crown level to be adopted.

- **Part 8.** Layout requirement. This chapter gives the criteria for the geometric layout definition of the following navigation channels and harbour basins: Fairways, Harbour Entrances, Manoeuvring Areas, Anchorages, Mooring Areas and Buoy Systems, Basins and Quays. It also shows the values which have normally been used as limit conditions of environmental variables for different manoeuvres involving approach navigation, turning, berthing, staying and departure of vessels from similar ports and facilities, values on which the navigation and anchoring area dimensions depend. In the case they are adopted, these dimensions or those which may be established in each particular case shall be incorporated into the operational or running Rules of the port or facility under consideration. Finally, recommendations are included on the navigation marking to be established in the different Areas.

- **Part 9.** Scale model simulation and testing. This chapter collects the main principles, mathematical formulas and criteria applicable to use scale model simulators and testing in analysing manoeuvring and defining the Areas which are the subject of this ROM.

In addition, two Annexes are included:

- **Annex I** includes a file of manoeuvres most used in vessel operation. The knowledge of these manoeuvres is an accessory to understand why certain space requirements are specified in certain areas and why Operatonal Limits are associated to certain environmental conditions. Although it is feasible to dimension Navigation Channels and Harbour Basins without knowing how a vessel behaves, it would seem obvious that knowing these manoeuvres leads to a better understanding of the grounds for these specifications. Such knowledge will be imperative in the case of using simulation techniques because what will be done in the models, after all, is to reproduce manoeuvres being performed in real life.

- **Annex II** presents the technical aspects contained in the General Provisions on Ship's Routeing as published by the International Maritime Organization (IMO).

1.3. DEFINITIONS

The following fundamental terms are the most commonly used and are expressly defined to the effects of this Recommendation. These and other terms will generally be defined and explained in more detail in those sections of this Recommendation where they are used in the text.

- ACCEPTABLE RISK. Probability of at least one incident (contact, running aground, impact or collision) involving at least one ship during the useful lifetime of the design phase under analysis.

- ACCIDENT CASES. Cases of a fortuitous or abnormal nature which may occur as a result of an accident, misuse, human errors or exceptional weather or working conditions.

- ADDED MASS. Mass of water which moves with the vessel.

- ADVANCE. A vessel's advance for an alteration of course is the distance its centre of gravity moves in the direction of the original course, measured from the position where the rudder was deflected hard over.

- ANCHOR. Iron or steel piece made up of a bar or shank, arms and flukes prepared for digging into the sea bottom and, joined to the ship by a hawser or chain, keeps it steady.

- ANCHOR CHAIN. Stretch of chain secured to an anchor.
- ANCHOR DRAGGING. Dragging an anchor over the seabed when it has not been held in the ground.
- ANCHOR RING. Iron or steel ring located at the top end of the anchor's shank to which the chain is secured.
- ABOVE WATER CLEARANCE. Clear space above the water necessary for vessels to navigate.
- ANCHORAGE. Place with sufficient depth and conditions for a ship to be able to drop anchor and be held steady thereby.
- ANCHORING. Manoeuvre involving dropping the anchor to the seabed to hold a vessel steady.
- DRIFT ANGLE. Angle formed by the centre line plane with the navigation route taken by the vessel.
- ANGLE OF YAW. Angle formed by the centreline plane with the wind direction when running close to the wind.
- APPARENT WIND. Wind received by the vessel when in motion, the direction and force of which are the resultants of the actual wind and a speed equal and opposite to the vessel's.
- APPROACHES AND HARBOUR BASINS. All spaces of water where vessel operations related to Maritime and Port Work maritime traffic vessel operations can be carried out.
- AREA CLOSURE. Condition of total or partial inoperability of an Area because of weather conditions over and above those established for Limit Operating Conditions.
- AREA TO BE AVOIDED (IMO). Traffic organization measure comprising an area within defined limits in which either navigation is particularly hazardous or it is exceptionally important to avoid casualties and which should be avoided by all ships, or certain classes of ship.
- ASTRONOMICAL TIDE. Tide due to the gravitational attraction of the Moon and other astral bodies. Its intensity is in close relation to the relative position in which the Sun and Moon are with respect to the Earth.
- AVERAGE REGIME. A variable's average regime is the variable's distribution function in an interval of time (year, season, month, etc.).
- BALLAST DISPLACEMENT. Weight of a ship including stores, provisions, crew, fuel and water. It does not carry cargo but the minimum weight of ballast for the vessel to sail and manoeuvre safely.
- BEAM. Vessel's greatest width.
- BEARING AWAY. Increasing the angle taken by the centreline plane with the wind.
- BERTHING. Manoeuvring for coming alongside a quay or mooring to it.
- BITT. Mooring element, generally steel or cast iron, which, when placed on deck in manoeuvring places, serves for securing mooring lines.
- BLOCK COEFFICIENT. Quotient between the displacement of a vessel expressed by volume of underwater body and the product of the following factors: length between perpendiculars x beam x draught.
- BOLLARD PULL. Horizontal force which a tug boat working ahead applies in the case of zero speed.

- BOTTOM WORKS. That part of a vessel's hull under the waterline.

- BOW. Front part of a ship.

- BRAKE HORSEPOWER. A vessel's propelling horsepower measured at the engine's output coupling flange during bench testing.

- CASTING. A vessel's moving off course through the effect of wind, waves or current. The term "casting" is generally used when the move is due to the wind and "drift" when caused by the current.

- CENTRELINE. Centreline plane

- CENTRELINE PLANE. Vertical longitudinal plane through the middle of the vessel from fore to aft.

- CHARACTERISTIC VALUE OF A DIMENSION. Value of the dimension associated to a probability of exceedance during the design's lifetime.

- INSHORE TRAFFIC ZONE (IMO). A routeing measure comprising a designated area between the landward boundary of traffic separation scheme and the adjacent coast, to be used in accordance with the provisions of rule 10(d), as ammended, of the International Regulations for Preventing Collisions at Sea (Collision Regulations), 1972.

- COMBINATION VALUE. A variable's representative value when combined with others of a predominating effect.

- CONSTRUCTION PHASE. Period ranging from the commencement of the construction of the Navigation Channel or Harbour Basin until it comes into service.

- DEEP WATER ROUTE (IMO). A route within defined limits which has been accurately surveyed for clearance of sea bottom and submerged obstacles as indicated on the chart.

- DESIGN VESSEL. The ship or set of ships which will be used to design the approaches and harbour basins which are the subject of this ROM. In general, these will be the most requiring vessels which may operate in the area under consideration, according to its operating conditions, assuming that the ship is under the worst loading conditions.

- DETERMINIST METHOD. Design method based on using mathematical tables or formulas leading to a specific, certain result, not associated to probabilities of occurrence.

- DISPLACEMENT. Weight of the volume of water displaced by a vessel at a certain waterline.

- DOCK BASIN OR BASIN. Part of a port's navigable water artificially sheltered from outer water to allow vessel operation (loading and unloading, repairs, etc.).

- DOWNTIME. Time during which an Area is totally or partially out of service for certain vessel operations through weather conditions over and above those established as Limit Operating Conditions.

- DRAUGHT OF A VESSEL. The vertical distance measured from a vessel's under keel centre to the floatation or water line.

- DRIFT. Movement of a vessel consisting in its overall motion in the direction of its main horizontal axis perpendicular to the centreline plane passing through its centre of gravity. Although this term is synonymous with "casting", it is generally applied when the movement is caused by the force of a current.

- DRY DOCK. A cavity excavated below sea level into which one or several vessels can enter for carrying out any work, once they are "dry", which cannot be performed under water (repairs, building, cleaning, etc.).
- DURATION. Duration of a certain threshold value of a variable in the time elapsing between two consecutive steps of its value through the preset threshold.
- DWELLING VESSEL AREAS. Areas fundamentally intended for vessels to lie or stay (anchorages, mooring berths, basins, quays, berths, terminals, etc.).
- DYNAMIC TRIM. Additional increase to the static trim, caused by the vessel moving at a certain speed.
- EMERGENCY GROUNDING AREA. A preset area to which a vessel heads should the type and degree of emergency it undergoes advise running aground to avoid greater damage.
- ESTABLISHED DIRECTION OF TRAFFIC FLOW (IMO). A traffic flow pattern indicating the directional movement of traffic as established within a traffic separation scheme.
- EXCEPTIONAL CONDITIONS. State when Navigation Channels and Harbour Basins are subjected to extraordinary limitations which, whilst not usual, are foreseeable as a result of accidents, misuse or exceptional weather or working conditions.
- EXTREME CONDITIONS. State when Navigation Channels or Harbour Basins have to stop or limit their operability whilst weather actions higher than operating or running limits persist.
- EXTREME REGIME. A variable's extreme regime is the distribution function of the variable's extreme value, considering a single value as representative of the time considered.
- FAIRWAY; TRAFFIC LANE (IMO). An area within defined limits in which one-way traffic is established. Natural obstacles, including those forming separation zones, may constitute a boundary.
- HARBOUR BASINS. Areas fundamentally intended for vessels to dwell.
- FREEBOARD. Height of the vessel's hull from the waterline to the main deck, measured on the sides in at midship section.
- GROUNDING. To run a vessel ashore.
- HARBOUR ENTRANCE. The entry and exit mouth to a port.
- TO HAUL. Receive the wind within the least possible angle (between 0 and 6 points from the bow).
- HAWSE HOLES. Holes located on either side of a vessel's stem through where ropes or chains holding the anchor pass, and where the anchor's shank is bedded.
- HEADWAY STOPPING. Headway stopping is the manoeuvre carried out to halt the vessel. If performed by stopping engines, it is called natural stopping and if with engines in reverse, it is called forced stopping.
- HEAVE. Movement of a ship consisting in its overall displacement in the direction of its main vertical axis passing through the centre of gravity.
- HOLDING GROUND. Sea bottom where ship anchors can hold steady.
- ISODISPLACEMENT SURFACE. Surface formed by the intersection of the plane corresponding to the waterline and the vessel's hull.

- KEEL. Longitudinal piece at the bottom-most part of a vessel's hull running from bow to stern, from which the frames start.

- LENGTH BETWEEN PERPENDICULARS. Distance measured on the centreline plane between the forward perpendicular (vertical line by the intersection of the summer load waterline and the front of the stem) and the aft perpendicular (which may be the vertical through the intersection of the summer load waterline with the rudder stock axis, with the vessel's stern outline or the vessel's stern post outline, according to the classification society. The 1st meaning is taken to the effects of this ROM).

- LENGTH OVERALL. Maximum length of the ship's hull measured from bow to stern.

- LIE ALONGSIDE. To position the ship so that its side is almost in contact with another vessel's or with a quay.

- LIGHT DISPLACEMENT. Overall weight of a vessel as it leaves the shipyard, without stores, provisions, crew, fuel and water. The vessel cannot sail under these conditions.

- LIMIT OPERATING CONDITIONS. Values of weather variables as from which certain vessel operations must be totally or partially stopped.

- LIST. Inclination a vessel takes up to a longitudinal axis located in the centreline plane passing through its centre of gravity. Heel is an unsteady inclination, due to rolling

- LOCK. Enclosure fitted with entry and exit gates which is built on a navigation canal so that ships may pass from one stretch to another on a different water level, by filling or emptying the space between the two gates with water.

- LONG WAVES. Waves generally of a small amplitude in the open sea and a long period (>20-30 s.) produced by atmospheric pressure, sharp changes in the wind or by groups of waves.

- LUFF. Part of a ship's sides where they start to narrow towards the bow.

- LUFFING. Bringing the bow to the wind.

- MAINTENANCE. Phase in which work is performed for conserving the requirements of water or above water spaces in the Navigation Channels and Harbour Basins.

- MANOEUVRING AREAS. Areas where a vessel halts, gets underway or turns.

- MARKING. Action and effect of signaling some place in navigable waters with navigation marks.

- MARKING. Placing suitable signs acting as guides to users in Navigation Channels and Harbour Basins.

- MAXIMUM DISPLACEMENT. Overall weight of a ship when loaded with the maximum cargo allowed.

- MAXIMUM OUTER WATER LEVEL UNDER OPERATING CONDITIONS. Maximum water level to be expected under operating conditions, taking into account astronomical and meteorological tides and river regimes, should such be the case.

- MEAN OPERATING LEVEL OF FREE OUTER WATER. Mean level of the water taking into account astronomical and meteorological tides and river regimes, should such be the case.

- METEOROLOGICAL TIDE. Changes in the water depth at a point due to variations in the atmospheric pressure, as well as those caused by wind force.

- MOORING. To secure the vessel with anchors, chains or mooring ropes. When only chains and anchors are used, the operation is usually called “anchoring”.

- MOORING BERTH. Place where ships are moored.

- MULTIBUOY MOORING. Facilities where vessels are moored to buoys or other fixed or floating elements other than quays, in which operations typical of a port can be performed.

- NAVIGATION CHANNELS. Areas fundamentally intended for vessel transit.

- NOMINAL DEPTH. Minimum depth of water required in an area for the Design Vessel.

- NOMINAL VALUE OF A DIMENSION. Guaranteed value of the pertinent dimension.

- NON SIGNIFICANT ASTRONOMICAL TIDE. Astronomical tide whose Unit of Height is equal to or less than 0.50 m.

- NON SIGNIFICANT HYDRAULIC REGIME. A hydraulic regime whose range is equal to or less than 1.00 m.

- NORMAL OPERATING CONDITIONS. State when a Navigation Channel or a Harbour Basin operates with no restrictions and is not affected by weather conditions.

- OPERATING MANUALS. Simplified procedures facilitating the application of Operating Rules to a specific Area.

- OPERATING RULES. Rules regulating nautical operations (and, by extension, other types of operation) to be carried out in the Navigation and Harbour basins which are the subject of this ROM.

- OVERHANG. Distance between two ships moored to one alignment of a quay, measured by their projection over the quay’s longitudinal axis.

- PIER. Quay advancing into the sea.

- PITCH. A vessel’s motion consisting in a rotation around the main horizontal axis perpendicular to the centreline plane passing through its centre of gravity.

- PIVOT POINT. Point located in a vessel’s centreline plane in which the speed vector is directed at all times along the centre line plane.

- PORT. The left hand side of the vessel looking forward.

- PORT ZERO LEVEL. Local reference level used in each port, which does not usually coincide with the zero level on topographical maps of a general scope nor with that of sea charts.

- PRECAUTIONARY AREA (IMO). A routeing measure comprising an area within defined limits where ships must navigate with particular caution and within which the direction of traffic flow may be recommended.

- PROBABILITY OF EXCEEDANCE. Probability of a variable exceeding a certain value.

- PROPELLER. Set of blades revolving round a shaft which, when rotating, produce a thrust which moves the ship.

- PROPELLER. A vessel’s mechanism which generates the thrust necessary for movement.

- QUARTER. Part of a vessel's sides where they start to narrow towards the stern.

- QUAY. Masonry work built on the sea shore or on a navigable river which serves to facilitate vessel unloading and loading and other types of operation.

- RACON. Acronym for Radar Responder Beacon. Active system for reflecting radar waves which, when receiving them, emits a radioelectric signal, generally a letter of the Morse alphabet, which identifies the lighthouse, beacon or place where it is installed.

- RANGE OF A HYDRAULIC REGIME. Difference in water level between the values for the NmaxHR and NminHR

- RECOMMENDED DIRECTION OF TRAFFIC FLOW (IMO). A traffic flow pattern indicating a recommended directional movement of traffic where it is impractical or unnecessary to adopt an established direction of traffic flow.

- RECOMMENDED ROUTE (IMO). A route of undefined width, for the convenience of ships in transit, which is often marked by centre line buoys.

- RECOMMENDED TRACK (IMO). A route which has been specially examined to ensure so far as possible that it is free of dangers and along which ships are advised to navigate.

- REGIME OF DURATIONS. A variable's regime of durations is the distribution function of the "duration" of the variable in a time scale (year, season, month, etc.). See "duration".

- REGIME OF EXCEEDANCES. A variable's regime of exceedances is the distribution function which lists the maximum foreseeable values of a variable with its probability of not exceeding them in a certain period.

- REPRESENTATIVE VALUE OF A DIMENSION. Value of a dimension associated to its level of variation in time.

- RIGHTING MOMENT. Moment of forces tending to make the vessel recover transverse stability by returning to its equilibrium position.

- RISK OF DAMAGE. Risk of damage occurring but not significantly affecting the operability of the area in question.

- ROLL. Vessel's motion consisting in a rotation around the main longitudinal axis located in the centreline plane, which passes through the centre of gravity.

- ROUNDABOUT (IMO). A routeing measure comprising a separation point or a circular separation zone and a circular traffic lane within defined limits. Traffic within the roundabout is separated by moving in a counterclockwise direction around the separation point or zone.

- ROUTEING SYSTEM (IMO). Any system of one or more routes or routeing measures aimed at reducing the risk of casualties. It includes traffic separation schemes, two-way routes, recommended tracks, areas to be avoided, inshore traffic zones, roundabouts, precautionary areas and deep water routes.

- RUDDER. An apreciably flat item located in a vessel's stern frame which, as it can turn forming an angle with the centreline plane, serves to steer the vessel.

- RUN CLOSE TO THE WIND. Receive the wind within the least possible angle (between 0 and 6 points from the bow).

- SAFETY CLEARANCE. Value by which the designed dimensions must be increased to take into account effects not foreseen in the calculation.

- SAFETY CLEARANCE APPLIED TO A DIMENSION. Quantification of the Safety Clearance when dealing with a geometric dimension. In this ROM, this Safety Clearance is determined by an additional factor and not by a multiplying coefficient.

- SEMIPROBABILISTIC METHOD. Design method based on statistically analysing data which lead to results associated to probabilities of occurrence.

- SEPARATION ZONE OR LINE (IMO). A zone or line separating two traffic lanes in which ships are proceeding in opposite or nearly opposite directions, or separating a traffic lane from the adjacent sea area, or separating traffic lanes designated for particular classes of ship proceeding in the same direction.

- SERVICE PHASE. Period ranging from when the Navigation Chnnel or Harbour Basin is brought into service until it is decommissioned, abandoned or changed in use.

- SHIP MEASUREMENT. Measuring the volume of a vessel's enclosed spaces.

- SHIP'S DEPTH. Height of the ship's hull from the keel to the main deck, measured at the midship section at side.

- SIDE. Each of the two sides of the vessel hull; the right hand side looking to the bow is called starboard and the left hand, port.

- SIGNIFICANT ASTRONOMICAL TIDE. Astronomical tide whose Unit of Height is greater than 0.50 m.

- SIGNIFICANT HYDRAULIC REGIME. A hydraulic regimen whose range is greater than 1.00 m.

- STARBOARD. The right hand side of the vessel looking forward.

- STARTING AREA. Areas where vessels start up or commence moving.

- STATIC DRAUGHT. Draught of a vessel at rest.

- STEM. Thick, curved piece forming a vessel's bow.

- STERN. Rear part of a vessel.

- STERN POST. A piece which, joined to the end of the keel at the stern part, acts as a foundation for the whole frame of this part of the vessel, whilst shaping the stern.

- STOPPING AREA. Areas where the vessel's headway stops.

- STOPPING DISTANCE. Space ahead travelled by a vessel in a stopping manoeuvre measured as from the moment when the manoeuvre commences.

- STOPPING MANOEUVRE. Manoeuvre carried out to bring the vessel to a halt. See "headway stopping".

- SWAY. A vessel's motion consisting in an overall displacement of the vessel in the direction of the main horizontal axis transverse to the centreline plane and passing through the centre of gravity.

- THRUSTER. A propeller situated crosswise to the vessel's centreline plane, located in a tunnel crossing through the vessel's underwater hull in the vicinity of the bow or stern.

- TIDAL COEFFICIENT. Ratio between the height of a tide at a point and the Unit of Height of the tides at that point.

- TIDAL LIMIT. Point located in a river where the tide effect is cancelled out.
- TIDAL PERIOD. Interval of time elapsing between two ascending tide levels crossing the mean sea level in the tidal wave.
- TIDAL WAVE. Variation in water depth at a point due to the tide's action over time.
- TOTAL LOSS RISK. Risk of damage occurring and significantly affecting the operability of the area in question.
- TRACK. Course or direction taken by ships when underway.
- TRAFFIC SEPARATION SCHEME (IMO). A routeing measure aimed at the separation of opposing steams of traffic by appropriate means and by the establishment of traffic lanes.
- TRANSFER. A vessel's lateral deviation for a certain change in course is the distance its centre of gravity moves in a direction perpendicular to the original course.
- TRANSIT. Vessel positioning system using radioelectric means.
- TRANSIT VESSEL AREAS. Areas fundamentally intended for vessels to transit (approaches, fairways, channels, entrances, manoeuvring areas, etc.)
- TRIM. Difference between a vessel's draughts forward and aft.
- TUG BOAT. Auxiliary boat for the navigation and manoeuvres of ships and other floating elements.
- TURNING AREAS. Areas where a vessel changes course with no significant advance in any direction.
- TURNING CIRCLE. Trajectory described by a vessel's centre of gravity when turned whilst maintaining a constant engine speed and rudder angle.
- TWO-WAY ROUTE (IMO). A route within defined limits inside which two-way traffic is established, aimed at providing safe passage to ships through waters where navigation is difficult or dangerous.
- ULTIMATE LIMIT STATES. Modes of incident (collision, impacts, grounding, etc.) which may occur in operating a vessel in the Areas studied by this ROM.
- UNBERTHING. Manoeuvre for pulling away from a quay.
- UNIT OF HEIGHT. Height of the tide above sea level on equinoctial spring tide days when the Moon's declination is null and the Moon and the Sun are at their mean distances from the Earth.
- UPPER WORKS. The part of a vessel's hull above the waterline.
- USEFUL LIFETIME. Duration of the service phase.
- USEFUL LIFETIME OF A DESIGN PHASE. Duration of the design phase under consideration.
- WATER DEPTH. Height of water existing in an area.
- WINDOW. Period of high water time generally associated to the tidal wave, in which the water depth at the site exceeds a certain value.
- YAWING. Motion of a vessel consisting in a rotation around the main vertical axis passing through its centre of gravity. Deviation of the bow of the vessel to one side or the other of the course on which it is navigating. Change in the direction of a vessel's bow when at anchor.

1.4. SYSTEM OF UNITS

The system of units used in these Recommendations relates to the Legal System of Measurement Units mandatory in Spain called the International System of Units (IS), with the exception of the unit deriving from force, the tonne (t), which is also used as it is common for measuring loads and forces in Spain.

The basic units in the International System most commonly used in civil engineering are as follows:

- Length : Metre (m).
- Mass : Kilogram (kg) or its multiple the tonne (t) (1 t = 1,000 kg).
- Time : Second (s).
- Temperature : Degree centigrade (°C).
- Force : Newton (N) or its multiple the kilonewton (kN) (1 kN = 1,000 N).
- Frequency : Hertz (Hz).

The tonne-force relation with the unit of force in the International System (Newton -N-) is: 1 t = 9.8 kN.

In some cases, information in units usually used in navigation (miles, knots, etc.) will also be incorporated when assumed suitable for better understanding of the case involved.

1.5. NOTATIONS

The fundamental conventional notations, abbreviations and symbols used in these recommendations and their units are detailed in table 1.1.

1.6. REFERENCES

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Table 1.1. Fundamental conventional notations, abbreviations and symbols used in these recommendations

Symbol	Definition	Units
I. LATIN CAPITAL UNITS		
A_a	Regression model adjustment parameter	–
A_{BMVE}	Half amplitude of the tidal wave corresponding to the LAT	m
A_b	Main cross section of a vessel's bottom works	m^2
A_c	Cross section of a channel	m^2
A_{helaux}	Area of a vessel's auxiliary propeller's Kort vent	m^2
A_{LC}	Submerged lateral area of the vessel subjected to the force of the current	m^2
A_{LCF}	Area of the vessel's wetted surface longitudinal to the centreline direction	m^2
A_{LV}	Area of the vessel's lateral surface exposed to wind action	m^2
A_{MC}	Half amplitude of a coefficient «C» tidal wave	m
A_{PA}	Automatic pilot coefficient	–
A_{PMVE}	Half amplitude of the tidal wave corresponding to the HAT	–
A_{TV}	Area of the vessel's transverse surface exposed to wind force	m^2
A_{TC}	Vessel's submerged cross section subject to the force of the current	m^2
A_{TCF}	Area of the vessel's wetted surface transverse to the centreline direction	m^2
B	Beam of a vessel	m
B_I	Vessel related factors, including tug boat availability, on which the area necessary for vessels to navigate, manoeuvre or remain in the Area under consideration depends	–
B_2	Factors related to the accuracy and reliability of the marking and beaconing systems	–
B_3	Factors related to the boundaries of a Navigation Chanele or a Harbour Basin	–
B_a	Regression model adjustment parameter	–
B_G	Dimension defining the width of the vessel Turning Area in manoeuvres carried out with tug boats	–
BM_C	Low water of a tidal wave with coefficient «C»	m
B_{max}	Maximum beam of the largest Design Vessel	m
B_n	Nominal width of a fairway	m
B_{nd}	Nominal width of a basin measured between outside face planes of the longitudinal quay fenders	m
B_{ndp}	Increase in the nominal width of a basin «B_{nd}» due to vessels alongside those berthed at its longitudinal quays	m
B_{PA}	Automatic pilot coefficient	m
B_r	Additional reserve width of a Navigation Channel or a Harbour Basin for taking boundary related factors into account	–
B_{rd}	Width B_r, referred to the right hand side of a fairway	m
B_{ri}	Width B_r, referred to the left hand side of a fairway	m
B_t	Overall width of a fairway	m
B_{to}	Overall width of a waterway in the stretch where there is a change in weather conditions	m
B_{tla}	Overall width of a waterway in the permanent navigation stretch before the area of weather condition change	m
B_{tlp}	Overall width of a waterway in the permanent navigation stretch after the area of weather condition change	m
B_{tc}	Overall width of a curved fairway	m
B_{tr}	Overall width of a straight stretch of fairway	m
C	Tidal coefficient	*
C_a	Regression model adjustment parameter	–

(Continued)

Table 1.1. **Fundamental conventional notations, abbreviations and symbols used in these recommendations**

Symbol	Definition	Units
I. LATIN CAPITAL UNITS		
C_b	Vessel's block coefficient	*
C_{CL}	Shape factor for calculating the resultant of the current's pressures on vessels, acting in the direction of their longitudinal axis	*
C_{CT}	Shape factor for calculating the resultant of the current's pressures on vessels, acting in the direction of their transversal axis	*
C_{dw}	Depth coefficient for calculating wave actions on the vessel	*
C_{fw}	Coefficient of floatation for calculating wave actions on the vessel	*
C_i	Tidal coefficient «i»	*
C_m	A vessel's coefficient of hydrodynamic mass or quotient between the total mass of the system in motion (vessel + water moving with it) and the vessel's mass	*
C_{PA}	Automatic pilot coefficient	–
C_r	Coefficient of friction for calculating the current's friction forces on the vessel	*
C_v	Non dimensional coefficient for calculating a vessel's drift angle caused by wind.	*
C_{VF}	Shape factor for calculating the resultant of wind pressures on the vessel	*
C_{VL}	Shape factor for calculating the resultant of wind pressures on the vessel, acting in the direction of its longitudinal axis	*
C_{VT}	Shape factor for calculating the resultant of wind pressures on the vessel, acting in the direction of its transverse axis	*
D	A vessel's draught	m
D_e	A vessel's static draught	m
D_p	A vessel's stopping distance	m
D_{PA}	Automatic pilot coefficient	–
E	Acceptable risk	*
E_{ij}	Risk associated to type (i) vessel operation under operating conditions of the interval (j)	*
E_{max}	Maximum acceptable risk	*
E_{PA}	Automatic pilot coefficient	t
F_a	Horizontal aerodynamic force resulting from wind action on a vessel's sails	t
F_c	Centrifugal force	t
F_h	Horizontal hydrodynamic force resulting from the action of water on a vessel's bottom	t
F_i	Inertia force	t
F_{LC}	Longitudinal component of the force resulting from the current's action on a vessel	t
F_{LCF}	Longitudinal component of the force resulting from the current's friction on a vessel	t
F_{LCP}	Longitudinal component of the force resulting from the current's pressure on a vessel	t
F_{LRi}	Longitudinal component of the force resulting from the action of a tug boat on a vessel	t
F_{LV}	Longitudinal component of the force resulting from the wind's action on a vessel	t
F_{LW}	Longitudinal component of the force resulting from wave action on a vessel	t
F_{nh}	Froude number	t
F_{PA}	Automatic pilot coefficient	t
F_{Ri}	Horizontal force resulting from the action of a tug boat operating on the vessel	t
F_t	Rudder factor	t
F_{TC}	Transverse component of the force resulting from the current's action on a vessel	t
F_{TCF}	Transverse component of the force resulting from the current's friction on a vessel	t
F_{TCP}	Transverse component of the force resulting from the current's pressure on a vessel	t
F_{TRi}	Transverse component of the force resulting from the action of a tug boat on a vessel	t

(Continued)

Table 1.1. Fundamental conventional notations, abbreviations and symbols used in these recommendations

Symbol	Definition	Units
I. LATIN CAPITAL UNITS		
F_{TV}	Transverse component of the force resulting from the wind's action on a vessel	t
F_{TW}	Transverse component of the force resulting from wave action on a vessel	t
G	A vessel's freeboard	m
G_{PA}	Automatic pilot coefficient	–
H_1	Vessel related factors which may cause some point in its hull to reach a lower level than that for a flat keel plate under static conditions at sea	–
H_2	Factors affecting the Water Level's variability	–
H_3	Sea bottom related factors.	–
H_S	Significant wave height	m
I	Moment of inertia of the isodisplacment waterplane about its longitudinal axis	m4
I_p	Hydrodynamic moment of inertia of a vessel with respect to its centre of gravity	$t.m.s^2$
K	Distance of the pivot point to a vessel's stern (or bow if greater), expressed as a fraction of the vessel's Length Overall (L).	*
K_I	Correction factor for calculating the dynamic trim	*
K_{ec}	Coefficient of eccentricity for obtaining the moment resulting from the current's pressure on the vessel	*
K_{ev}	Factor of eccentricity for obtaining the moment resulting from the wind's pressures on the vessel	*
KG	Height of the weight centre of gravity over the keel	m
K_{mf}	Factor quantifying the vessel manoeuvring area between the two alignments of buoys or anchors dropped in both longitudinal alignments of a basin	*
K_{mr}	Factor quantifying the vessel manoeuvring area between the two alignments of vessels berthed end on in the longitudinal alignments of a basin	*
K_{PF}	A dimensional coefficient which relates a tug boat's bollard pull with its brake horsepower	–
K_r	Non-dimensional coefficient for calculating the drift angle of a vessel underway caused by the action of tug boats	*
K_s	Non-dimensional correction coefficient for determining the dynamic trim in submerged or conventional channels	*
K_T	A dimensional constant for determining the force P_T generated at a vessel's rudder blade	–
K_v	Non-dimensional coefficient for calculating a vessel's drift angle caused by wind	*
K_{VD}	A dimensional coefficient relating the effective horsepower supplied by a vessel's engine to its displacement and service speed	–
K_w	Non-dimensional coefficient for calculating a vessel's drift angle caused by waves	*
K_z	A vessel's radius of gyration with respect to a vertical axis passing through its centre of gravity	m
L	Overall length	m
L_f	Period of time assigned in a design to each of the phases thereof (Useful lifetime of the design phase)	years or months
L_G	Dimensions defining the length of the vessel Turning Area in manoeuvres with tug boats	m
L_n	Natural Logarithm	–
L_{pp}	Length between perpendiculars	m
L_{proy}	Length of a vessel's projection in the direction of incident waves	m
L_r	Sum of a tug boat's overall length and the horizontal projection of the towline for berthing and deberthing manoeuvres in docks.	m
L_v	A vessel's longitudinal component of the propulsion force F_a caused by wind action on the sails	t

(Continued)

Table 1.1. Fundamental conventional notations, abbreviations and symbols used in these recommendations

Symbol	Definition	Units
I. LATIN CAPITAL UNITS		
L_w	Absolute wave length at the location's depth	m
L_{wr}	Length of apparent wave or relative to the vessel at the location's depth	m
M	Vessel's mass comprising its own mass and the mass of water moving with it	$t.s^2/m$
M_e	A vessel's turning moment caused by rudder forces	t.m
M_{TC}	Moment resulting from the action of the current's pressure forces on a vessel, applied on a vertical axis passing through its centre of gravity	t.m
M_{TRi}	Moment resulting from the action of a tug boat on a vessel, applied on a vertical axis passing through its centre of gravity	t.m
M_{TV}	Moment resulting from the action of the wind on a vessel, applied on a vertical axis passing through its centre of gravity	t.m
M_x	Hydrodynamic mass (mass plus added mass) of a vessel in motion along the axis x	$t.s^2/m$
M_y	Hydrodynamic mass (mass plus added mass) of a vessel in motion along the axis y	$t.s^2/m$
N	Moment resulting from the outside force with respect to the vessel's centre of gravity	t.m
N_a	Number of vessels per year forecast to be operating in the mean representative year of the whole Useful Lifetime of the Area and phase being analysed	*
N_{BC}	Water level of a Coefficient C Tidal Wave corresponding to Low Water	m
N_{helaux}	Moment induced by a vessel's auxiliary propeller	t.m
N_{hidr}	Moment of the hydrodynamic force acting on a vessel	t.m
N_{ij}	Probable number of manoeuvres of each type of ship associated to certain operational conditions forecast to be performed during the whole useful Lifetime of the Area being analysed	*
N_{wave}	Moment of the forces produced by wave action on a vessel	t.m
N_{bank}	Moment of suction/repulsion caused by a shore	t.m
N_{PC}	Water level of a Coefficient C Tidal Wave corresponding to High Water	m
N_{prop}	Moment of a vessel's propulsion force	t.m
N_{wind}	Moment of forces due to wind	t.m
N_{rudder}	Moment of a vessel's steering force (rudder)	t.m
N_w	Number of waves	*
O	Instant rotation centre	–
P	Pivot Point	–
PM_c	High water of a tidal wave with Coefficient «C»	m
P_T	Forces resulting from loads generated by a current of water impinging on a vessel's rudder in a direction perpendicular to the rudder blade	m
P_{TL}	Component of the force P_T generated by the current on the rudder blade in a vessel's longitudinal direction.	t
P_{TN}	Component of the force P_T generated by the current on the rudder blade in a vessel's transverse direction	t
R	Radius of a vessel's path	m
R_a	Resistance to a vessel's advance	t
R_{ao}	A vessel's resistance to advance when commencing the stopping manoeuvre	t
R_c	Horizontal force resulting from the current's action on a vessel	t
R_{CF}	Horizontal force resulting from the current's friction action on a vessel	t
R_{CP}	Horizontal force resulting from the current's pressure action on a vessel	t
R_{cr}	Dimensions defining the circular perimeter of the vessel Turning Area in tug boat aided manoeuvres	m
R_{sr}	Turning manoeuvre circle's radius in the event the operation is carried out without tug boat assistance	m

(Continued)

Table 1.1. ***Fundamental conventional notations, abbreviations and symbols used in these recommendations***

Symbol	Definition	Units
1. LATIN CAPITAL UNITS		
R_v	Horizontal force resulting from wind action on a vessel	t
R_w	Horizontal force resulting from wave action on a vessel	t
S_1	Working hypothesis for Normal Operating Conditions	–
S_2	Working hypothesis for Extreme Conditions	–
S_3	Working hypothesis for Exceptional Conditions	–
S_4	Working hypothesis for Maintenance	–
S_t	Rudder blade area	m^2
T	A vessel's depth	m
T_a	Time necessary for a vessel overtaking manoeuvre	s
T_c	A chain's working load	t
T_M	Horizontal component of the force applied in a vessel's mooring rope	t
T_m	Tidal wave period	s
T_{ML}	Component of force T_M due to a mooring line in a vessel's longitudinal direction	t
T_{MT}	Component of force T_M due to a mooring line in a vessel's transverse direction	t
T_P	Thrust applied at a vessel's propeller	t
T_{PF}	Bollard pull of a tug boat	t
T_{PT}	Component of the propeller thrust transverse to the vessel	t
T_v	Component of the propulsion force Fa in a vessel's transverse direction caused by wind action on the sails	t
T_w	Absolute wave period	s
U.A.	A tide's unit of height	m
U	Temporary width of a window or period of time in which the depth of water available exceeds preset values	s
V	Absolute speed of the vessel with respect to the sea bottom	m/s
V_c	Absolute current velocity	m/s
V_{cr}	Relative current velocity referred to the vessel	m/s
T_{wr}	Wave period, apparent or relative to the vessel, or Period of Encounter	s
$V_{c.1\ min}$	Mean current velocity at a depth of 50% of the vessel's draught in a 1 minute interval	m/s
V_F	Flow velocity in the nozzle of a vessel's auxiliary propeller	m/s
V_L	Component in the vessel's absolute speed in the direction longitudinal to the path	m/s
V_o	Vessel's absolute speed when commencing the stopping manoeuvre	m/s
V_r	Vessel's relative speed with respect to the water	m/s
V_{rr}	Vessel's relative speed referred to the waterway's current speed in the same direction as its route	m/s
V_T	Speed of the flow of water impinging on the rudder	m/s
V_v	Absolute wind velocity	m/s
V_{vr}	Relative wind velocity referred to the vessel	m/s
$V_{10.1\ min}$	Mean wind velocity at 10 m height and 1 minute gust	m/s
V/H	Gradient of a slope calculated by the ratio between the vertical and horizontal projection of a unit of length measured on the slope	*
W	Effective horsepower supplied by a vessel's engine	t.m/s
W_o	Effective horsepower supplied by a model vessel's engine	t.m/s
W_r	A tug boat's brake horsepower	t.m/s

(Continued)

Table 1.1. Fundamental conventional notations, abbreviations and symbols used in these recommendations

Symbol	Definition	Units
I. LATIN CAPITAL UNITS		
X	Component along axis x of the outside force acting on a vessel	t
X_b	Area sweeped by a vessel	m
X_{bk}	Characteristic value of the dimension defining the area sweeped by a vessel	m
X_e	Space available at a location	m
X_{ek}	Characteristic value of the dimension defining a location's available space	m
X_{hidr}	Component x of the hydrodynamic force acting on a vessel	t
X_k	Characteristic value of a dimension	m
X_n	Variable quantifying the area sweeped by a vessel	m
X_o	Specific value of the dimension of a space	m
X_{wave}	Longitudinal wave force acting on a vessel	m
X_{bank}	Longitudinal component of the suction/repulsion force of a shore	t
X_{prop}	Component x of a vessel's propulsion force	t
X_s	Safety Clearance	t
X_{sd}	Safety Clearance applicable to the dimension being considered	m
X_{rudder}	Component x of a vessel's steering force (rudder)	m
X_{wind}	Longitudinal wind force acting on a ship	t
Y	Component along axis y of the outside force acting on a vessel	t
Y_{helaux}	Transverse component of the force induced by a vessel's auxiliary propeller	t
Y_{hidr}	Component y of the hydrodynamic force acting on a ship	t
Y_{wave}	Longitudinal wave force acting on a vessel	t
Y_{bank}	Transverse component of the suction/repulsion force of a shore	t
Y_{prop}	Component y of a vessel's propulsion force	t
Y_{rudder}	Component y of a vessel's steering force (rudder)	t
Y_{wind}	Transverse wind force acting on a ship	t
Z_x	Random variable distributed normally according to mean-square error in regression models	–

Symbol	Definition	Units
II. LATIN SMALL LETTERS		
a	Above water space associated to a depth of water for determining clearances over Harbour Basins	m
a_e	Coefficient of eccentricity for quantifying a shore's suction and repulsion effects	*
b_b	Widening of the vessel's route to cover the error which might derive from the navigation marking systems	m
b_d	Widening of the vessel's route caused by navigating with a certain drift angle in relation to the waterway's axis	m
b_{dc}	Widening of the route sweeped by the vessel, caused by navigating in curved stretches	m
b_{dv}	Widening of the route sweeped by a vessel caused by variable weather conditions.	m
b_{dva}	Widening «b_{dv}» referred to a stretch before that with variable weather conditions.	m
b_{dvd}	Widening «b_{dv}» referred to the right hand side of a waterway.	m
b_{dvi}	Widening «b_{dv}» referred to the left hand side of a waterway.	m
b_{dvp}	Widening «b_{dv}» referred to a stretch after that with variable weather conditions.	m
b_e	Widening of the vessel's route due to positioning errors.	–

(Continued)

Table 1.1. Fundamental conventional notations, abbreviations and symbols used in these recommendations

Symbol	Definition	Units
II. LATIN SMALL LETTERS		
b_r	Widening of the vessel's route due to the response time from the instant when the vessel's deviation in relation to its theoretical position is detected and the moment when the correction becomes effective	m
b_{ro}	Widening «b_r» for a value of E_{max} = 0.50	m
b_{rc}	Widening of the vessel's route due to the response time for anticipating navigating in a curve with a constant radius	m
b_s	Width of the intermediate separation area or strip between the two lanes of a fairway	m
d_{bg}	Vertical distance between the weight centre of gravity and a vessel's centre of buoyancy (centroid of the submerged volume)	m
d_c	Vessel's additional draughts due to listing motions caused by the current's action	m
d_{cg}	Vertical distance between force line F_{TC} and the vessel's centre of gravity	m
d_{dg}	Vertical distance between a vessel's centre of drift and centre of gravity	m
d_g	Increases in draught occurring in the ship in relation to its even keel position, due to trim, listing or deflections caused by different loading conditions	m
d_r	Vessel's additional draughts due to listing motions caused by changing course	m
d_s	Changes in the ship's draught caused by variations in the density of the water in which it is navigating	m
d_T	Distance of the ship's rudder pressure centre to the leading edge	m
d_t	Dynamic trim or «squat»	m
d_v	Vessel's additional draughts due to listing motions caused by wind action	m
d_{vd}	Vertical distance between the F_{TV} line of action for the case of ships underway and the centre of drift. For moored ships, the vertical distance between the F_{TV} line of action and that of the mooring or fender forces balancing it	m
d_w	Increase in a ship's draught caused by wave action	m
e_v	Eccentricity of the resulting wind force with respect to the vessel's centre of gravity, measured on the centreline plane	–
e_{cp}	Eccentricity of the resulting current pressure force on the vessel, with respect to its centre of gravity, measured on the centreline plane	m
f	Frequency of occurrence	*
f_{bi}	Frequency with which vessels appear, broken down into types or categories of homogeneous characteristics in relation to their manoeuvrability conditions (expressed in «rate per one» in relation to the number of vessels per year N which it is forecast will operate in the average year representative of the whole Useful Lifetime of the Area and Phase being analysed)	*
f_{oj}	Frequency with which the conditions of operability in which vessel manoeuvres can be undertaken occur (expressed in «rate per one» in relation to the average year)	*
$f_{(mNw)}$	Increment factor for calculating the greatest value of a vessel's vertical motion caused by wave action, as a function of the probability of exceedance and the number of waves	*
f_1	Reduction factor of a vessel's transverse propeller thrust through the interaction of the flow and the hull at different navigation speeds	*
f_2	Reduction factor of the moment produced by a vessel's transverse propeller thrust through the interaction of the flow and the hull at different navigation speeds	*
g	Acceleration of gravity	m/s^2
h	Depth of water at rest	m
h_b	Depth of water of a Tidal Wave for low water measured in relation to the LAT	m
h_e	Height of the hawse hole above the water surface	m
h_{ef}	Height of the hawse hole above the sea bottom.	m

(Continued)

Table 1.1. Fundamental conventional notations, abbreviations and symbols used in these recommendations

Symbol	Definition	Units
II. LATIN SMALL LETTERS		
h_L	Mean height of the vessel's superstructure surface above the deck projected onto a longitudinal plane	m
h_M	Mean depth of water for a Tidal Wave, measured in relation to the LAT	m
h_m	Depth of water for any point of the Tidal Wave, measured in relation to the LAT	m
h_p	Depth of water of a Tidal Wave for high water measured in relation to the LAT	m
h_T	Mean height of the vessel's superstructure surface above the deck projected onto a transverse plane	m
h_z	Depth of the trench dredged referred to the mean sea bottom level	m
l	Length	m
l_a	Length of mooring line	m
l_c	Length of chain	m
l_d	A buoy's run or displacement	m
l_g	Length of an anchor's dragging	m
l_i	Lack of precision in dropping an anchor	m
l_o	Overhang or longitudinal component of the clear distance between ships berthed in the same alignment	m
l_s	Separation or longitudinal component of the distance between a ship berthed at a quay and the closest change in the alignment of the quay or in its type of structure	m
l_T	Length of a vessel's rudder blade	m
n	Revolutions of a vessel's propeller	1/s
n_b	Number of ships moored abreast	*
p_{ij}	Probability of exceedance that any space (X_o) is exceeded by a type (i) vessel under interval (j) operability conditions in conducting a separate manoeuvre	*
r	Absolute angular velocity of a vessel's rotation	degrees/s
r_c	Absolute angular velocity of the current's rotation	degrees/s
r_e	Index of economic repercussion in the case of an incident	*
rh_{sd}	Safety margin or clear horizontal clearance which shall always be available between the vessel and the boundaries, slopes or limiting structures of a waterway or Manoeuvre Area	m
$(rh_{sd})_d$	Safety margin «rh_{sd}» referred to the right hand side of a waterway	m
$(rh_{sd})_i$	Safety margin «rh_{sd}» referred to the left hand side of a waterway	m
rh_{sm}	Safety clearance which must be considered on each side of the waterway to allow the vessel to navigate without being affected by the effects of suction and rejection of the banks	m
$(rh_{sm})_d$	Safety clearance «rh_{sm}» referred to the right hand bank of a waterway	m
$(rh_{sm})_i$	Safety clearance «rh_{sm}» referred to the left hand bank of a waterway	m
r_r	Relative angular velocity of the vessel's rotation with respect to the water	degrees/s
rv_{sd}	Free vertical clearance which shall always be available between the ship's hull and the sea bottom (Safety Margin)	m
rv_{sm}	Vertical clearance for safety and control of a ship's manoeuvrability	m
S_l	Correction factor for calculating dynamic trim	*
t	Time any point of the Tidal Wave associated to a depth of water «y_m» measured in relation to the closest high water occurs	s
t_{b1}	Time low water «1» occurs	s
t_{b2}	Time low water «2» occurs	s
t_{bi}	Time low water «i» occurs	s
t_c	Time necessary to correct the manoeuvre of a vessel with variable weather conditions	s

(Continued)

Table 1.1. **Fundamental conventional notations, abbreviations and symbols used in these recommendations**

Symbol	Definition	Units
II. LATIN SMALL LETTERS		
t_{p1}	Time high water «1» occurs	s
t_{p2}	Time high water «2» occurs	s
t_{pi}	Time high water «i» occurs	s
t_r	Reaction time for commencing vessel overtaking or passing manoeuvres	s
t_{ri}	Reaction time necessary to reverse the propeller thrust from the moment when the stopping manoeuvre commences until the value T_p is reached in reverse	s
u	Component of the vessel's absolute velocity in direction x	m/s
u_c	Component of the current's absolute velocity in direction x	m/s
u_r	Component of the vessel's relative speed with respect to the water in direction x	m/s
v	Component of the vessel's absolute velocity in direction y	m/s
v_c	Component of the current's absolute velocity in direction y	m/s
v_r	Component of the vessel's relative speed with respect to the water in direction y	m/s
w	Weight per unit of length	t/m
x	Coordinate	m
x_b	Block coefficient for calculating a shore's suction and repulsion effect	m
x_G	Longitudinal coordinate of the vessel's centre of gravity in the axes fixed to it	m
x_{helaux}	Longitudinal position of the auxiliary propeller in the axes fixed to the vessel	m
x_{prop}	Longitudinal position of the propeller in the axes lfixed to the vessel	m
x_{rudder}	Longitudinal position of the rudder in the axes fixed to the vessel	m
y	Coordinate	m
y_m	Depth of water at any point of the Tidal Wave measured in relation to the NM	m
y_{xi}	Distance to the edge of a waterway measured at the section «x» of the simulation «i»	m

Symbol	Definition	Units
III. GREEK LETTERS		
α	Angle	degrees
α_c	Angle between the direction of the absolute current (from where it is coming) and the vessel's centreline plane	degrees
α_{cr}	Angle between the direction of the relative current (from where it is coming) and the vessel's centreline plane	degrees
α_{cv}	Angle between the direction of the absolute current (from where it is coming) and the vessel's absolute speed	degrees
α_v	Angle between the direction of the absolute wind (from where it is coming) and the vessel's centreline plane	degrees
α_{vr}	Angle between the direction of the relative wind (from where it is coming) and the vessel's centreline plane	degrees
α_T	Angle between the rudder and the direction of the current impinging on it	degrees
α_w	Angle between the direction of wave propagation (from where it is coming) and the vessel's centreline plane	degrees
α_{wb}	Angle formed between the vessel's absolute speed and the wave direction (from where it is coming)	degrees
β	A vessel's drift angle	degrees

(Continued)

Table 1.1. ***Fundamental conventional notations, abbreviations and symbols used in these recommendations***

Symbol	Definition	Units
III. GREEK LETTERS		
β_o	A vessel's maximum drift angle in the area of a waterway where there exists a variation in the weather conditions	degrees
β_1	Drift angle of vessel «1»	degrees
β_2	Drift angle of vessel «2»	degrees
β_{1a}	Drift angle of a vessel in the permanent navigation stretch before the area of weather condition variation	degrees
β_{1p}	Drift angle of a vessel in the permanent navigation stretch after the area of weather condition variation	degrees
γ_w	Specific weight of the water	t/m^3
Δ	A vessel's weight. Displacement	t
Δ_y	A vessel's course error	degrees
Δ_y	A vessel's position error	m
∇	Vessel's displacement volume	m^3
Θ_{CR}	A vessel's angle of hell caused by centrifugal force	degrees
Θ_{TC}	A vessel's angle of hell caused by the force of a cross current	degrees
Θ_{TV}	A vessel's angle of hell caused by the force of a cross wind	degrees
μ	Probability of exceedance	*
ξ	Factor quantifying the distance from the anchor's anchoring point to the vessel's bow, as a function of the depth of water at the location	*
$\varnothing$	Specific weight of the air	t/m^3
$\varnothing_C$	Angle between the vessel's longitudinal axis, from stern to bow, and the direction of the resultant of the current's action on the vessel	degrees
$\varnothing_{CF}$	Angle between the vessel's longitudinal axis, from stern to bow, and the direction of the resultant of the current's friction on the vessel	degrees
$\varnothing_{CP}$	Angle between the vessel's longitudinal axis, from stern to bow, and the direction of the resultant of the current's pressures on the vessel	degrees
$\varnothing_V$	Angle between the vessel's longitudinal axis, from stern to bow, and the direction of the resultant of wind pressures on the vessel	degrees
ψ	Vessel's course	degrees

Abbreviation	Meaning
IV. ABBREVIATIONS	
AISM	International Maritime Marking Association
BM_C	Low Water of Coefficient «C» Tidal Wave
BMVE	Low Astronomical Tide
CG	Centre of gravity
CV	Power expressed in horsepower
DGPS	Differential Global Positioning System
DW	Deep water
ELU	Ultimate Limit State
GPS	Global Positioning System
GT	Gross Tonnage of a vessel
NAVGUIDE	Aids to Navigation Guide
N_{BC}	Water level corresponding to the Low Water of a Coefficient C Tidal Wave

(Continued)

Table 1.1. Fundamental conventional notations, abbreviations and symbols used in these recommendations

Abbreviation	Meaning
IV. ABBREVIATIONS	
NM	Mean Sea Level
NME	Mean Low Water level in fluvial currents
NMF	Mean Level of the Fluvial Current
NMI	Mean Level of the annual maximums in fluvial currents
NMO	Mean Operating Level in free outside water
$N_{max}O$	Maximum level of the free outside water under operating conditions
$N_{max}RH$	Extreme expectable level of the annual maxima in a fluvial regime associated to an acceptable risk
$N_{min}RH$	Extreme expectable level of the annual minima in a fluvial regime associated to an acceptable risk
N_{PC}	Water level corresponding to the High Water of a Coefficient C Tidal Wave
OMI	International Maritime Organization
PM_C	High Water of a Coefficient «C» Tidal Wave
PMVE	High Astronomical Tide
RACON	Abbreviation of Radar Responder Beacon
ROM	Recommendations for Maritime Works
SI	International System of Units
TEU	Twenty Feet Equivalent Unit (20 feet long container)
TPM	A vessel's Dead Weight in tons
TRB	A vessel's Registered Gross Tonnage or GT
VTS	Vessel Traffic Services
YG	Signal given in the International Signal Code which, referring to a vessel, means «it appears you are not complying with the traffic separation system»

(Continued)

Annex I
Vessel manoeuvring

VESSEL MANOEUVRES

Annex I

This Annex gives descriptive notes on the most usual vessel manoeuvring undertaken in Navigation and Floatation Areas which are the subject of this ROM, whether under calm weather conditions or when environmental conditions may be more complex for the manoeuvring being considered. The following manoeuvring are particularly analysed:

- NAVIGATION ON RIVERS, CANALS AND FAIRWAYS (side wind, waves or current).
- NAVIGATION ROUND BENDS IN RIVERS OR CANALS (against a strong current).
- NAVIGATION ROUND BENDS IN RIVERS OR CANALS (with a strong current).
- NAVIGATION ROUND BENDS IN RIVERS OR CANALS (before the wind with a strong current).
- CLEARING NARROW PASSAGES IN A FAIRWAY (wind, waves or current transverse to the fairway's axis).
- CLEARING NARROW PASSAGES IN A FAIRWAY (wind, waves or current transverse to the fairway's axis). Alternative manoeuvring.
- TURNING A SINGLE SCREW VESSEL IN SMALL AREAS (calm weather: environmental conditions not significantly affecting the manoeuvring).
- TURNING A SINGLE SCREW VESSEL IN SMALL AREAS (strong head wind).
- TURNING A SINGLE SCREW VESSEL IN SMALL AREAS (strong starboard beam or bow wind).
- TURNING A SINGLE SCREW VESSEL IN SMALL AREAS (strong port beam or bow wind).
- TURNING A SINGLE SCREW VESSEL IN SMALL AREAS (strong starboard or port quartering wind).
- TURNING A SINGLE SCREW VESSEL IN SMALL AREAS (before a strong wind).
- TURNING A TWIN SCREW VESSEL IN SMALL AREAS (calm weather: environmental conditions not significantly affecting the manoeuvring, or hard wind in any direction).
- TURNING A VESSEL IN SMALL AREAS WITH A TUG-BOAT (calm weather: environmental conditions not significantly affecting the manoeuvring).
- TURNING A VESSEL IN SMALL AREAS WITH A TUG-BOAT (strong wind, waves or current).
- TURNING A VESSEL IN SMALL AREAS WITH TWO OR MORE TUG-BOATS (wind, waves or current in any direction).
- TURNING A VESSEL IN SMALL AREAS WITH TWO OR MORE TUG-BOATS (wind, waves or current in any direction). Alternative manoeuvring.
- ANCHORING A VESSEL WITH A SINGLE ANCHOR (anchoring in calm weather with headway).
- ANCHORING A VESSEL WITH A SINGLE ANCHOR (anchoring in calm weather with sternway).
- ANCHORING A VESSEL WITH A SINGLE ANCHOR (strong wind).
- ANCHORING A VESSEL WITH A SINGLE ANCHOR (heavy current).
- ANCHORING A VESSEL WITH TWO ANCHORS IN FLOOD AN EBB TIDE (wind or current acting in the same direction but alternately in opposite directions).

- ANCHORING A VESSEL WITH TWO ANCHORS DOWN (wind or current in any direction, preferably transversely to the alignment of the anchors).

- LEAVING AN ANCHORAGE WITH A SINGLE ANCHOR (calm weather: environmental conditions not significantly affecting the manoeuvring or with a wind).

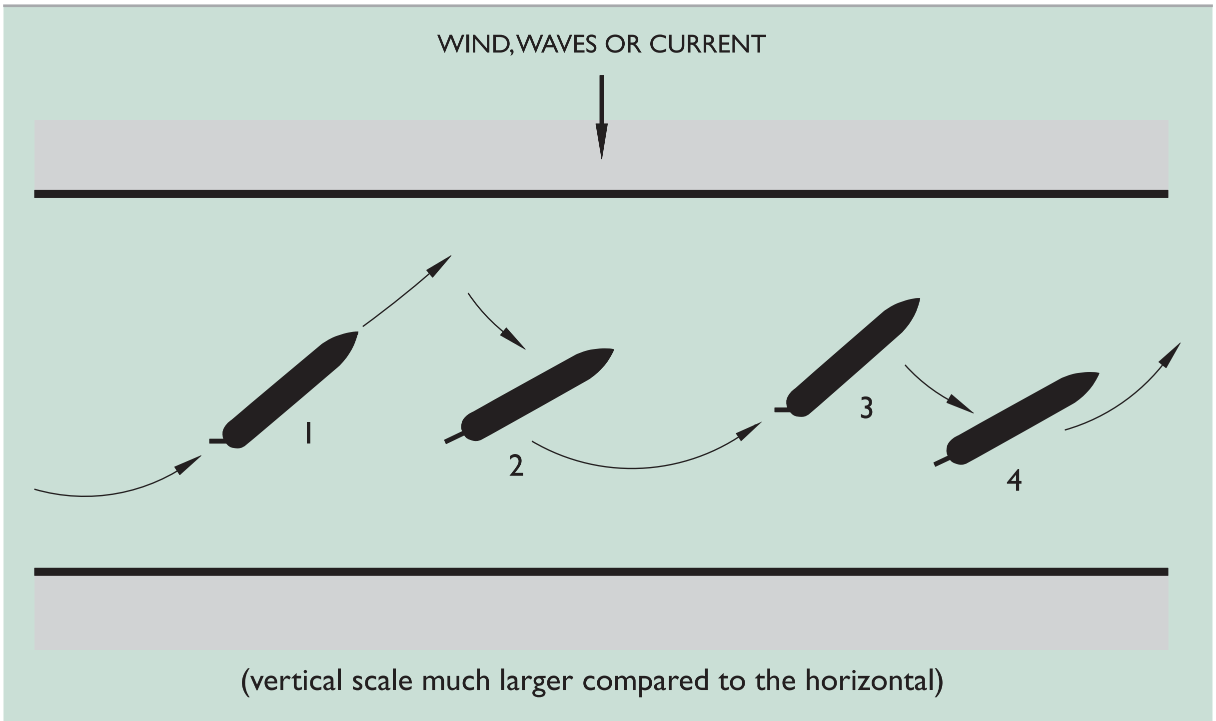
In practice, a high number and type of different manoeuvring can be performed and they must be carried out in each specific case with the intervention of professionals specially qualified for appraising all the elements and resources available and adopting the most suitable solutions.

I.1. NAVIGATION ON RIVERS, CANALS AND FAIRWAYS

Conditions under which the manoeuvring is performed

Side wind, waves or current

Figure I.01. ***Wind, waves or current (vertical dimension not to scale)***



Brief description of the manoeuvring

A vessel has to be sailed in a fairway with side winds, waves or currents with a drift angle towards the direction in which these forces act to offset the transverse forces caused by them. The drift angle will be larger as the the vessel's speed is lower. Due to the external agents' fluctuation, it is practically impossible to keep the drift angle constant and, therefore, the vessel will describe an oscillating path like that exaggeratedly shown in the figure, requiring greater occupation of spaces to undertake the manoeuvring.

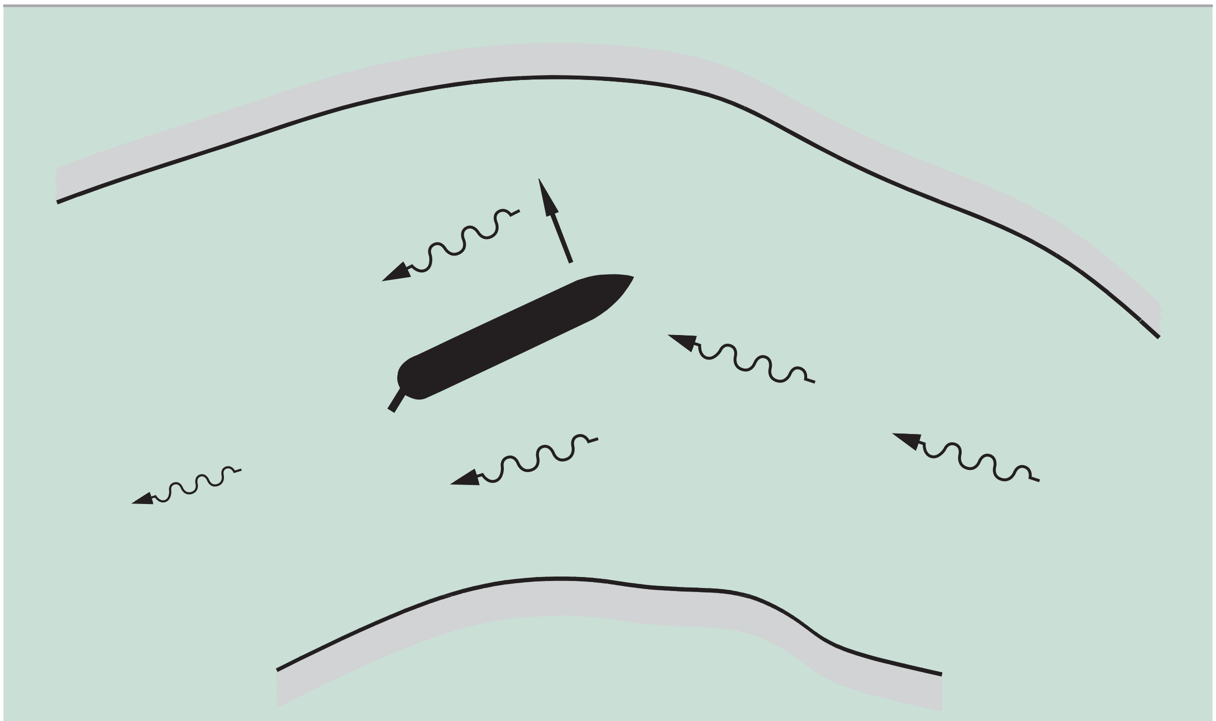
Remarks

I.2. NAVIGATION ROUND BENDS IN RIVERS OR CANALS

Conditions under which the manoeuvring is performed

Against a strong current

Figure I.02.



Brief description of the manoeuvring

Sailing against the current is the safest condition because the ship can be steered well at a moderate speed and can be stopped in very little space.

When taking a bend with a head current, it is very likely that the bow will come across faster moving water before the stern does and a yawing movement will be generated towards the side opposite to that where it is wished to turn, even counteracting the effect of the proximity of the outer bank which would tend to push the bow away from that edge.

This situation must be foreseen beforehand and the handler must be ready to deflect the rudder in the direction of the curvature in time to offset hazardous yawing.

The best position to start the turn will be on the canal's axis avoiding both vortices or counter-currents close to the inner bank and the more intense currents of the opposite bank.

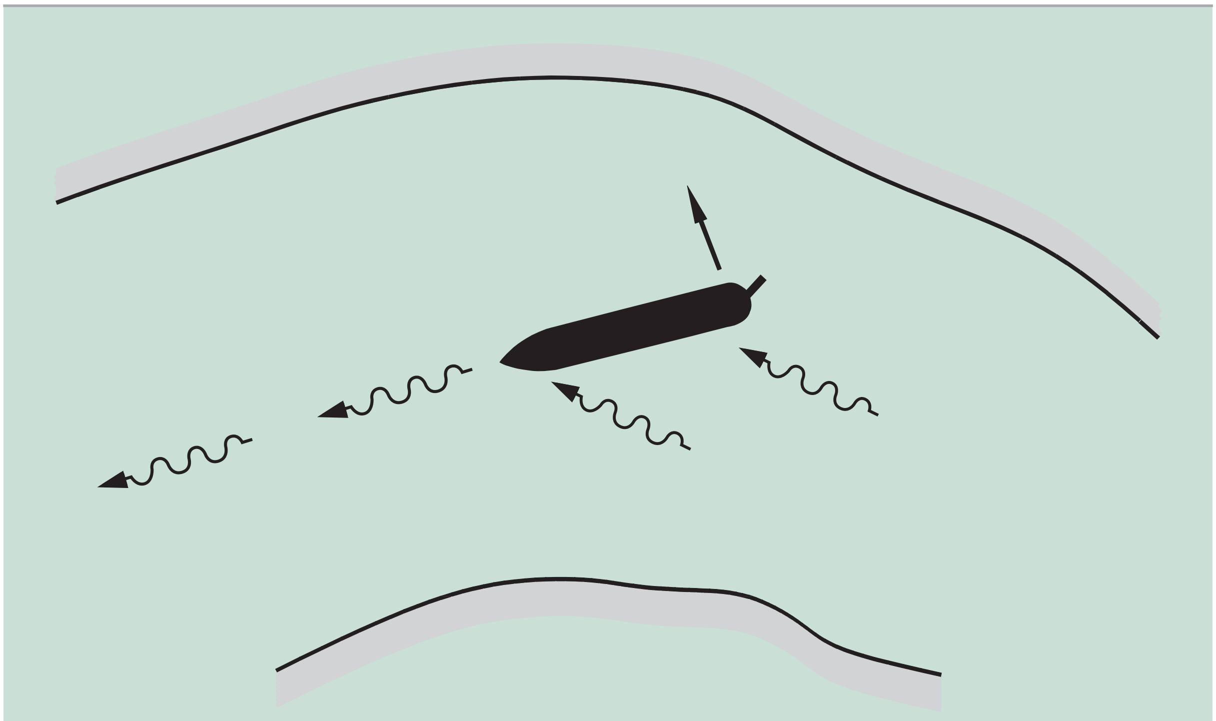
Remarks

I.3. NAVIGATION ROUND BENDS IN RIVERS OR CANALS

Conditions under which the manoeuvring is performed

With a strong current

Figure I.03.



Brief description of the manoeuvring

Sailing with a current enables headway to be made at a good rate with little propulsion although with a reduced steering capability and no possibility of quickly stopping the vessel in a short space.

If sailing with the current, no problems arise and the vessel can keep to the canal's axis with no difficulty as the current helps the turn. If the bend's inner bank has been approached somewhat closely or if the turn is started too soon, it may occur that the stern is located in faster moving water and when the current acts on the inner quarter of the vessel, it pushes it with great force towards the outer edge, increasing the initial turn. The rudder may therefore have to be deflected to the outer bank to prevent this yawing.

The safest way to turn with the current is to approach the bend coming to it outwards of the canal's axis but very close to its centre. The excessive current of the outer bank will thus be avoided as will the vortices of the opposite bank and the moderate force of the current acting on the innner quarter of the vessel will aid the turn.

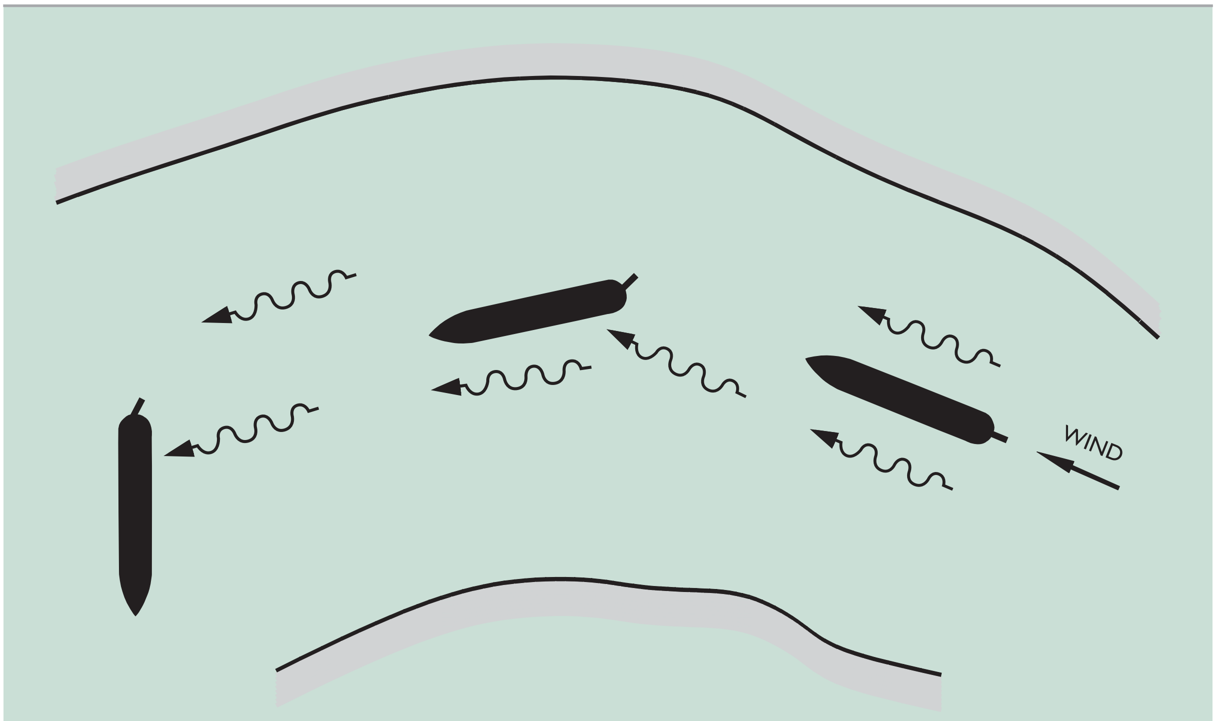
Remarks

I.4. NAVIGATION ROUND BENDS IN RIVERS OR CANALS

Conditions under which the manoeuvring is performed

Before the wind with a strong current

Figure I.04.



Brief description of the manoeuvring

According to the direction in which it is blowing, the wind action may facilitate or oppose the turn of a vessel taking a bend in a river or canal. The most hazardous situation may occur with single screw vessels sailing in ballast with the current and before the wind when taking a bend in which it should turn to port.

As can be seen in the figure, as the vessel is turning, both the current and the wind will try and make the stern turn towards the outer edge and if control is lost, setting the engine astern will be useless as the lateral force of the propeller will accentuate the stern's turning to port and the vessel will then come abeam of the current and will probably run aground on the inner bank.

The safest way of turning will be to deflect a little the rudder to the side of the force beforehand and not to start to alter course too soon. Thus, the vessel will remain within the main flow of the current and its turn can be controlled by keeping it continuously on the appropriate course.

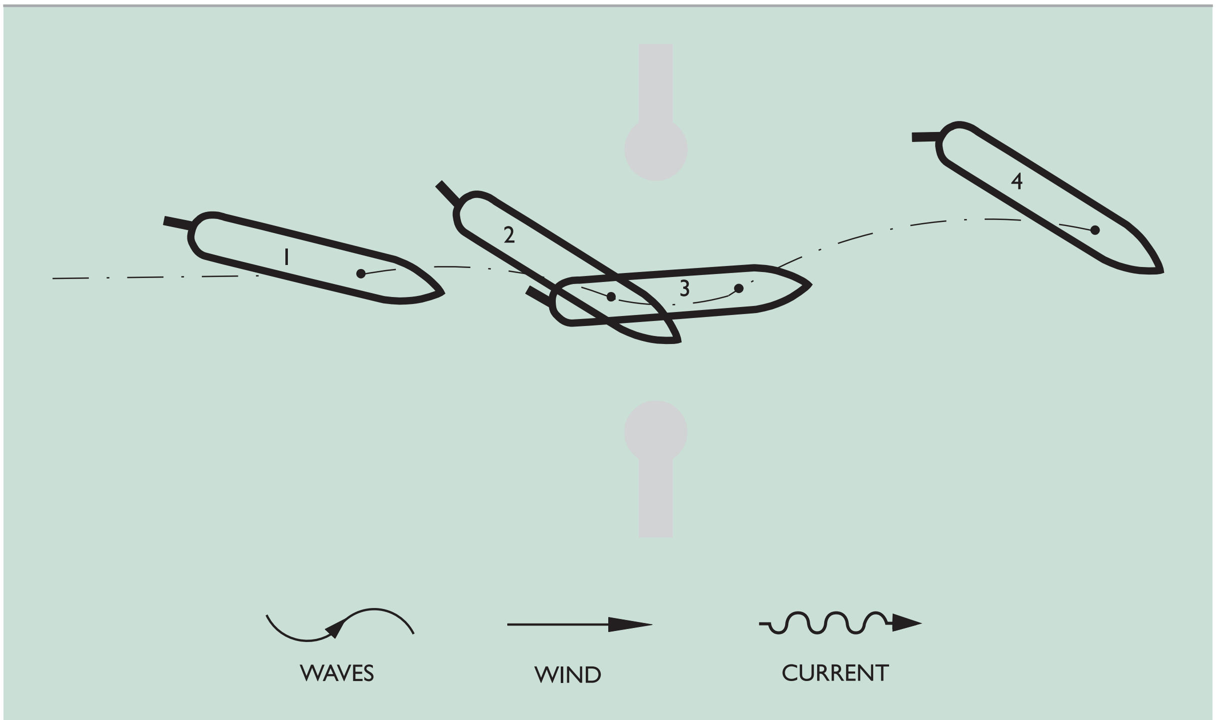
Remarks

I.5. CLEARING NARROW PASSAGES IN A FAIRWAY

Conditions under which the manoeuvring is performed

Wind, waves or currents transverse to the fairway's axis

Figure I.05.



Brief description of the manoeuvring

When there are wind, waves or current transverse to the fairway's axis, one solution consists in taking a course with a drift angle at a suitable distance such that it offsets the action of the external loads (1), sailing somewhat side on along the centre of the fairway and keeping a constant bearing to the mid point of the passage. If the drift angle is very large or the passage very narrow, the vessel will have to be turned to place it almost parallel to the fairway's axis as the passage is being sailed through (3), for which it will be necessary to make a clear yaw to port using a fair amount of rudder when the vessel reaches the entrance (2). This requirement will be additionally reinforced by the fact that when entering the calm water area, the stern will tend to move in the direction of the external forces unless a decisive measure is taken to prevent it. Once the narrow passage has been passed, it is natural for the vessel to move to the left of the fairway and it will therefore be necessary to have space available on that side to be able to manoeuvring until the fairway's centre is recovered (4).

Remarks

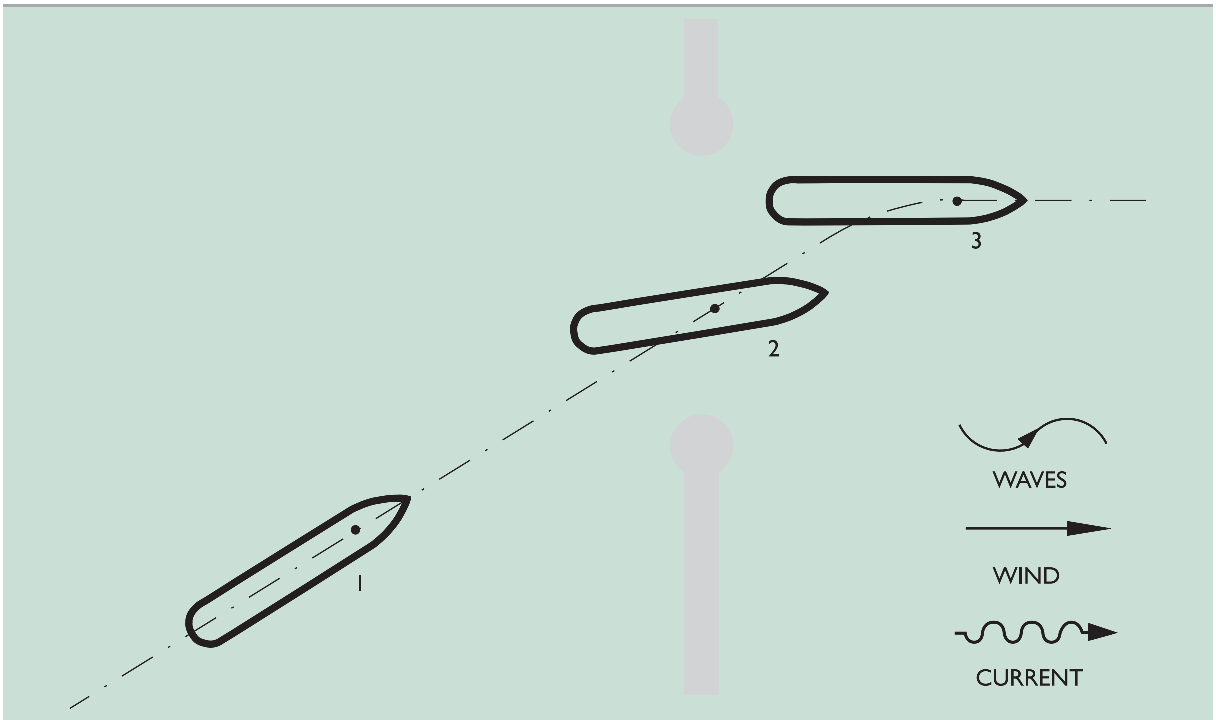
See alternative manoeuvring in figure I.06.

I.6. CLEARING NARROW PASSAGES IN A FAIRWAY

Conditions under which the manoeuvring is performed

Wind, waves or currents transverse to the fairway´s axis. Alternative manoeuvring

Figure I.06.



Brief description of the manoeuvring

When there are wind, waves or current transverse to the fairway's axis, an alternative solution to that described in I.05 consists in making the approach on an oblique track passing somewhat closer to the end of the passage located windward or seaward of the fairway's axis, if feasible. The vessel will approach with a smaller drift angle (1) and when arriving at position (2) with its bow somewhat more sheltered from external forces, these forces will tend to move the stern by turning the ship in relation to the approach path tending to guide it in the direction of the exit axis (3).

Remarks

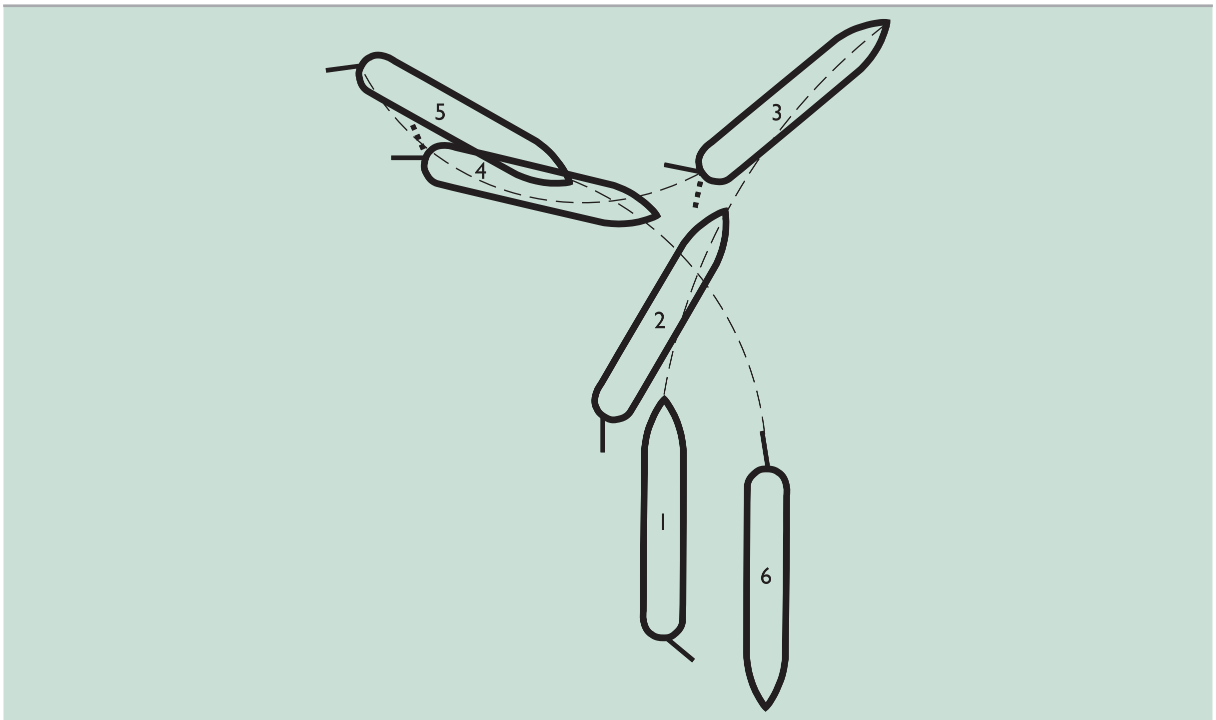
See alternative manoeuvring in figure I.05.

I.7. TURNING A SINGLE SCREW VESSEL IN SMALL AREAS

Conditions under which the manoeuvring is performed

Calm weather (environmental conditions not significantly affecting the manoeuvring)

Figure I.07.



Brief description of the manoeuvring

Assuming a ship with a right handed propeller, give engine ahead as from the initial position (1) and pull the helm hard to starboard (2). Before the vessel gains too much headway, give engine astern and change the rudder to port until the ship stops (3). Continue with engine astern and rudder to port until the ship gains sternway (4), where engines ahead will be given and the rudder will be changed to starboard until reaching position (5) in which the ship will be stopped. Continue with engines ahead and rudder to starboard, reducing the angle deflected until the opposite course to the initial one is recovered.

Remarks

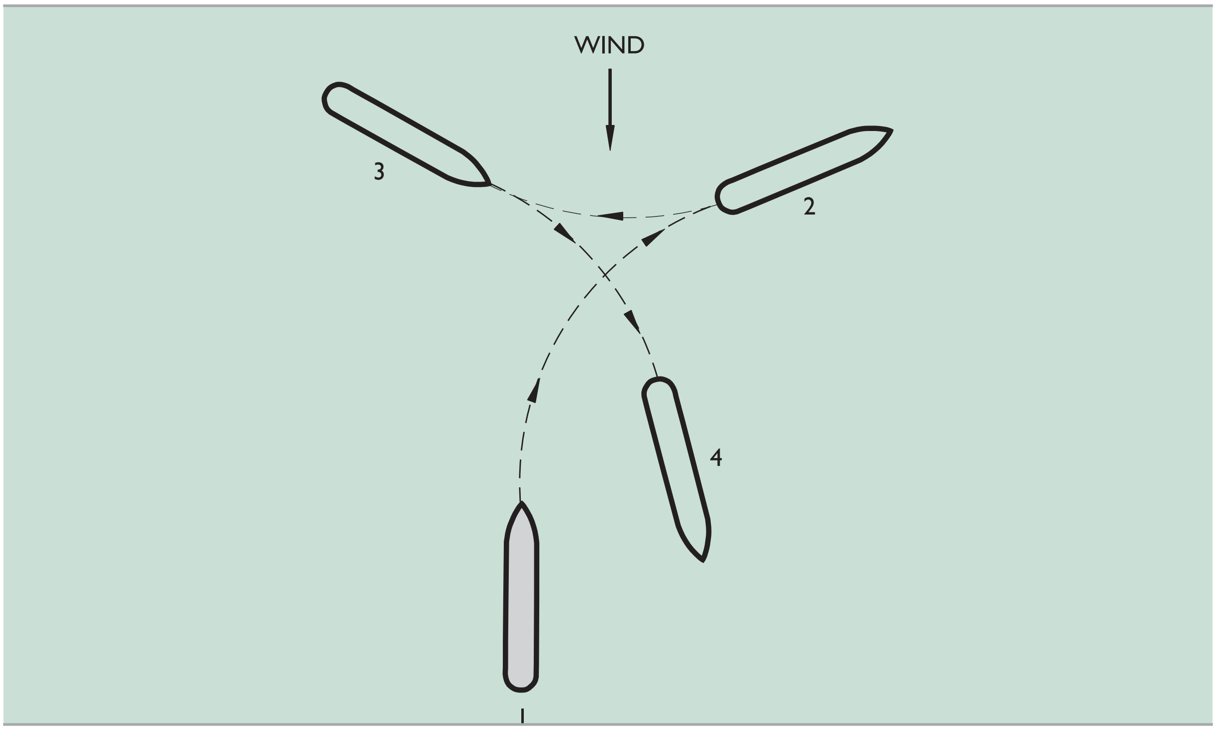
If the vessel has a left handed propeller, the manoeuvring will start towards port and will be symmetrical to the above.

I.8. TURNING A SINGLE SCREW VESSEL IN SMALL AREAS

Conditions under which the manoeuvring is performed

Strong head wind

Figure I.08.



Brief description of the manoeuvring

In general lines, the manoeuvring is similar to that described for calm weather in figure I.07, with the peculiarity that the stern tends to seek the wind when the ship is going astern, and the vessel could then be turned in an angle greater than in calm weather in position (3) and, consequently, the turn is completed in a position (4) further forward than that of the manoeuvring's start (1).

Remarks

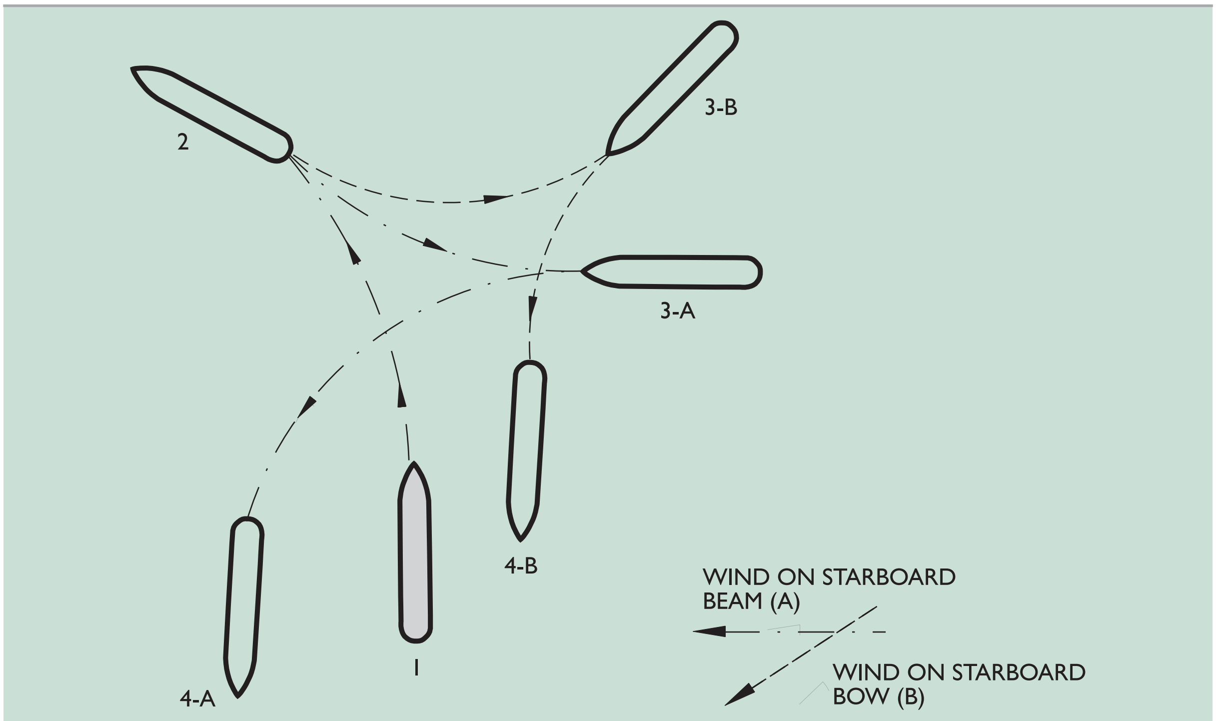
The manoeuvring is shown for a right handed propeller vessel. If the ship had a left handed propeller, the manoeuvring will start towards port and will be symmetrical to that schematically shown.

I.9. TURNING A SINGLE SCREW VESSEL IN SMALL AREAS

Conditions under which the manoeuvring is performed

Strong starboard beam or bow wind

Figure I.09.



Brief description of the manoeuvring

When there is a strong starboard beam wind, it is not advisable to perform the manoeuvring by making the vessel fall to starboard as in the case of calm weather since should this be done, when going astern in the second leg of the manoeuvring, the vessel's tendency to bear away would counteract the propeller's lateral effect and the ship would be in a position close to the initial one. It is preferable to start the manoeuvring with headway and the rudder hard to port to position (2), from which the propeller's side force will be increasingly overcome by the stern's tendency to seek the wind in going astern, with which position (3A) would be reached, from where it is easy to go ahead with the rudder deflected to port and to complete the turn.

The manoeuvring is similar when there is a strong starboard bow wind with the peculiarity that in position (3B), a greater part of the turn will have been completed due to the stern's tendency to seek the wind in going astern.

Remarks

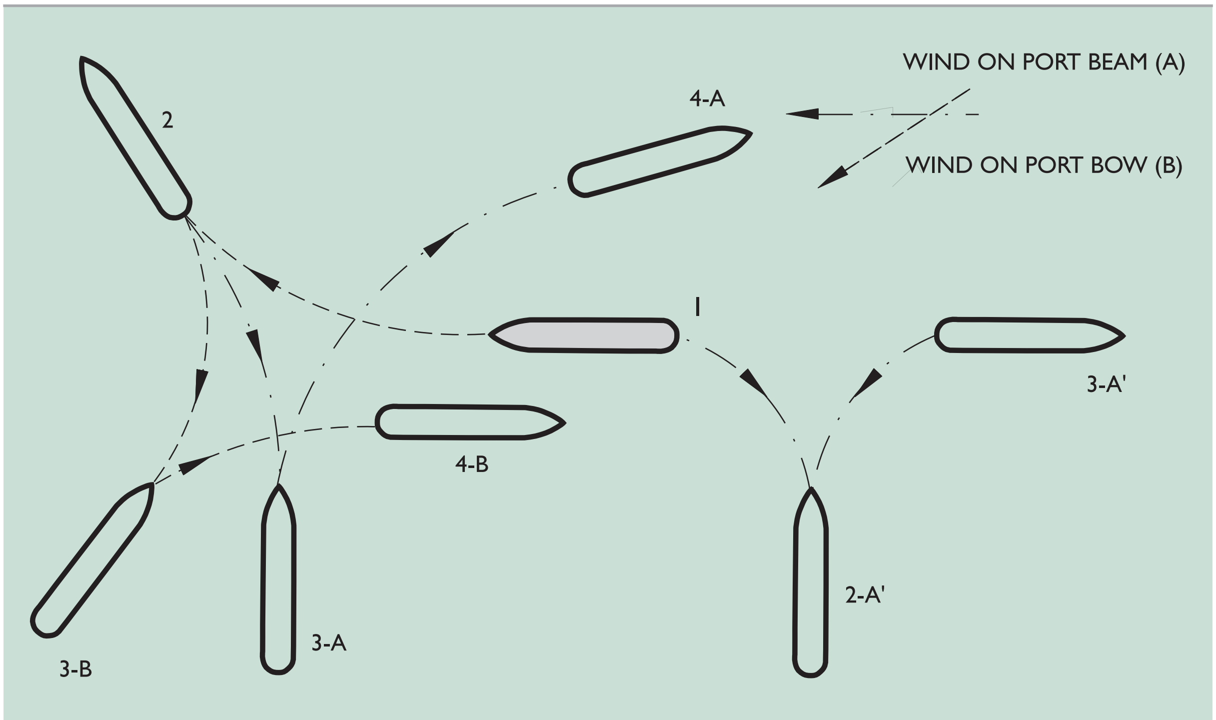
The manoeuvring will be performed the same irrespective of the vessel having a right handed or left handed propeller.

I.10. TURNING A SINGLE SCREW VESSEL IN SMALL AREAS

Conditions under which the manoeuvring is performed

Strong port beam or bow wind

Figure I.10.



Brief description of the manoeuvring

When there is a strong port beam wind, the manoeuvring will be performed as described for calm weather in figure i.07. However, the vessel's stern tendency to seek the wind when going astern will lead to a position (3A) in which a smaller angle of turn will have been completed so that the final position (4A) will be reached at a more backward point to starboard of the initial position. In order to prevent this fall in course, an alternative manoeuvring (A´) may be carried out in which the vessel starts the manoeuvring with sternway seeking the natural balance position (2A´) from which it will be able to continue the manoeuvring up to (3A´), with less fall compared to the foregoing but in a position far backward from the initial one.

When the strong wind is incoming on the starboard bow, the manoeuvring is easy to perform as per the initial scheme, since position (3B) is reached without problem given the stern's tendency to seek the wind direction in going astern.

Remarks

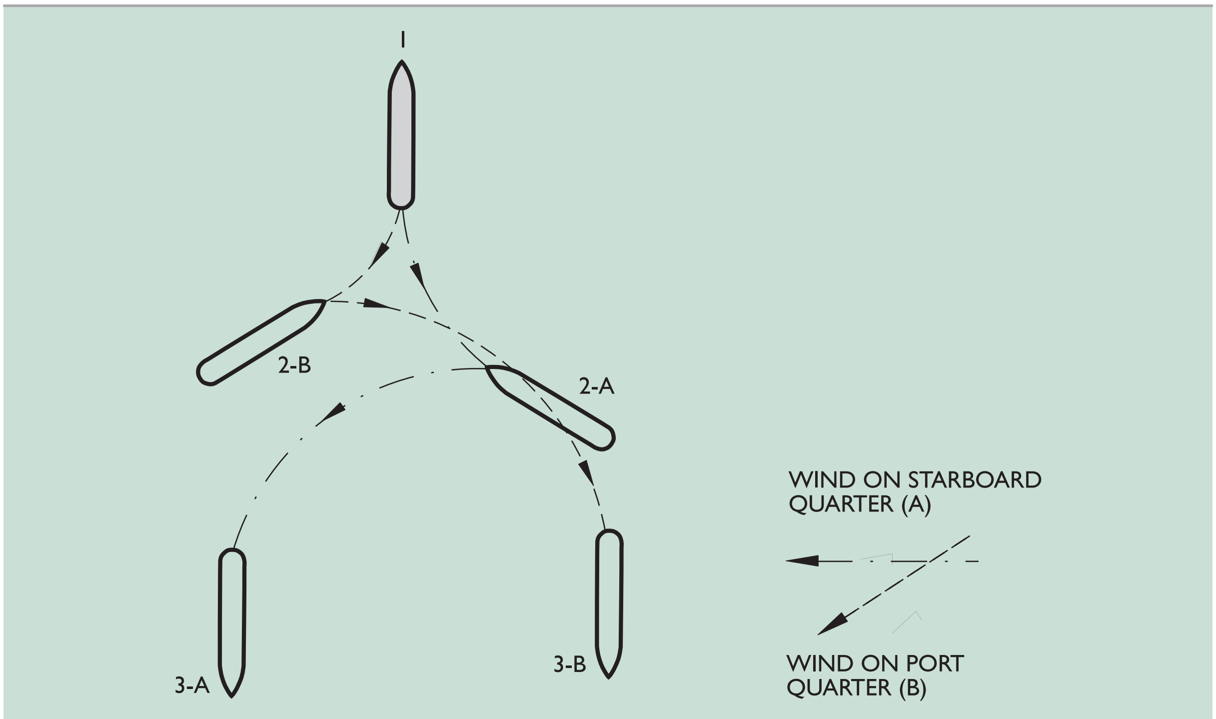
The manoeuvring will be performed the same irrespective of whether the vessel has a right handed or left handed propeller.

I.11. TURNING A SINGLE SCREW VESSEL IN SMALL AREAS

Conditions under which the manoeuvring is performed

Strong starboard or port quartering wind

Figure I.11.



Brief description of the manoeuvring

When a strong wind blows on either of the two quarters, the normal turning manoeuvring shown in calm weather is difficult to perform, since when trying to go astern in the 2nd leg of the manoeuvring, the vessel's tendency to bear away would counteract the propeller's lateral effect and the vessel would find itself in a position close to the initial one. The manoeuvring shown schematically in the figure is recommended, starting by going astern to seek the vessel's natural turn with the stern towards wind direction, positions (2A) or (2B), from which headway may be given with the rudder respectively to port or starboard until the turn is completed in positions (3A) or (3B) which will be very far back and with substantial fall compared to the initial one (1).

Remarks

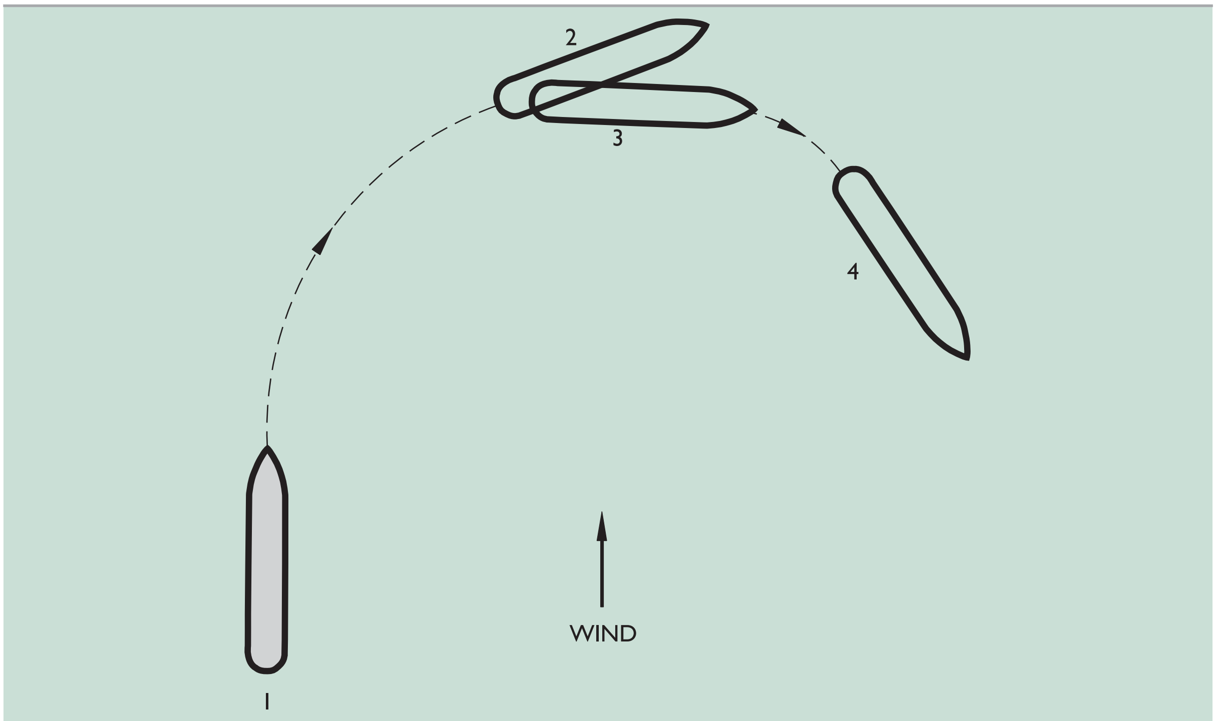
The manoeuvring will be performed the same irrespective of whether the vessel has a right handed or left handed propeller.

I.12. TURNING A SINGLE SCREW VESSEL IN SMALL AREAS

Conditions under which the manoeuvring is performed

Before a strong wind

Figure I.12.



Brief description of the manoeuvring

When a strong wind blows from the stern, the manoeuvring will start as in the case described in the figure for calm weather although, when reaching position (2) in which the vessel receives the wind on the quarter, engines will be set astern and this will give a change of course to position (3) from the effect of the propeller's transverse force, and once achieved, engines ahead will be given to complete the turn by taking advantage of the bow's tendency to seek the wind.

Remarks

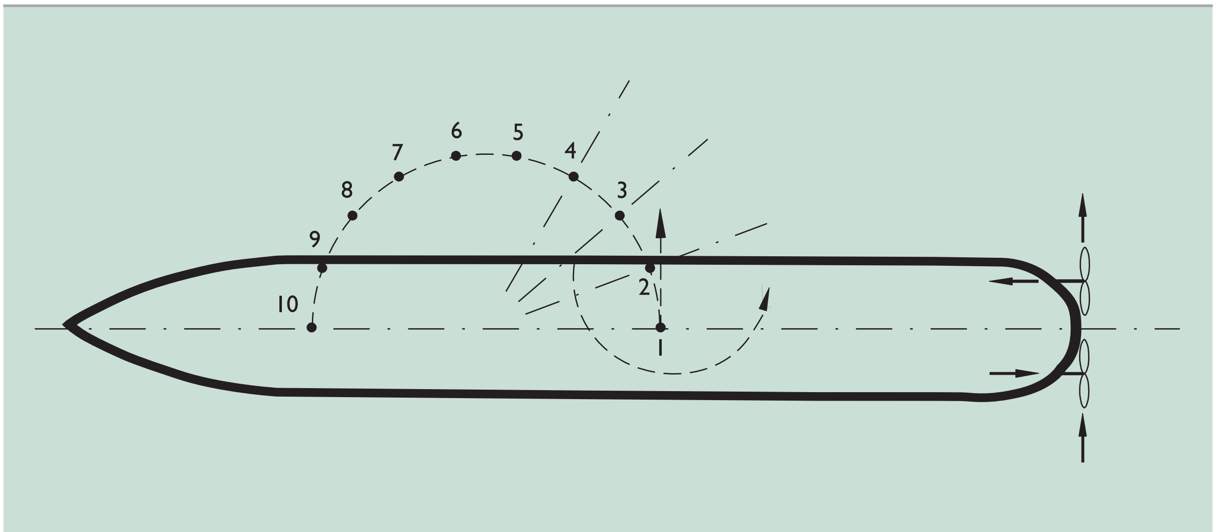
The manoeuvring is shown for a right handed propeller vessel. If the ship had a left handed propeller, the manoeuvring would start to port and would be symmetrical to that shown schematically.

I.13. TURNING A TWIN SCREW VESSEL IN SMALL AREAS

Conditions under which the manoeuvring is performed

Calm weather: environmental conditions not significantly affecting the manoeuvring or hard wind in any direction.

Figure I.13.



Brief description of the manoeuvring

To turn a vessel with two propellers rotating in opposite directions in calm weather when going ahead in the smallest space possible, their revolving direction must be changed, one rotating ahead and one astern according to which side it is required to perform the manoeuvring (in the figure it was assumed that the turn starts towards the port side). Considering that the propeller rotting astern is less efficient if it is wished to prevent a longitudinal component of the propeller's thrust displacing the manoeuvring, a certain number of revolutions in excess must be given to the shaft rotating astern. The transverse thrust generated in both propellers is added to the effect of the torque created by the propellers' equal thrusts in opposite directions (if the propellers rotate outwards in going ahead), which increases the turning moment although an unbalanced transverse component is generated. In this case, the vessel will practically turn on itself although the drift caused by the transverse force will displace the vessel's centre of gravity, as shown schematically in the figure's positions 1 to 10.

The rudder's effect on this manoeuvring depends on how many there are and where they are located.

Remarks

When there is a wind, the manoeuvring will be performed the same even though it is advisable to gain some headway or sternway, especially if the vessel is initially receiving the wind on the beam. In general, the highest efficiency is achieved by keeping the vessel slightly ahead when making it turn by luffing with the bow to the wind and slightly astern when making it turn by bearing off the wind.

I.14. TURNING A VESSEL IN SMALL AREAS WITH A TUG-BOAT

Conditions under which the manoeuvring is performed

Calm weather: environmental conditions not significantly affecting the manoeuvring

Figure I.14.

Brief description of the manoeuvring

The most effective method to turn a vessel in calm weather with the assistance of a single tugboat consists in the latter positioning itself as near to the bow as possible and pushing perpendicular to the side bow curve, with which, apart from giving the bow a good turn, makes the vessel go astern. Engine ahead is given to counteract the latter effect and the rudder is set hard over to the side to which it is wished to turn, with which the stern will veer in a direction opposite to the bow and a turning moment additional to the tugboat's will be produced making the vessel rotate practically in its position as, in addition, the longitudinal and transverse thrusts are offset.

If the vessel has two propellers, the foregoing effect will be reinforced by rotating one ahead and the other astern, as described in figure I.13.

Remarks

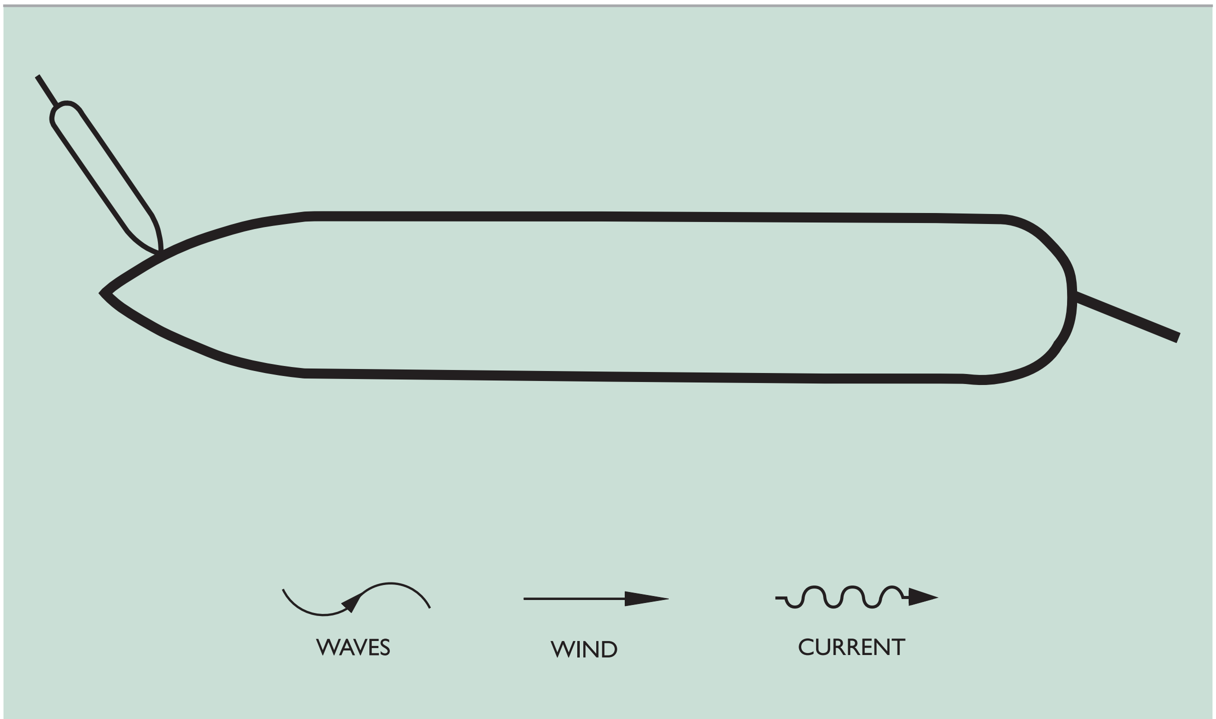
The effect of a bow thruster is equivalent to the tugboat's component in that direction, but the longitudinal thrust of the propeller going ahead cannot be offset and, therefore, the manoeuvring calls for larger spaces.

I.15. TURNING A VESSEL IN SMALL AREAS WITH A TUG-BOAT

Conditions under which the manoeuvring is performed

Strong wind, waves or current

Figure I.15.



Brief description of the manoeuvring

The tugboat should be used in this case to make fast the bow (or stern), taking advantage of the action of external agents to cause the vessel to turn. In the case whereby it is advisable to secure the bow to the tugboat, it will be positioned on the curve of the side bow, pushing ahead or astern as appropriate. If what is intended is to make fast the stern, the position of the tugboat pushing is less efficient since it cannot approach this end of the vessel as much as it did at the bow, apart from being affected by the interaction of the flow of water between the ship and the tugboat, particularly if the ship gives engine astern. This is why it is advisable to use the tugboat working in a pulling tow should the stern be made fast.

The vessel will give engine ahead or astern and will make use of the rudder as required depending on the direction in which external forces are acting. Should the vessel have twin screws, turning will be reinforced by making one propeller rotate ahead and the other astern, as described in figure I.13.

Remarks

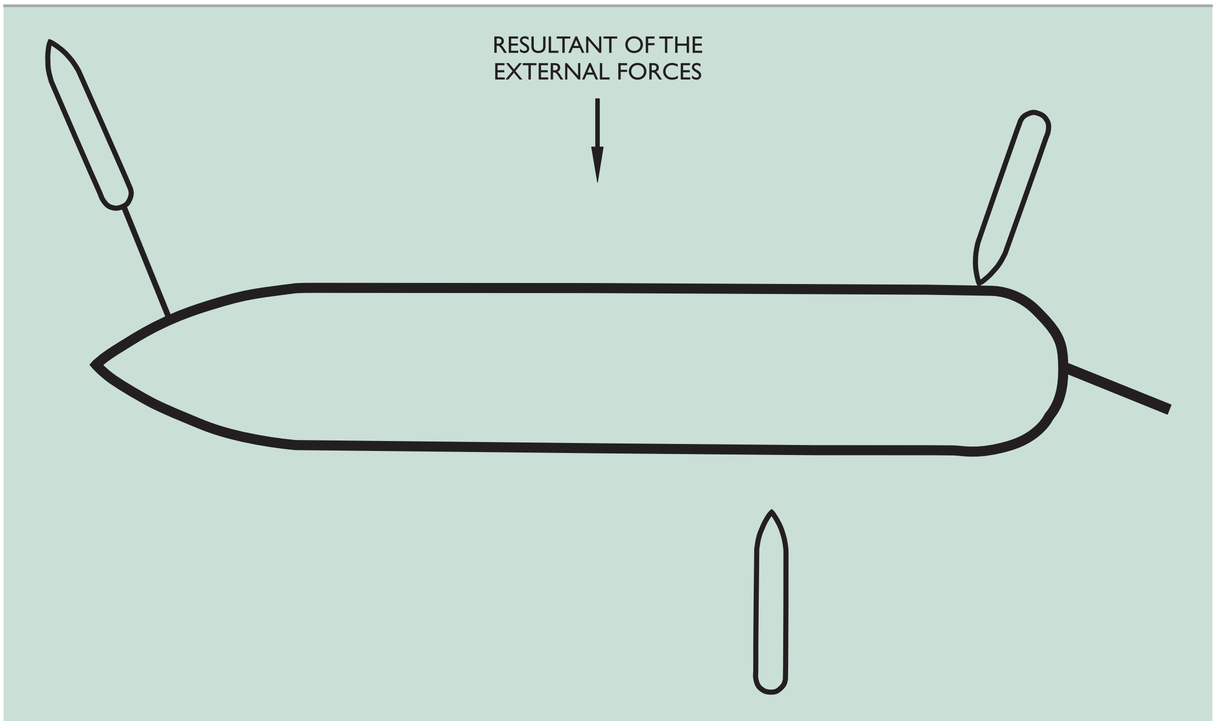
The effect of a bow or stern thruster is equivalent to the tugboat's component in this direction, but it cannot provide the longitudinal thrust offsetting the vessel propeller's longitudinal thrust which needs to be applied during the manoeuvring.

I.16. TURNING A VESSEL IN SMALL AREAS WITH TWO OR MORE TUGBOATS

Conditions under which the manoeuvring is performed

Winds, waves or currents in any direction

Figure I.16.



Brief description of the manoeuvring

If two tugboats are available, different configurations may be adopted with one tugboat working at the bow and the other at the stern which contributes to create forces and moments balancing external forces and controlling the turning manoeuvring. The scheme shown has one tugboat pulling from the bow and the other, normally with higher horsepower, pushing on the stern where it can push giving engines ahead or pull giving engines astern, as appropriate. If there are more tugboats, it is advisable to have them awaiting orders or located to act as close to the vessel's centre as may be appropriate. See alternative schemes in figure I.17.

Remarks

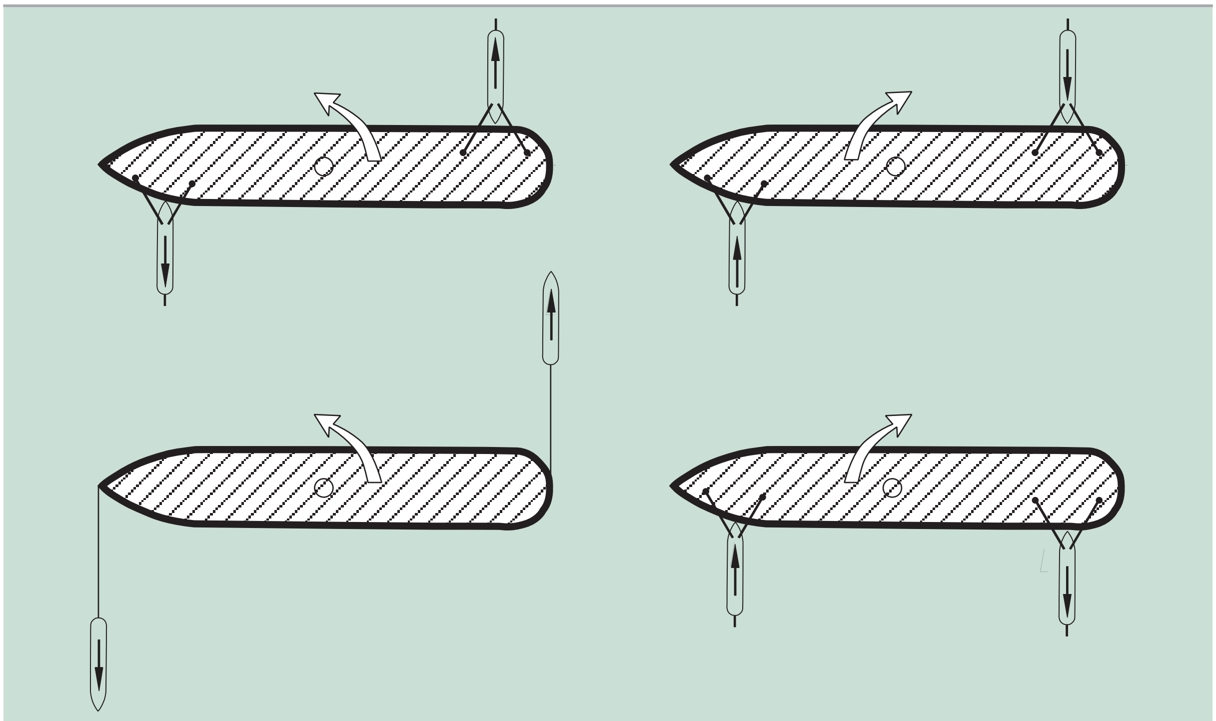
Using thrusters is equivalent to the transverse component of a tugboat working at the point where they are located.

I.17. TURNING A VESSEL IN SMALL AREAS WITH TWO OR MORE TUGBOATS

Conditions under which the manoeuvring is performed

Winds, waves or currents in any direction. Alternative manoeuvring

Figure I.17.



Brief description of the manoeuvring

The figure shows various possible configurations for a tugboat arrangement which may generate a moment of forces which turn the ship. Adopting whichever procedure depends on the type of tugboat available, on the environmental conditions under which the manoeuvring is being carried out, on the space available, etc. Should there be additional tugboats, they will be positioned closest to the vessel's centre reinforcing the position of the ship's end proving to be most unbalanced.

Remarks

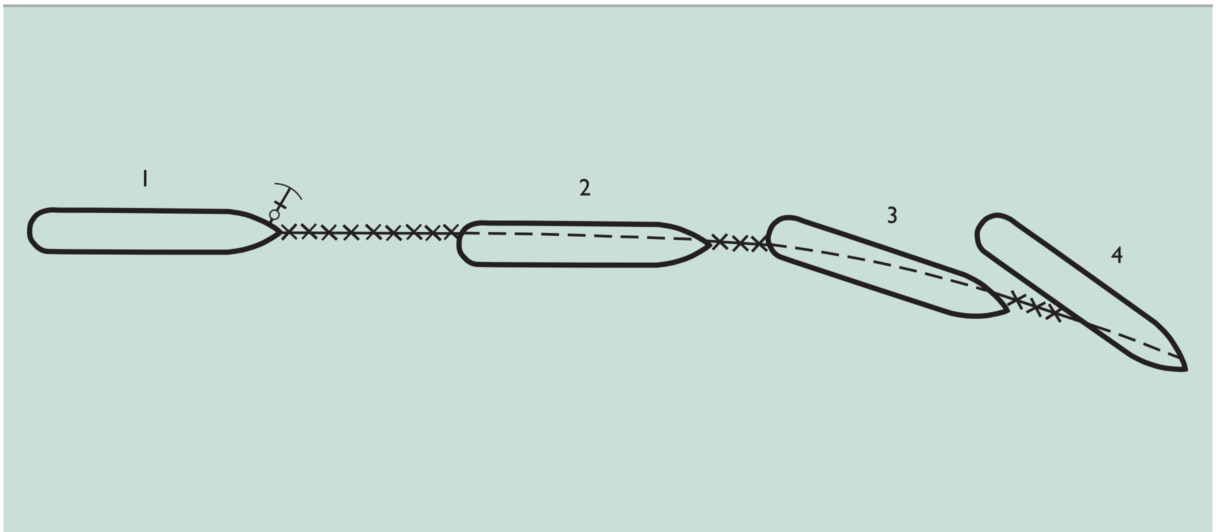
See alternative manoeuvring in figure I.16.

I.18. ANCHORING A VESSEL WITH A SINGLE ANCHOR

Conditions under which the manoeuvring is performed

Anchoring in calm weather with headway

Figure I.18.



Brief description of the manoeuvring

The vessel reaches the anchorage under suitable headway for passing the anchoring point in position (1) where it drops anchor, continuing its path when it sets engines astern to reduce the stopping distance, position (2) and the following. The chain is being paid out in the length required until headway stops without brusquely braking the winch to avoid excess stresses in the chain. At the end of the manoeuvring, positions (3) and (4), the vessel may turn and come abeam of the path. In any case, the chain will be laid working below the hull. Once the vessel has stopped, part of the chain can be pulled in and the vessel will then be in range with the anchoring point, in positions not shown in the figure.

Remarks

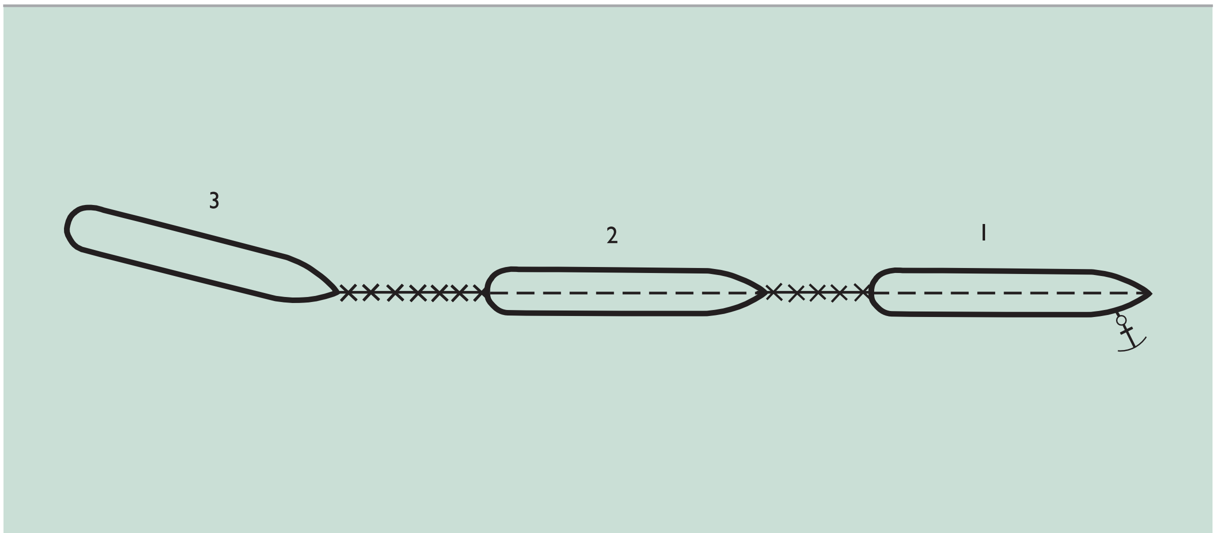
This method allows highly accurate anchoring because the rudder is operating until the anchor is let go. However, excessive stresses may occur in the chain, apart from leaving it under the hull, which may cause damage.

I.19. ANCHORING A VESSEL WITH A SINGLE ANCHOR

Conditions under which the manoeuvring is performed

Anchoring in calm weather with sternway

Figure I.19.



Brief description of the manoeuvring

The vessel arrives at the anchorage at a low speed, reaching the anchoring point in position (1) with the vessel practically stopped and the engines running astern so that once the anchor has been dropped and due to the sternway, it backs up along the approach route, position (2), letting the chain run out towards the bow. When the necessary length has been paid out, the winch brake will be gradually closed when the vessel still has some sternway, with which the chain will come under traction aiding the anchor to dig in. The vessel will be stopped in position (3) where the engine can still be set ahead or astern somewhat, as appropriate, to achieve the most suitable tension in the chain.

Remarks

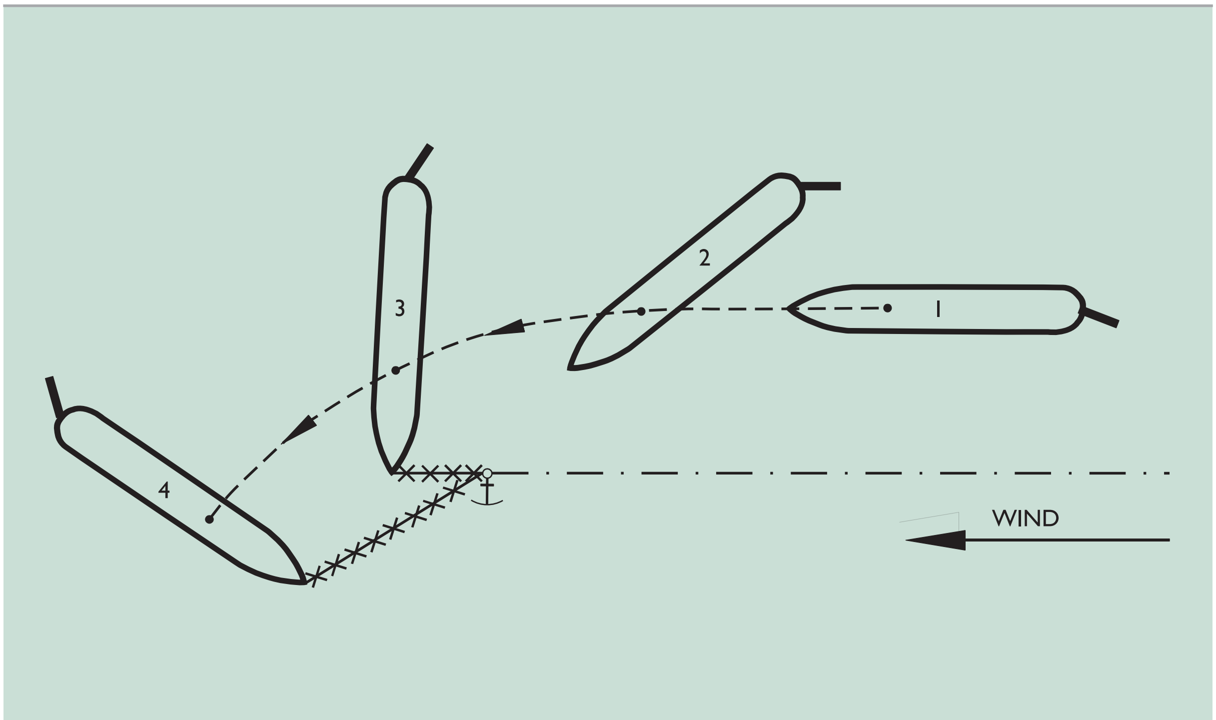
This method is more inaccurate at the anchoring point, since the vessel reaches it with no speed and no possibility of control. However, it always leaves the chain in front of the hull and allows the chain and anchor working conditions to be adjusted with greater accuracy.

I.20. ANCHORING A VESSEL WITH A SINGLE ANCHOR

Conditions under which the manoeuvring is performed

Strong wind

Figure I.20.



Brief description of the manoeuvring

When a strong wind blows, it is most desirable to make the approach, if feasible, in the wind's eye and use the anchoring method with sternway (similar to the case examined in figure I.19). Thus, the vessel will not cast and any unforeseen difficulty may be controlled better.

If it were not possible to perform this manoeuvring through lack of space and the wind were received on the beam, the effect of casting during the approach would have to be taken into account and offset with an alteration to course in order to endeavour to keep the vessel on the pre-set track when getting close to the anchorage, also bearing in mind the ship's tendency to turn to one or the other side when losing headway.

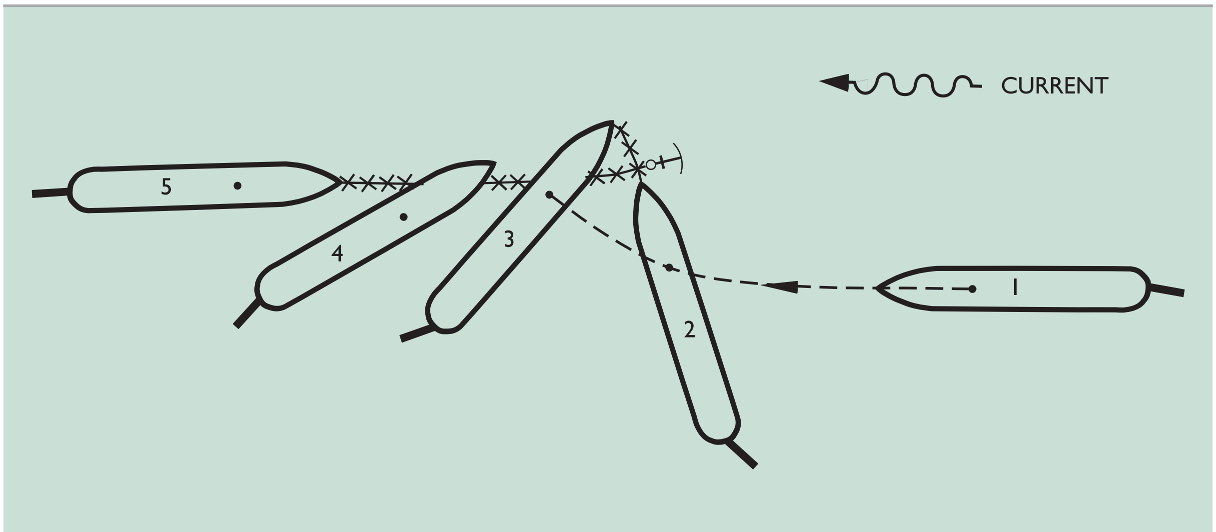
Remarks

I.21. ANCHORING A VESSEL WITH A SINGLE ANCHOR

Conditions under which the manoeuvring is performed

Heavy current

Figure I.21.



Brief description of the manoeuvring

When there is a strong current, and if feasible, what is most desirable is to make the approach with the bow to the current to prevent drift and use the anchoring method under sternway in a similar way as that described in figure I.19, with the additional advantage that the vessel may keep its capability of control, remaining practically stopped in relation to the seabed.

If conditions force anchoring with the current in favour and single screw vessels are involved, the procedure may be as shown in the diagram where the starboard anchor has been used to anchor, taking advantage of the effect of the propeller's transverse force on going astern and the chain tension to accelerate the turn and facilitate the anchor's work. A little before reaching the anchoring point, the rudder is set hard over to starboard and engine is given astern, with which the vessel turns to that side and drops anchor (2) while veering. If the vessel takes sternway, space will be provided ahead by changing the rudder to starboard (4) so that the bow reaches the current with the vessel slowly moving astern to prevent an excessive pull on the chain since the vessel is crossing the current, which could cause the anchor to drag.

If there are strong wind and current, criteria for anchoring as a function of the current will be generally taken, since its effects are usually far more noticeable.

Remarks

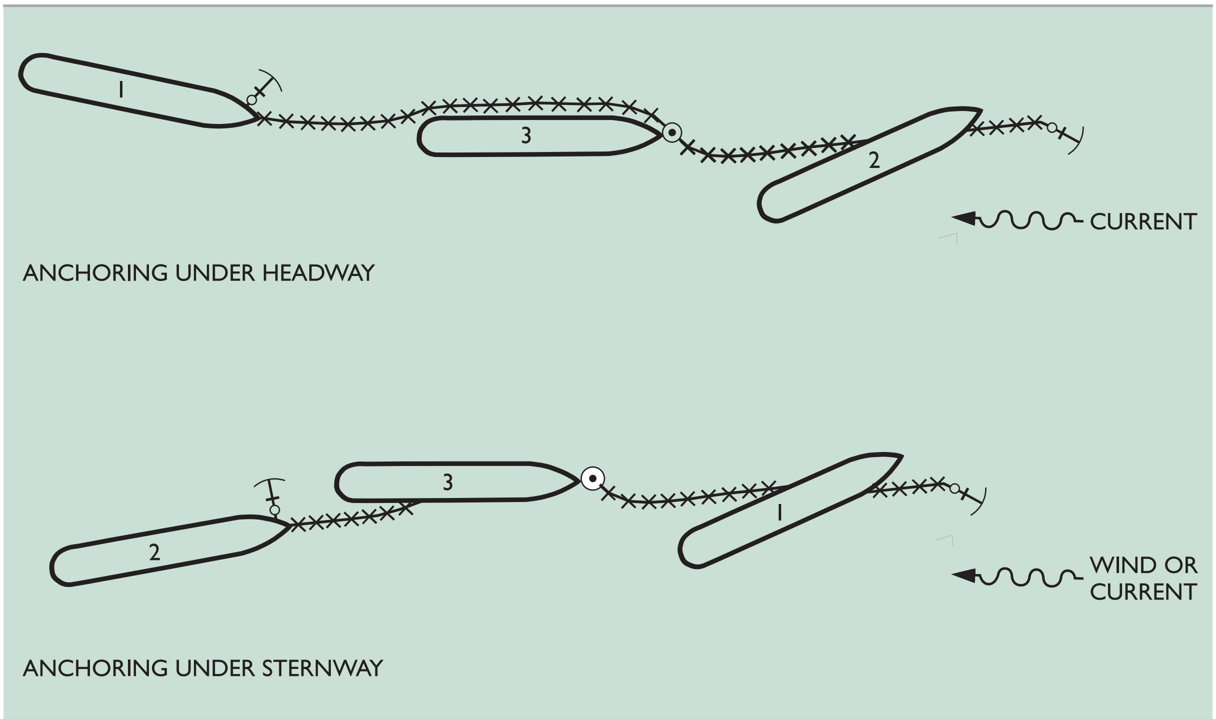
The anchoring manoeuvring in small areas with strong current is usually difficult and unsafe, and avoiding such is recommended, if feasible.

I.22. ANCHORING A VESSEL WITH TWO ANCHORS IN EBB AND FLOOD TIDE

Conditions under which the manoeuvring is performed

Winds or currents acting in the same direction but alternatively in opposite directions

Figure I.22.



Brief description of the manoeuvring

The anchoring manoeuvring may be performed under head or sternway as shown schematically in these figures, depending on whether the leeward (current sheltered) or windward (current against) anchor is dropped first. The manner in which these manoeuvring are performed is similar to that described in figures I.18 and I.19 respectively, going astern or ahead after having dropped the second anchor, hauling in the first chain and paying out the second until both are equal.

Remarks

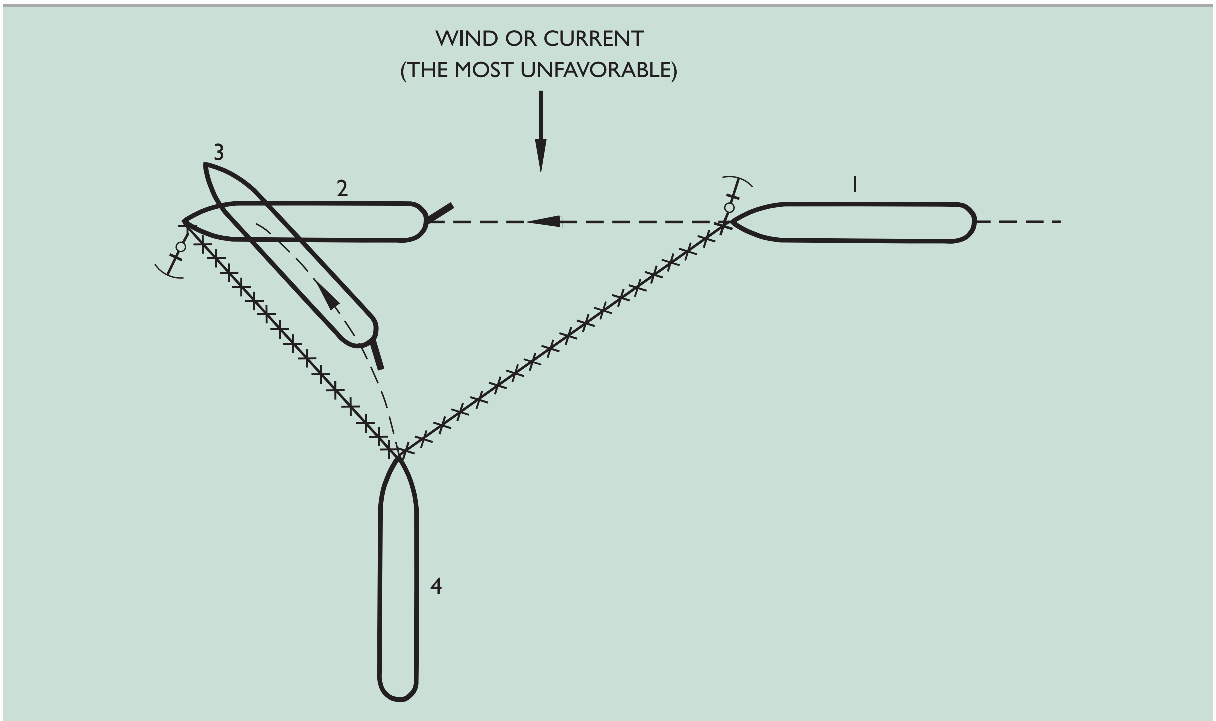
Anchoring with a flood or ebb tide is not applicable when there is wind or current transverse to the alignment defined by the two anchors.

I.23. ANCHORING A VESSEL WITH TWO ANCHORS DOWN

Conditions under which the manoeuvring is performed

Winds or currents in any direction, preferably transversely to the alignment of the anchors

Figure I.23.



Brief description of the manoeuvring

The vessel reaches position (1) which is the first anchoring point, sailing under headway and at a minimum speed to keep control. It drops the starboard anchor at that position, paying out chain without holding to stop the bow turning to that side. Before arriving at the second anchoring point, engines are set astern to cut off headway and the rudder is deflected to starboard to control the vessel's turn before dropping the port anchor (2). Once this anchor has been dropped, the starboard anchor chain is made fast causing the bow to turn towards position (3) before starting the run astern with rudder to port until the final position (4) is reached.

Remarks

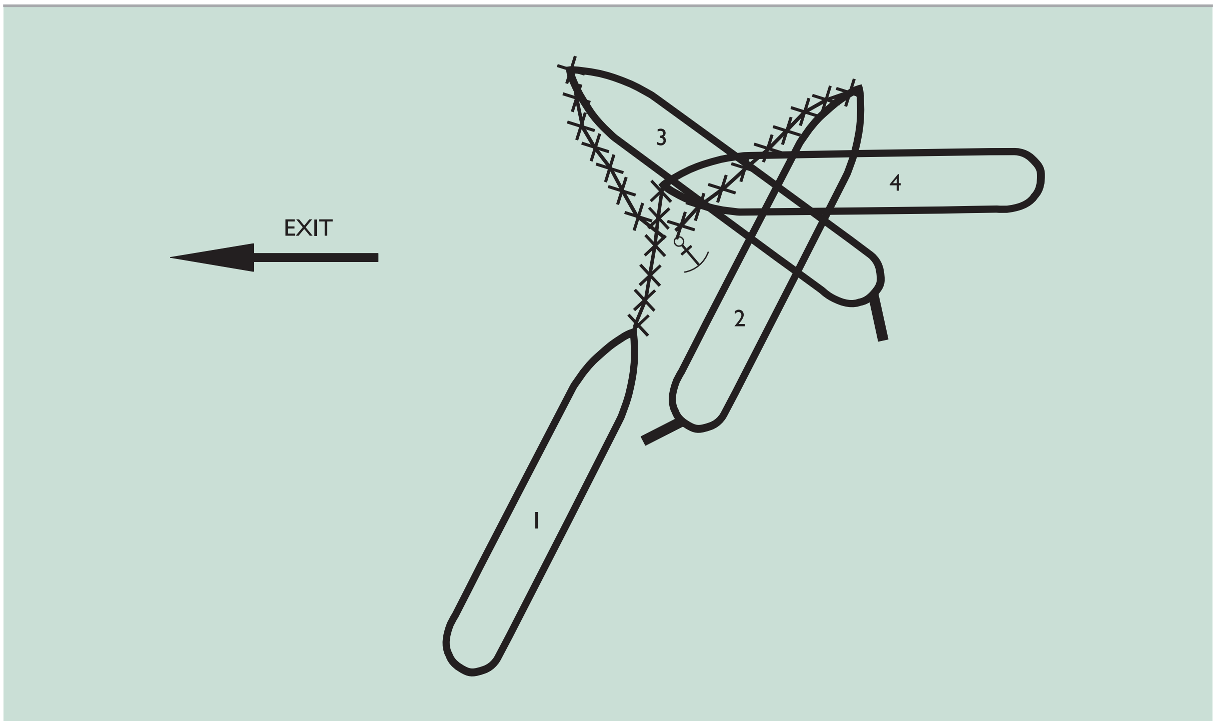
Should the wind and current expected not act in the same direction, anchoring will be guided by taking into account the most unfavourable effect, which will normally be the current.

I.24. DEPARTING AN ANCHORAGE WITH A SINGLE ANCHOR

Conditions under which the manoeuvring is performed

Calm weather: environmental conditions not significantly affecting the manoeuvring or with a wind

Figure I.24.



Brief description of the manoeuvring

To leave an anchorage in calm weather, it is advisable to first head the vessel to the exit and this is achieved by turning it on the anchor. Starting from position (1) where the vessel is anchored, engine is put ahead with the rudder amidships, with which the ship will move towards the anchor. When reaching position (2), the chain will be hauling round the stern and on setting the engine a little ahead and deflecting the rudder to port, the vessel will turn to position (3) where the anchor can be hauled in and the bow will move to the point where it is anchored. The anchor can then be weighed and the vessel will be heading for the exit (4).

If there is a wind, the anchorage leaving manoeuvring is simple, since the ship will easily turn to one or the other side. If the exit course is crosswind, much precaution must be taken whilst weighing the anchor so as not to receive the wind on the bow on the side to which the ship should turn to move towards the exit. If this happens, it will be very difficult to turn the ship against the wind.

Remarks

If the vessel has twin screws, the turning manoeuvring for heading towards the exit is much quicker since it suffices to set the propeller on the side opposite to the dropped anchor ahead.

Annex II

General provisions on ships´ routeing

(Extracted from OMI. Resolution A.572)

GENERAL PROVISIONS ON SHIP'S ROUTEING (Extracted from OMI resolution A.572)

Annex II

1. OBJECTIVES

1.1. The purpose of ships' routeing is to improve the safety of navigation in converging areas and in areas where the density of traffic is great or where freedom of movement of shipping is inhibited by restricted sea-room, the existence of obstructions to navigation, limited depths or unfavourable meteorological conditions.

1.2. The precise objectives of any routeing system will depend upon the particular hazardous circumstances which it is intended to alleviate, but may include some or all of the following:

1. the separation of opposing streams of traffic so as to reduce the incidence of head-on encounters;
2. the reduction of dangers of collision between crossing traffic and shipping in established traffic lanes;
3. the simplification of the patterns of traffic flow in converging areas;
4. the organization of safe traffic flow in areas of concentrated offshore exploration or exploitation;
5. the organization of traffic flow in or around areas where navigation by all ships or by certain classes of ship is dangerous or undesirable;
6. the reduction of risk of grounding to providing special guidance to vessels in areas where water depths are uncertain or critical;
7. the guidance of traffic clear of fishing grounds or the organization of traffic through fishing grounds.

2. DEFINITIONS

2.1. The following terms are used in connection with matters related to ships' routeing (These terms are included in the part I of this ROM.The terms marked with (*) are used in the 1972 Collision Regulations):

1. *Routeing system*

   Any system of one or more routes or routeing measures aimed at reducing the risk of casualties. It includes traffic separation schemes, two-way routes, recommended tracks, areas to be avoided, inshore traffic zones, roundabouts, precautionary areas and deep water routes.

2. *Traffic separation scheme* *

   A routeing measure aimed at the separation of opposing streams of traffic by appropriate means and by the establishment of traffic lanes.

3. *Separation zone or line* *

   A zone or line separating the traffic lanes in which ships are proceeding in opposite or nearly opposite directions; or separating a traffic lane from the adjacent sea area; or separating traffic lanes designated for particular classes of ship proceeding in the same direction.

4. *Traffic lane* *

   An area within defined limits in which one-way traffic is established. Natural obstacles, including those forming separation zones, may constitute a boundary.

5. *Roundabout*

   A routeing measure comprising a separation point or circular separation zone and a circular traffic lane within defined limits.Traffic within the roundabout is separated by moving in a counterclockwise direction around the separation point or zone.

6. *Inshore traffic zone* *

A routeing measure comprising a designated area between the landward boundary of a traffic separation scheme and the adjacent coast, to be used in accordance with the provisions of rule 10(d), as amended, of the International Regulations for Preventing Collisions at Sea (Collision Regulations), 1972.

7. *Two-way route*

A route within defined limits inside which two-way traffic is established, aimed at providing safe passage of ships through waters where navigation is difficult or dangerous.

8. *Recommended route*

A route of undefined width, for the convenience of ships in transit, which is often marked by centre line buoys.

9. *Recommended track*

A route which has been specially examined to ensure so far as possible that it is free of dangers and along which ships are advised to navigate.

10. *Deep water route*

A route within defined limits which has been accurately surveyed for clearance of sea bottom and submerged obstacles as indicated on the chart.

11 *Precautionary area*

A routeing measure comprising an area within defined limits where ships must navigate with particular caution and within which the direction of traffic flow may be recommended.

12 *Area to be avoided*

A routeing measure comprising an area within defined limits in which either navigation is particularly hazardous or it is exceptionally important to avoid casualties and which should be avoided by all ships, or certain classes of ship.

13. *Established direction of traffic flow*

A traffic flow pattern indicating the directional movement of traffic as established within a traffic separation scheme.

14. *Recommended direction of traffic flow*

A traffic flow pattern indicating a recommended directional movement of traffic where it is impractical or unnecessary to adopt an established direction of traffic flow.

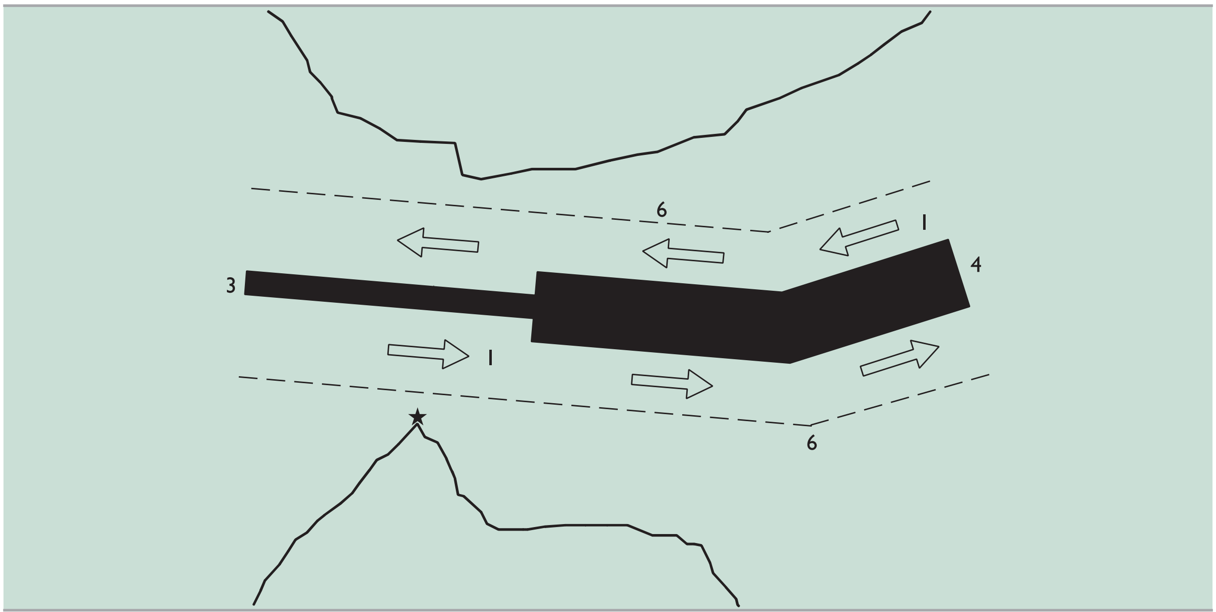
3. METHODS

In meeting the objectives set out in section 1 the following are among the methods which may be used:

3.1. The separation of opposing streams of traffic by separation zones, or lines where zones are not possible

In this method, streams of traffic proceeding in opposite or nearly opposite directions are separated by separation zones (4) or lines (3). The use of zones is to be preferred, but in narrow passages and restricted waters it may be necessary to use a separation line rather than a zone so as to allow more navigable space in the traffic

Figure II.01. ***Traffic separation by zone and line***

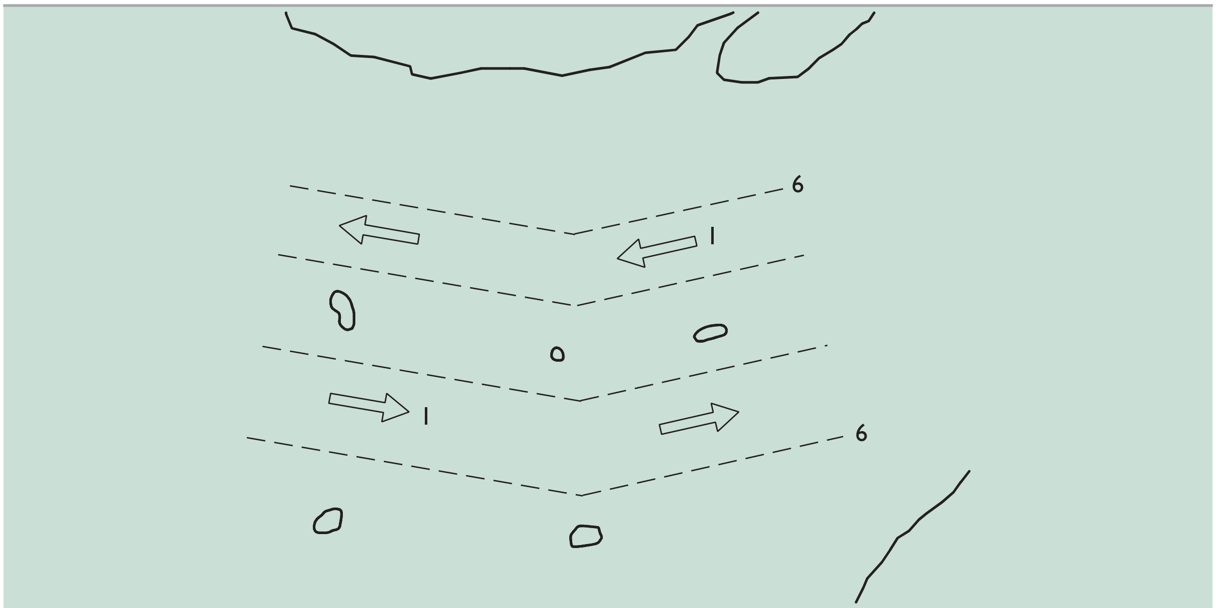


lanes. A length of separation line may also be substituted for a zone in positions where this may encourage and facilitate correct procedures by crossing traffic. The outside limits (6) of such traffic separation schemes are the outer boundaries of the traffic lanes. The arrows (1) indicate the established direction of traffic flow.

3.2. The separation of opposing streams of traffic by natural obstructions and geographically defined objects.

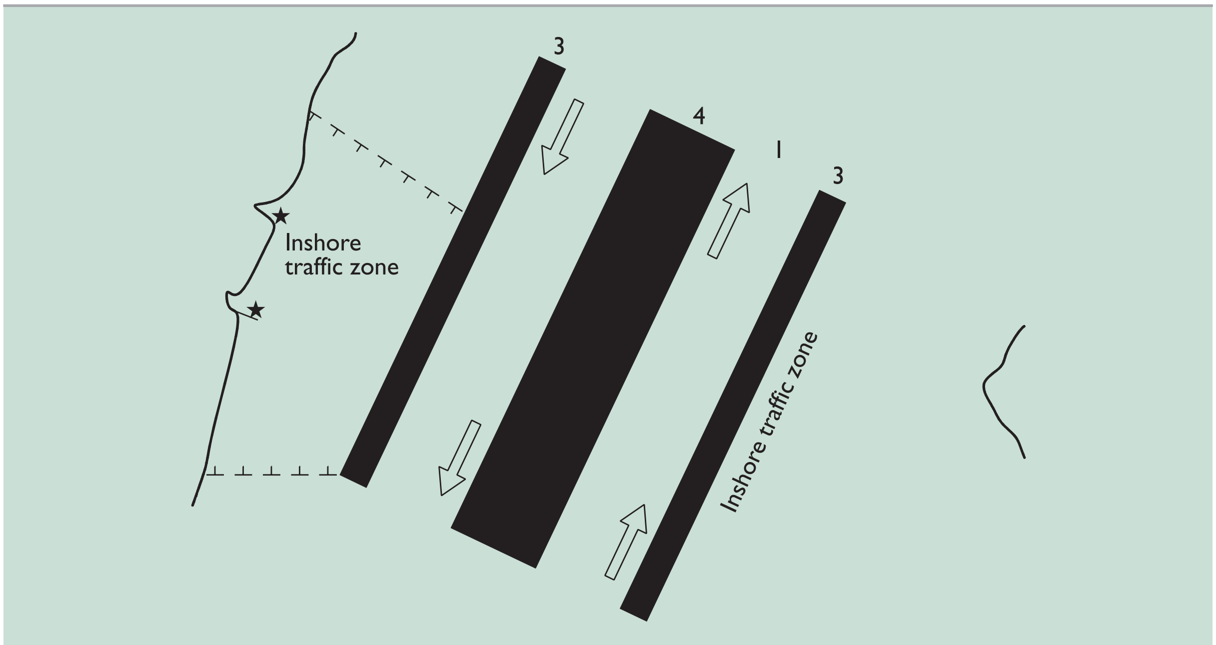
This method is used where there is a defined area with obstructions such as islands, shoals or rocks restricting free movement and providing a natural division for opposing traffic streams.

Figure II.02. ***Separation of traffic by natural obstructions***



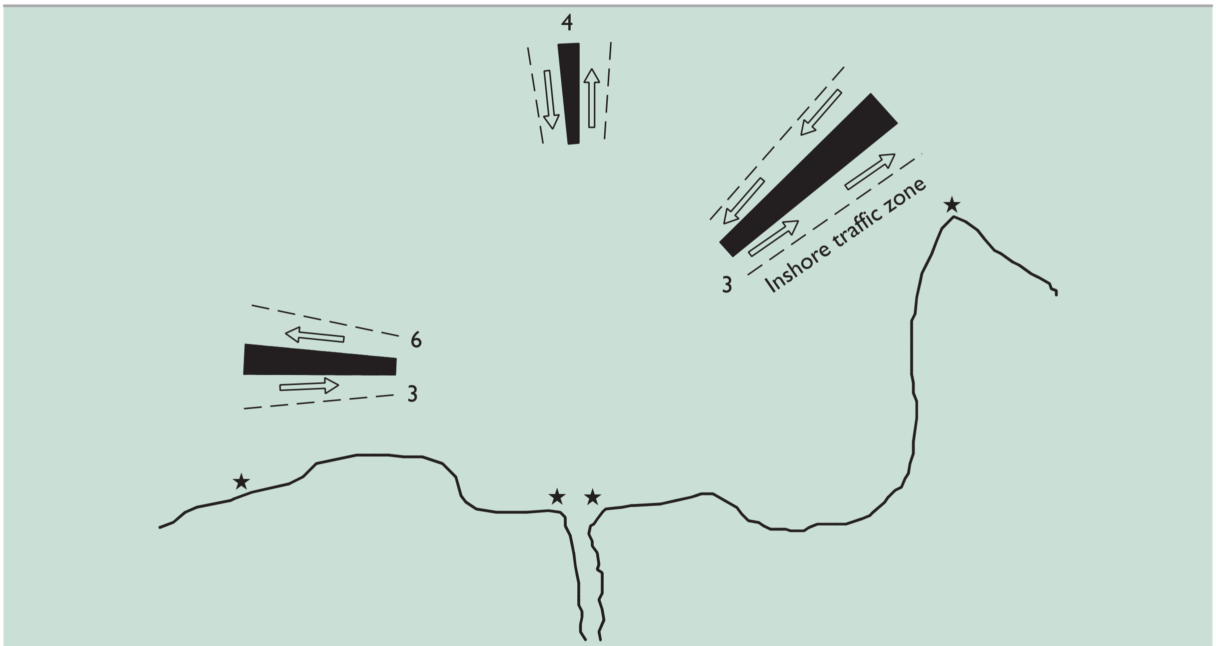
II.3.3. The separation of through and local traffic by providing inshore traffic zones

Figure II.03. ***Inshore traffic zones at a crossing***



Beyond the outside limits of traffic separation schemes, ships may navigate in any direction. Where such areas lie between the traffic separation scheme and the coast they may be designated as inshore traffic zones (see also figures 4 and 10), with the purpose of keeping local traffic clear of the traffic separation scheme which should be used by through traffic.

Figure II.04. ***Sectorial division of adjacent traffic separation schemes at approaches to focal points***



Traffic in inshore traffic zones is separated from traffic in the adjacent traffic lane by separation zones (4) or by separation lines (3) (see also figures 4 and 10).

3.4. The sectorial division of adjacent traffic separation schemes at approaches to focal points

This method is used where ships converge at a focal point or a small area from various directions. Port approaches, sea pilot stations, positions where landfall buoys or light vessels are located, entrances to channels, canals, estuaries, etc. may be considered as such focal points.

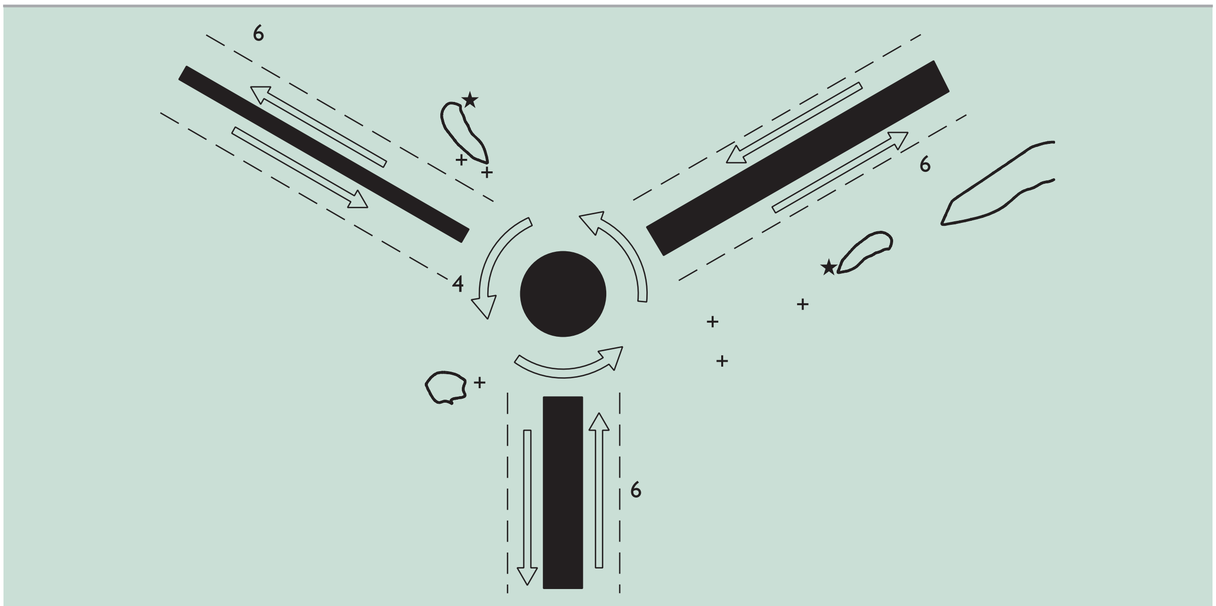
3.5. The routeing of traffic at focal points and route junctions where traffic separation schemes meet

The routeing measure to be utilized at focal points, route junctions and intersections should be selected from the most appropriate of the following methods:

3.5.1. Roundabouts

If the need can be demonstrated, a roundabout may be used to guide traffic counterclockwise round a circular separation zone (4) or specified point, as illustrated above.

Figure II.05. ***Sepatation of traffic at a roundabout***



3.5.2. Junctions

These methods are used where two routes join or cross. The directions of traffic flow are established in the lanes of the adjoining schemes. The separation zone may be interrupted, as shown in figures 6 and 7, or replaced by a separation line, as shown in figure 8, in order to emphasize the correct method of crossing by traffic changing from one scheme to the other.

Figure II.06. ***Separation of traffic at a crossing***

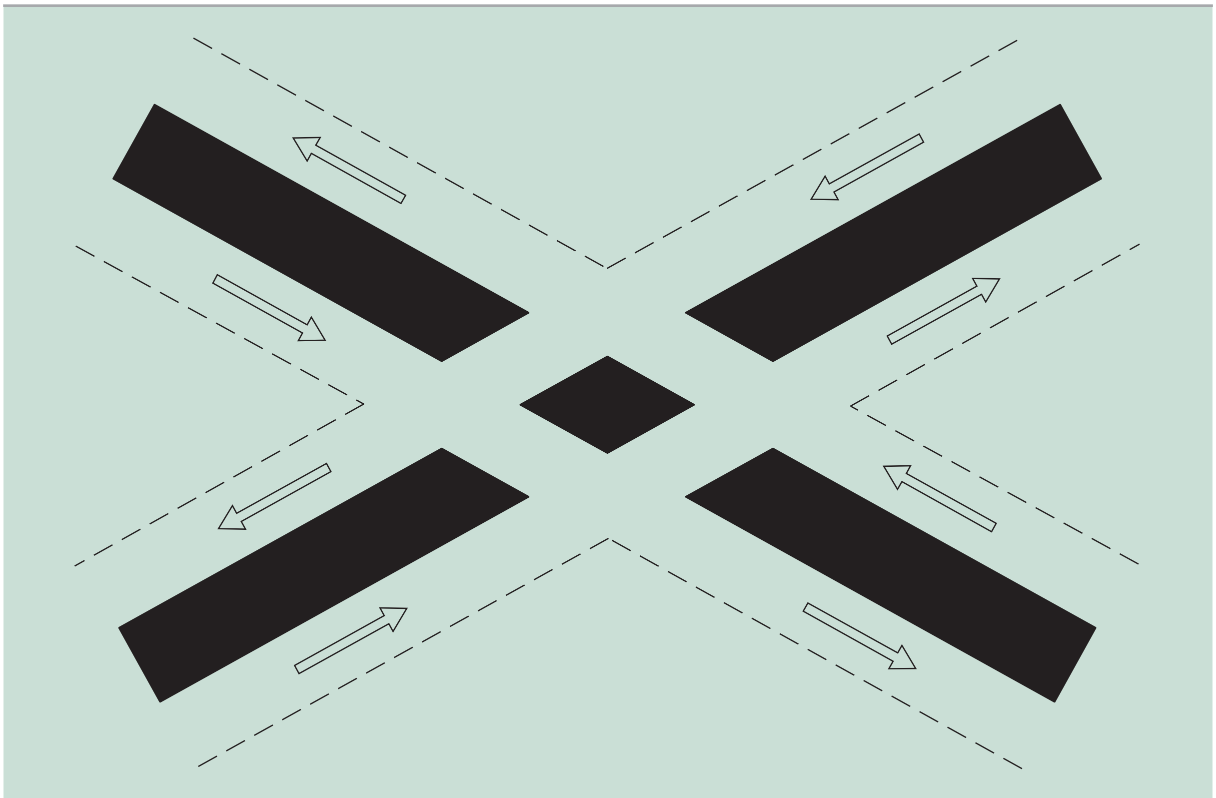


Figure II.07. ***Separation of traffic at a junction***

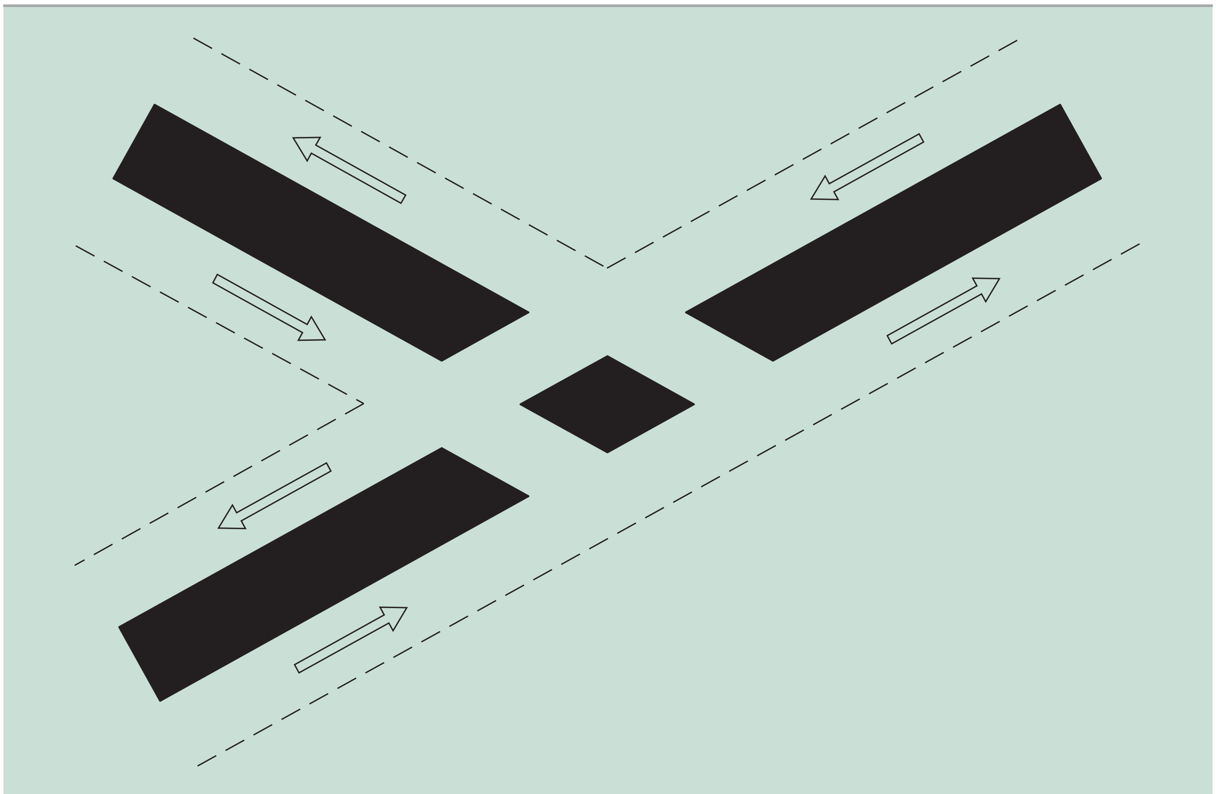
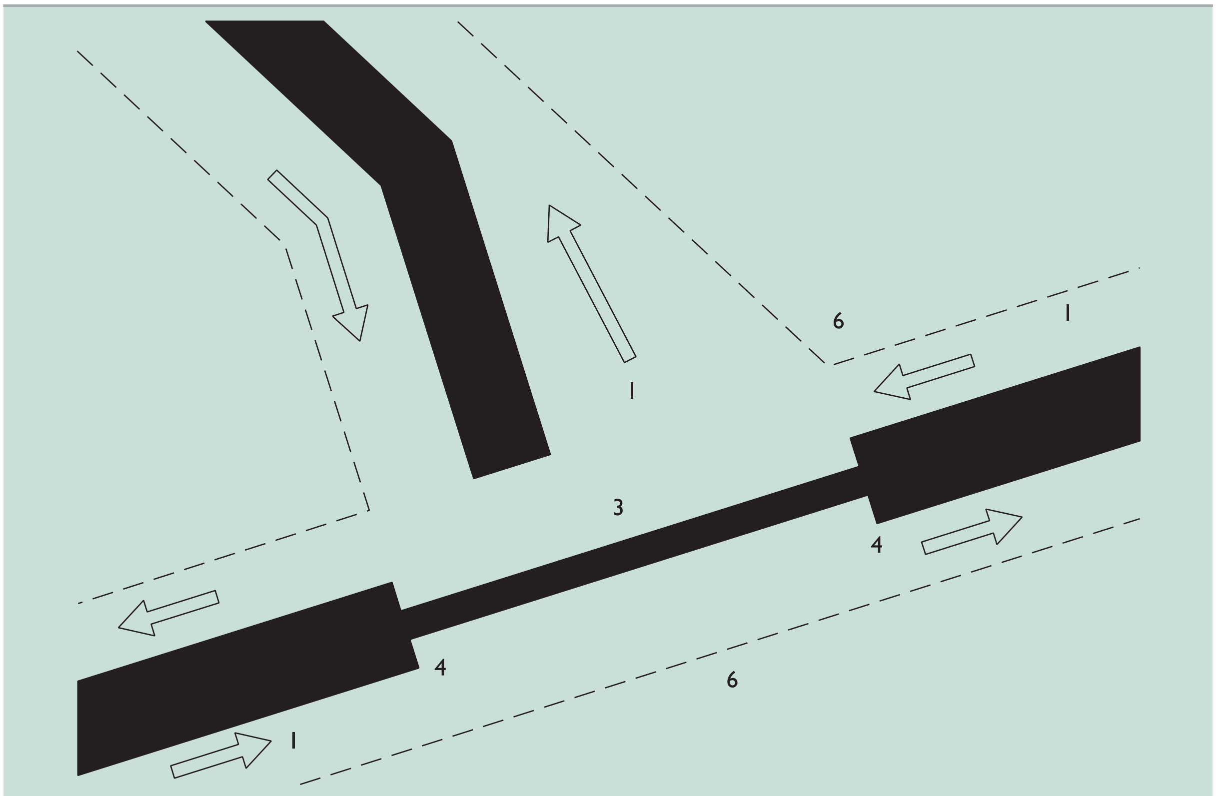


Figure II.08. ***A junction, showing a separation line substituted fo a zone, where there will be crossing traffic***



3.5.3. *Precautionary areas*

When routes converge, it may be best to terminate them clear of their potential joining points and in such a case a precautionary area (9) can be instituted so as to emphasize the need for care in navigation. Figures 9 and 10 illustrate the use of such an area at focal points; a direction of traffic flow may be recommended (2) around the focal point, as shown in figure 10.

Figure 11 gives an example of how a precautionary area (9) can be used at a junction with crossing traffic. The traffic lanes are terminated short of the point where traffic is expected to cross and replaced by a precautionary area within which the recommended directions of traffic flow (2) are indicated. Precautionary areas may also be used at the termination of any single route.

3.6. Other routeing methods

Other routeing methods which may be used are as shown in figures 12 to 18:

a. deep-water routes (figures 12 and 13);

b. areas to be avoided (figures 10 and 18);

c. recommended directions of traffic flow (figure 14), two-way routes (figure 15) and recommended routes and tracks through areas where navigation is difficult or dangerous (figures 16 and 17).

Figure II.09. **Precautionary area at a focal point**

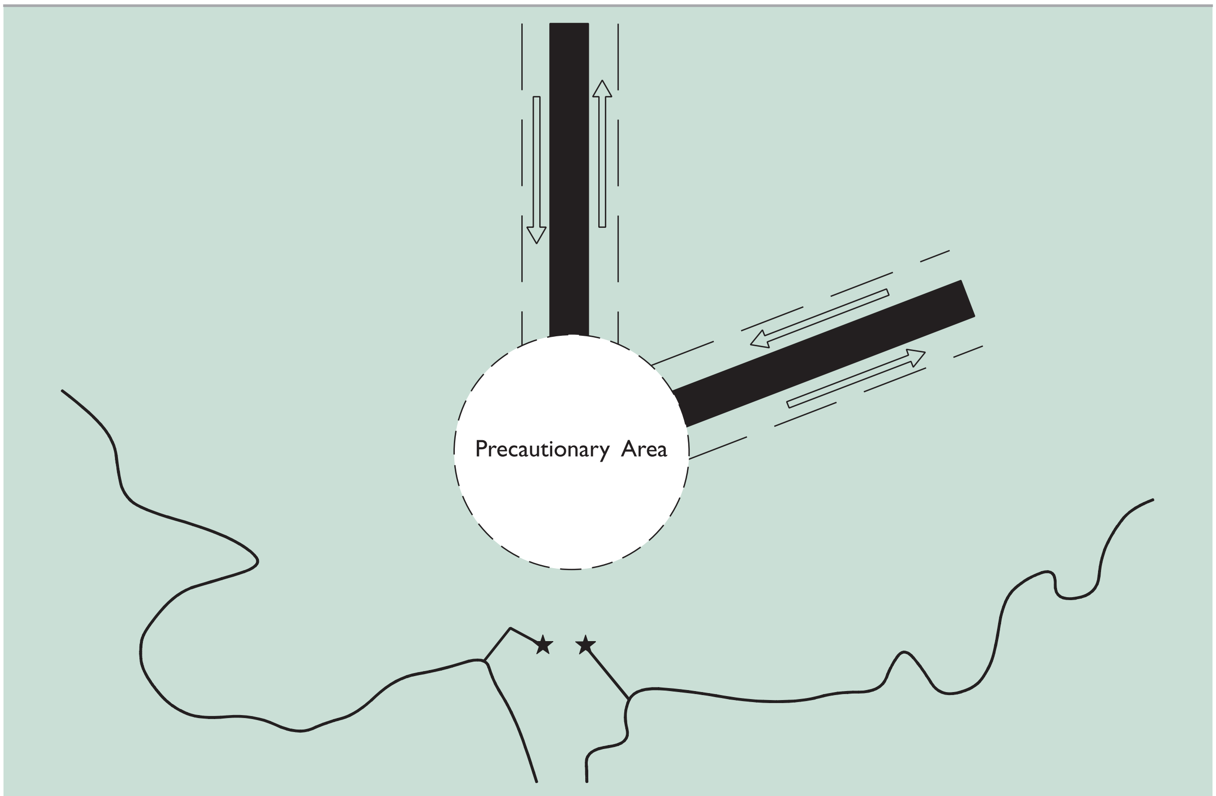


Figure II.10. **Precautionary area with recommended direction of traffic flow around an area to be avoided**

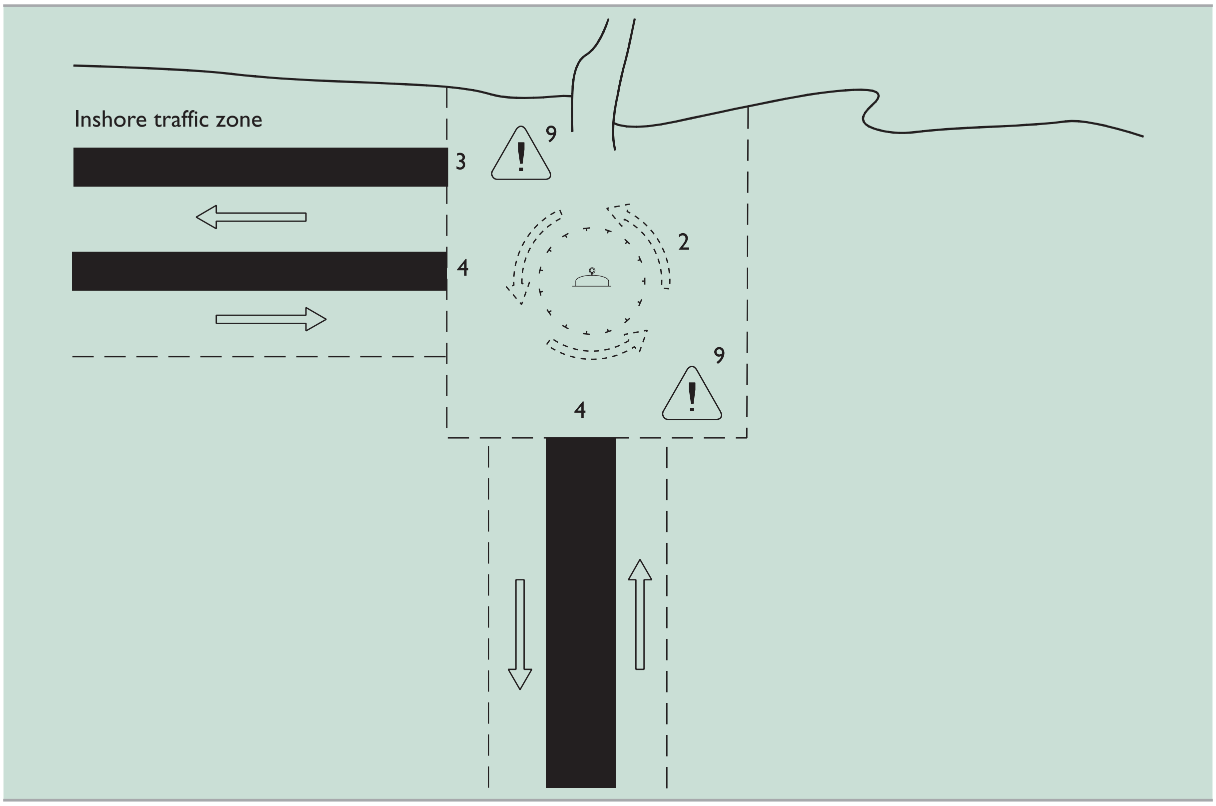


Figure II.11. ***Precautionary area at a junction, with recommended directions of traffic flow***

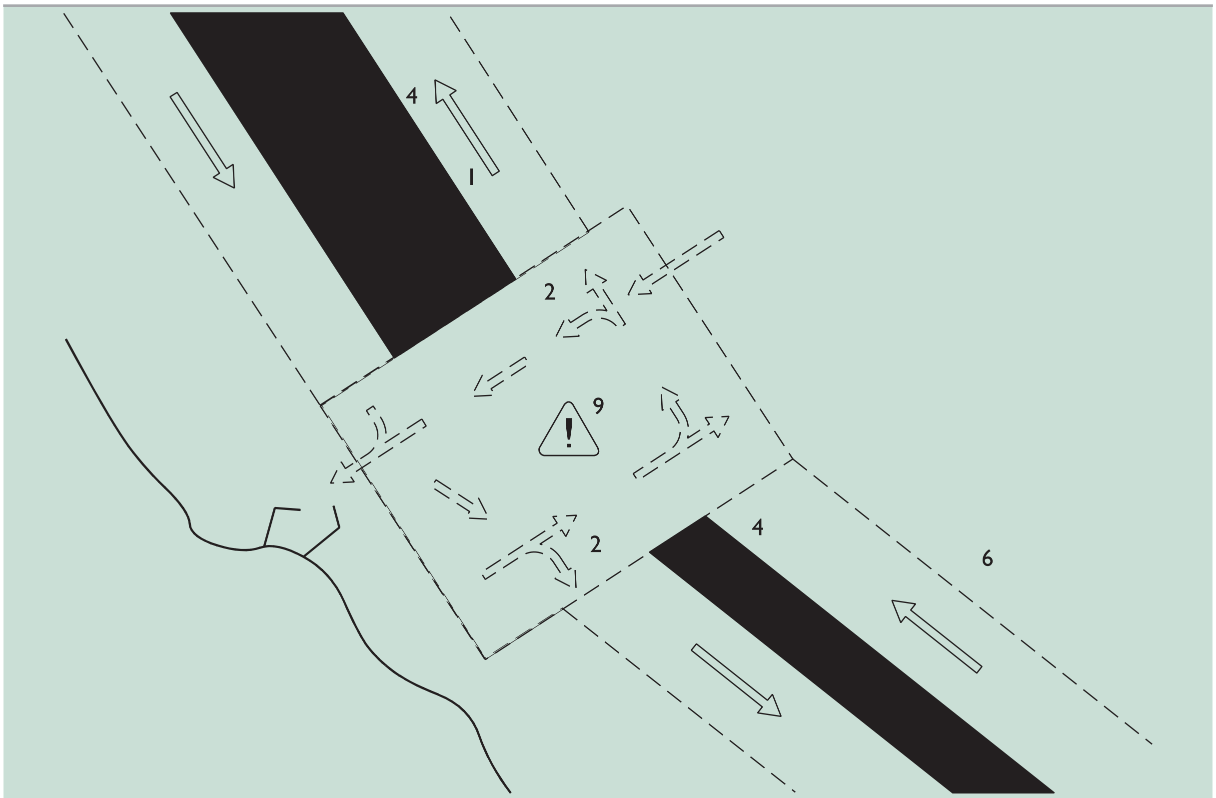


Figure II.12. ***Deep-water route (two-way)***

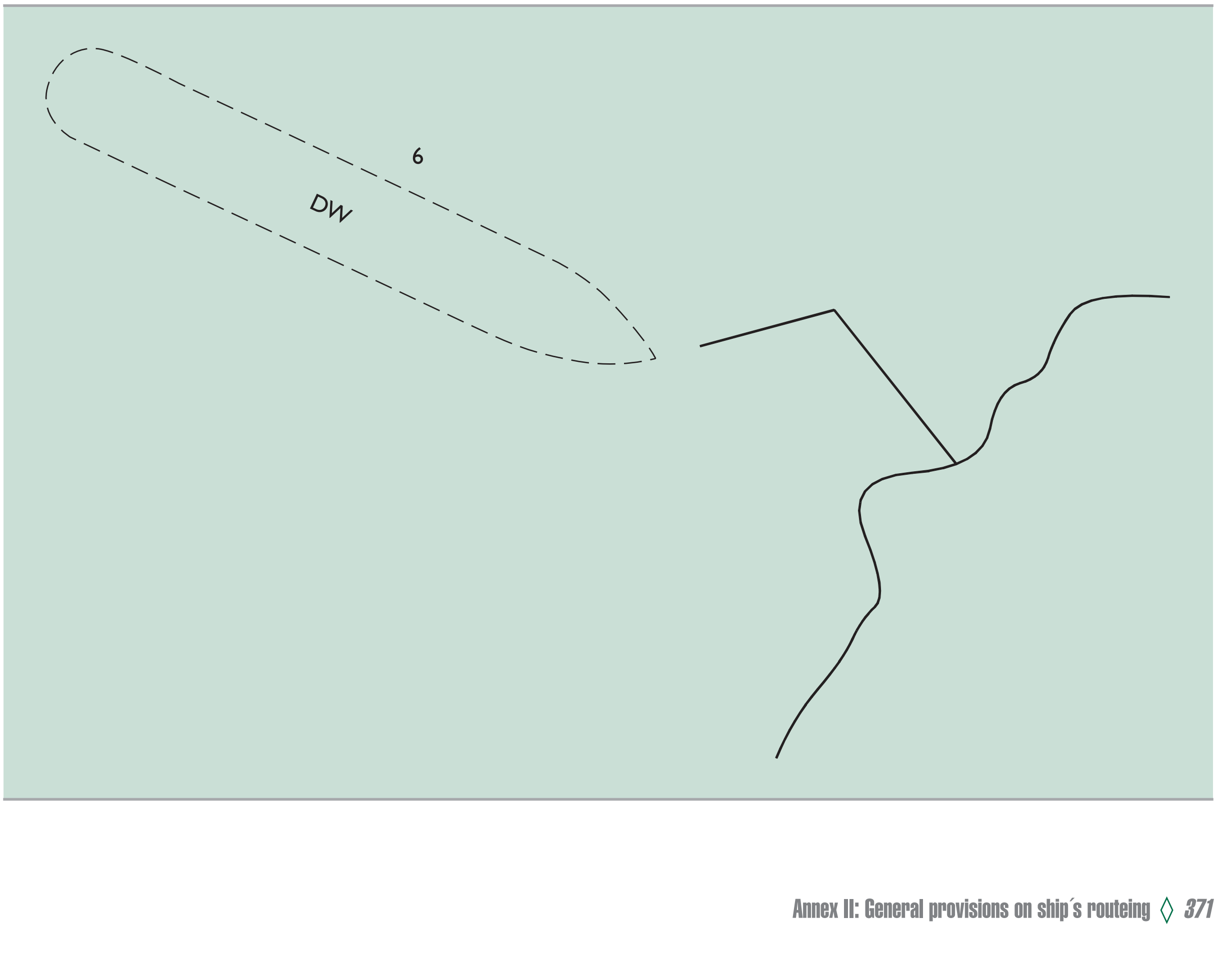


Figure II.13. ***One-way deep-water route (within a traffic lane)***

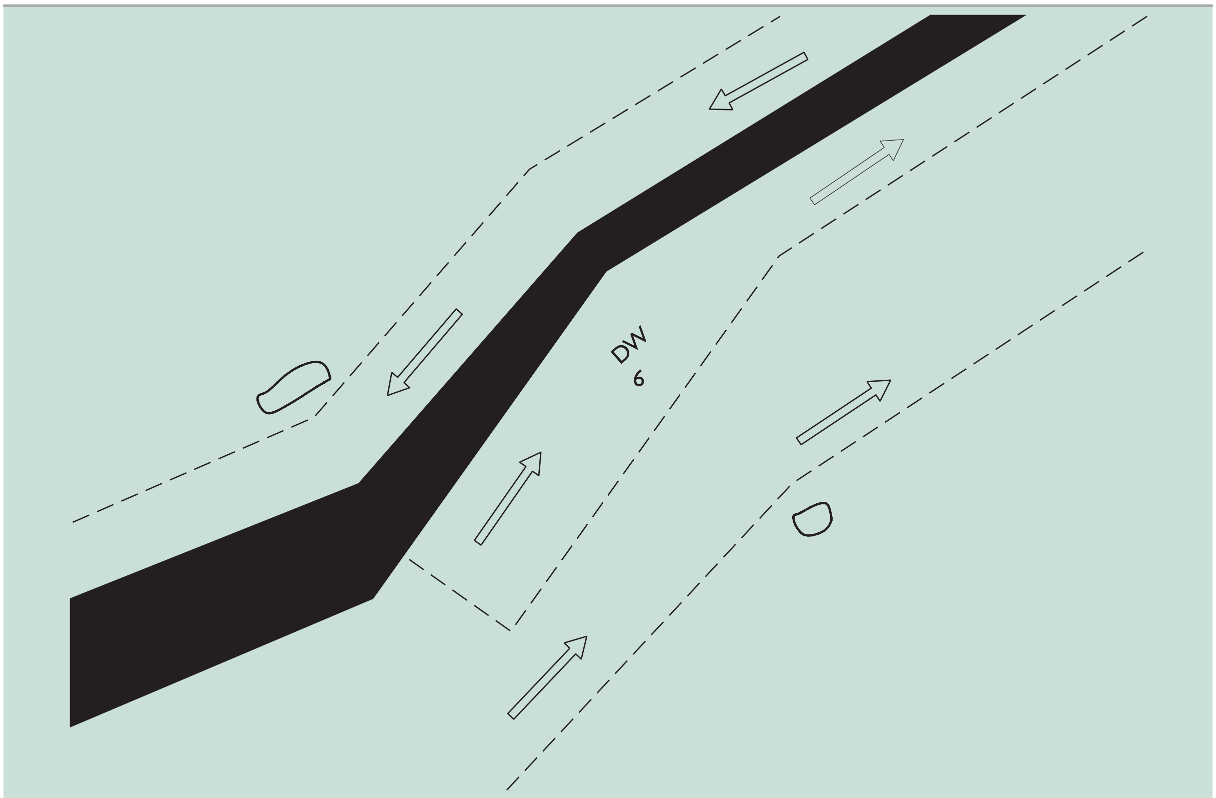


Figure II.14. ***Recommended directions of traffic flow between two traffic separation schemes***

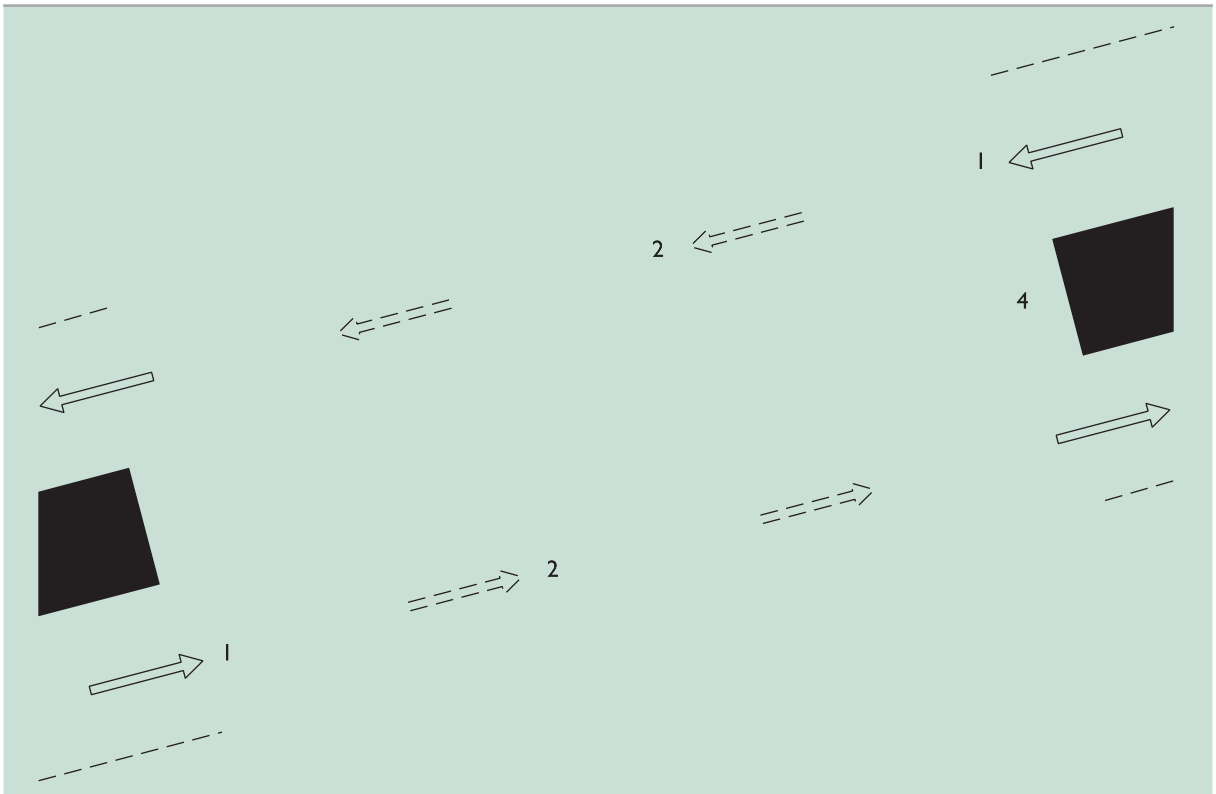


Figure II.15. **Two-way route (with one-way sections)**

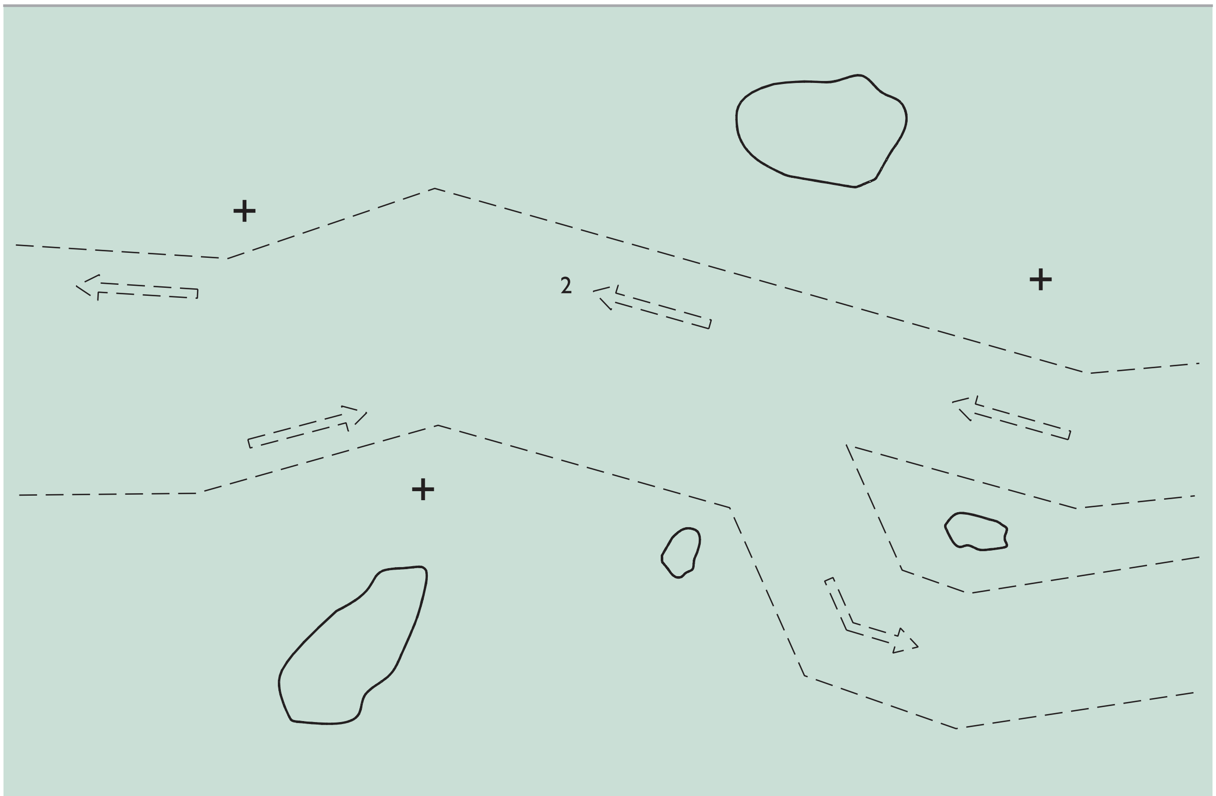


Figure II.16. **Recommended routes**

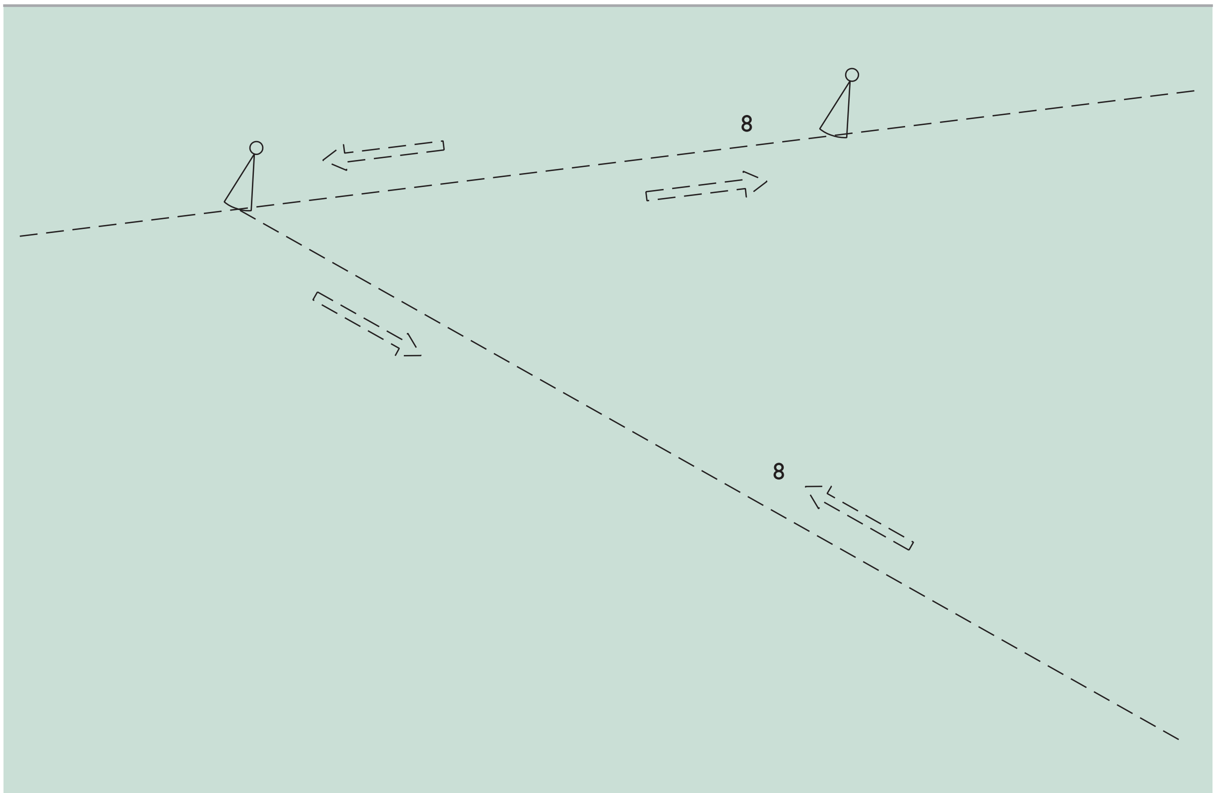
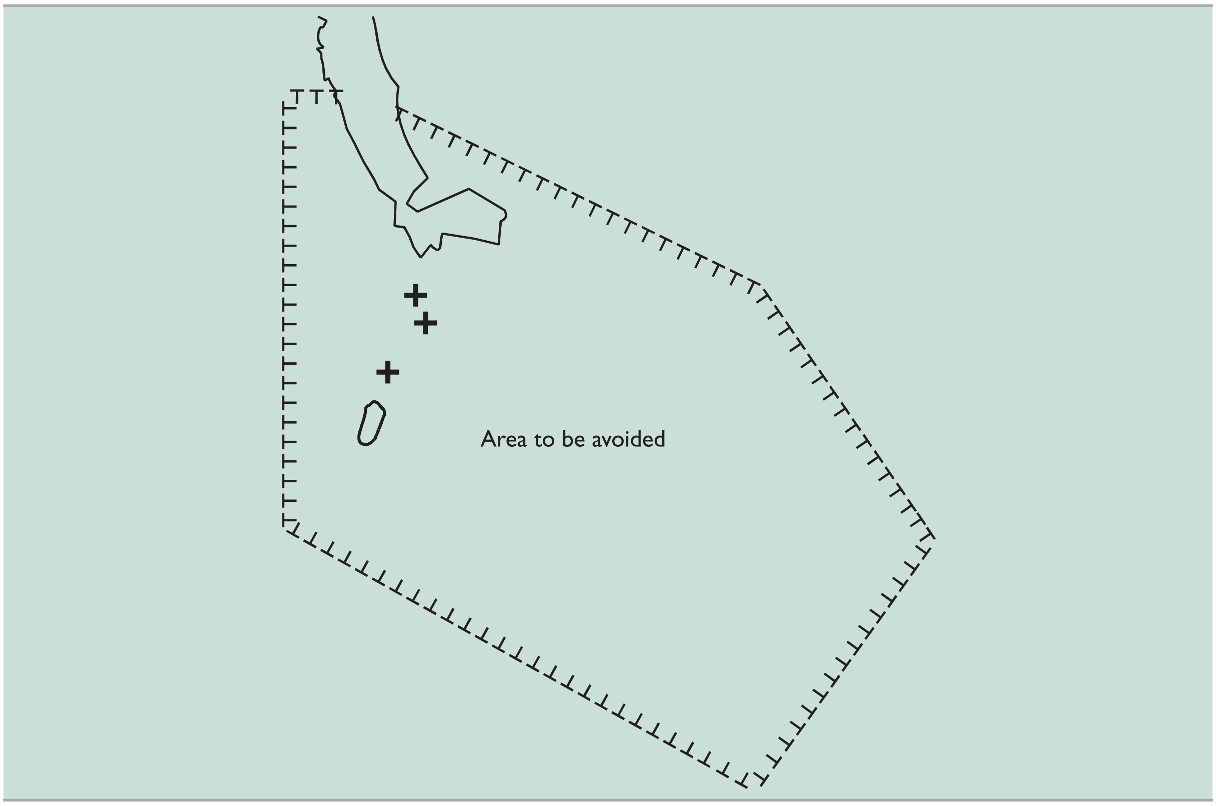


Figure II.17. **Recommended tracks (in blacks)**

Figure II.18. **Area to be avoided**



4. PLANNING

4.1. Routeing systems should only be established when safety of navigation in the area can thereby be clearly improved.

4.2. The routeing system selected for a particular area should aim at providing safe passage for ships through the area without unduly restricting legitimate rights and practices, and taking account of anticipated or existing navigational hazards.

4.3. When planning, establishing, reviewing or adjusting a routeing system, the following factors shall be among those taken into account by a Government:

1. their rights and practices in respect of the exploitation of living and mineral resources;
2. previously established routeing systems in adjacent waters, whether or not under the proposing Government's jurisdiction;
3. the existing traffic pattern in the area concerned, including coastal traffic, crossing traffic, naval exercise areas and anchorage areas;
4. foreseeable changes in the traffic pattern resulting from port or offshore terminal developments;
5. the presence of fishing grounds;
6. existing activities and foreseeable developments of offshore exploration or exploitation of the sea-bed and subsoil;
7. the adequacy of existing aids to navigation, hydrographic surveys and nautical charts of the area;
8. environmental factors including prevailing weather conditions, tidal streams and currents and the possibility of ice concentrations; and
9. the existence of environmental conservation areas and foreseeable developments in the establishment of such areas.

4.4. Routeing systems should be reviewed, re-surveyed and adjusted as necessary, so as to maintain their effectiveness and compatibility with trade patterns, offshore exploration and resource exploitation, changes in depths of water, and other developments.

4.5. Routeing systems should not be established in areas where the instability of the sea-bed is such that frequent changes in the alignment and position of the main channels, and of the whole routeing system, are likely.

4.6. When establishing areas to be avoided by all ships or by certain classes of ship, the necessity for creating such areas should be well demonstrated and the reasons stated. In general, these areas should be established only in places where inadequate survey or insufficient provision of aids to navigation may lead to danger of stranding, or where local knowledge is considered essential for safe passage, or where there is the possibility that unacceptable damage to the environment could result from a casualty, or where there might be hazard to a vital aid to navigation. These areas shall not be regarded as prohibited areas unless specifically so stated. The classes of ship which should avoid the areas should be considered in each particular case.

4.7. Governments considering establishing a new routeing system or amending an existing one should consult at an early stage with:

1. mariners using the area;
2. authorities responsible for aids to navigation and for hydrographic surveys and nautical publications;
3. port authorities; and

4. organizations concerned with fishing, offshore exploration or exploitation and environmental protection, as appropriate.

This consultation process is implied in several paragraphs of RESOLUTION A.572(14)

5. DESIGN CRITERIA

The following standards should, so far as the circumstances allow, be applied in the design of ships' routeing measures.

a. *General*

1. Routes should follow as closely as possible the existing patterns of traffic flow in the areas as determined by traffic surveys.

2. The configuration and length of routeing systems which are established to provide for an unobstructed passage through offshore exploration and exploitation areas may differ from the dimensions of usually established systems if the purpose of safeguarding a clear passage warrants such a special feature.

3. Course alterations along a route should be as few as possible and should be avoided in the approaches to convergence areas and route junctions or where crossing traffic may be expected to be heavy.

4. The number of convergence areas and route junctions should be kept to a minimum, and should be as widely separated from each other as possible. Adjacent traffic separation schemes should be placed such that nearly opposing streams of traffic in the adjacent schemes are separated as widely as possible. Route junctions should not be located where concentrated crossing traffic, not following established routes, may be expected, e.g. ferry traffic.

5. Routes should be designed to allow optimum use of aids to navigation in the area, and of such shipborne navigational aids as are required or recommended to be fitted by international conventions or by IMO resolutions and recommendations.

6. The state of hydrographic surveys within the limits of a routeing system and in the approaches thereto should be such that full information on existing depths of water and hazards to surface navigation is available to nautical charting authorities.

b. *Traffic separation schemes*

1. The extent of a traffic separation scheme should be limited to what is essential in the interests of safe navigation.

2. Traffic lanes should be designed to make optimum use of available depths of water and the safe navigable areas taking into account the maximum depth of water attainable along the length of the route. The width of lanes should take account of the traffic density, the general usage of the area and the sea-room available.

3. Where there is sufficient space, separation zones should be used in preference to separation lines to separate opposing streams of traffic and to segregate inshore traffic zones from adjacent traffic lanes. Separation zones or lines may also be used to separate a traffic lane from adjacent sea areas other than inshore traffic zones, in appropriate circumstances, taking into account traffic density and the available means of fixing ships' positions.

4. It should be possible for ships to fix their position anywhere within the limits of and in the immediate approaches to a traffic separation scheme by one or more of the following means, both by day and by night:

    - visual bearings of readily identifiable objects;
    - radar bearings and ranges of readily identifiable objects; and
    - D/F bearings.

5. When it is considered essential to provide within a traffic separation scheme an additional lane for ships carrying hazardous liquid substances in bulk, as specified in the International Convention for the Prevention of Pollution from Ships, 1973, in circumstances where it is not possible for ships to fix their position as set out in paragraph 5.11 over the whole area of that lane and an electronic position-fixing system covers that area, the existence of that system may be taken into account when designing the scheme.

6. The minimum widths of traffic lanes and of traffic separation zones should be related to the accuracy of the available position-fixing methods, accepting the appropriate performance standards for shipborne equipment as set out in IMO resolutions and recommendations.

7. Where space allows the use of traffic separation zones, the width of the zone should, if possible, be not less than three times the transverse component of the standard error (measured across the separation zone) of the most appropriate of the fixing methods listed in paragraph 5.11. Where necessary or desirable, and where practicable, additional separation should be provided to ensure that there will be adequate early indication that traffic proceeding in the opposite direction will pass on the correct side.

8. If there is doubt as to the ability of ships to fix their positions positively and without ambiguity in relation to separation lines or zones, serious consideration should be given to providing adequate marking by buoys.

c. *Converging and junction areas*

1. Whichever of the several available routeing methods is chosen for use at a route junction or in a converging area, it must be a cardinal principle that any ambiguity or possible source of confusion in the application of the 1972 Collision Regulations must be avoided. This principle should be particularly borne in mind when establishing or recommending the direction of traffic flow in such areas. If recommended directions of traffic flow are adopted, these should take full account of the existing pattern of traffic flow in the area concerned, and also of all other applicable provisions of ships' routeing.

2. At route junctions the following particular considerations apply:

    - the need to encourage the crossing of traffic lanes as nearly as possible at right angles;
    - the need to give ships which may be required to give way under the 1972 Collision Regulations as much room to manoeuvre as possible;
    - the need to enable a stand-on vessel to maintain a steady course, as required by the 1972 Collision Regulations, for as long as possible before the route junction; and
    - the need to encourage traffic not following an established route to avoid crossing at or near route junctions.

d. *Deep-water routes*

In designing deep-water routes, consideration should be given to marking critical turning points. Any wrecks or sea-bed obstructions which lie within the limits of a deep-water route and which have less depth of water over them than the minimum depth of water for the route as indicated on the charts, should be marked.

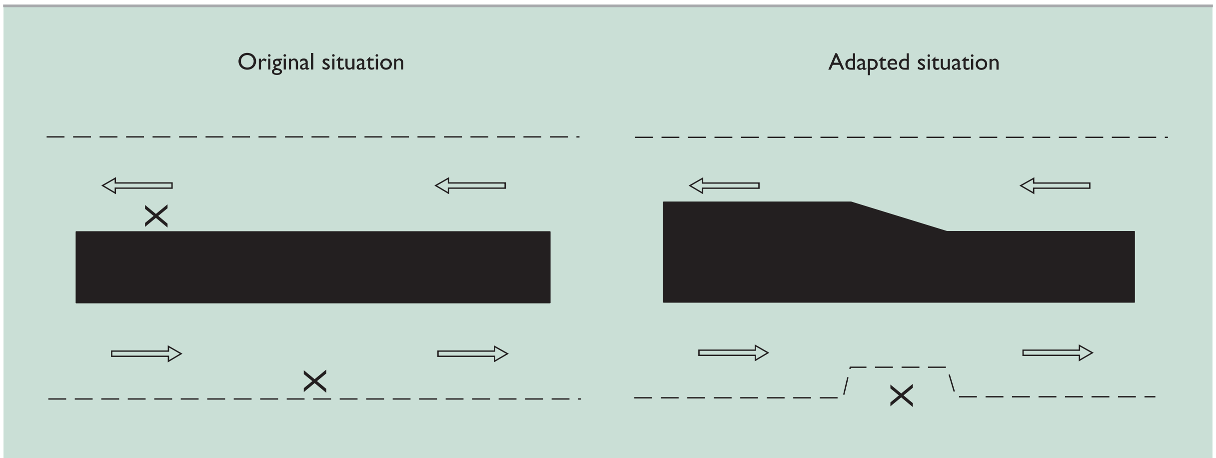
6. TEMPORARY ADJUSTMENTS TO TRAFFIC SEPARATION SCHEMES

a. When the temporary positioning of an exploration rig is unavoidable, the design criteria and the provisions for planning should be taken into account before permitting the positioning of the rig or subsequently adjusting a traffic separation scheme.

b. The said adjustments should be made in accordance with the following:

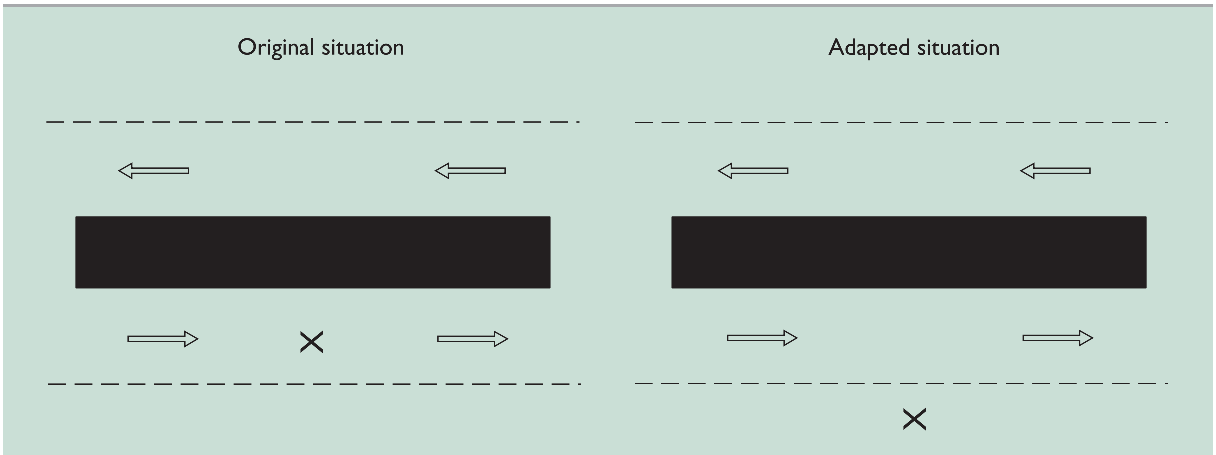
 1. When the drilling location is situated near the boundary of a traffic lane or separation zone, a relatively slight adjustment of the scheme could have such effect that the drilling rig and its associated safety zone are sufficiently clear of the traffic lane;

Figure II.19. Example of Original situation and Adapted situation



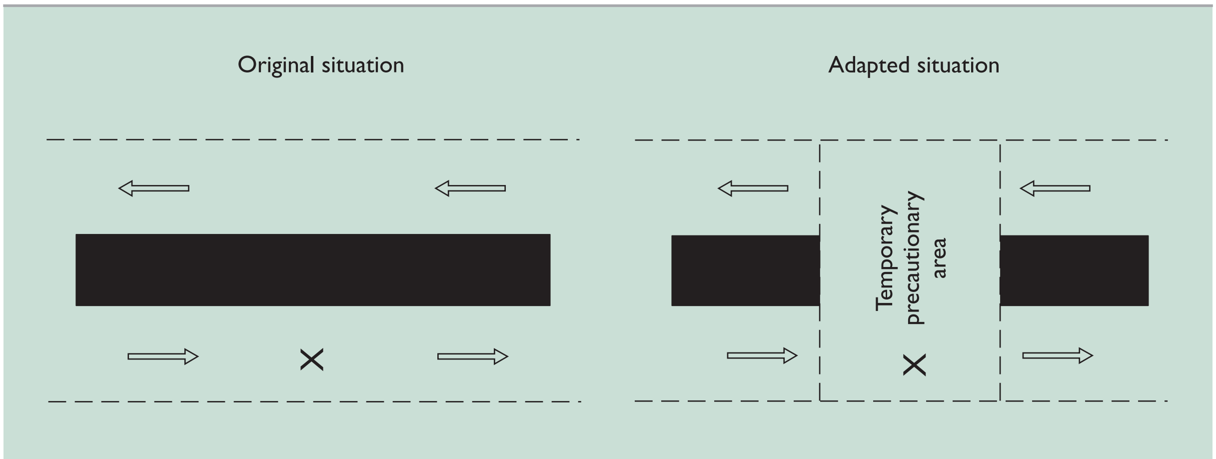
 2. If a small temporary adjustment of the traffic lane is not possible the whole or part of the scheme could be temporarily shifted away from the drilling area so that traffic connected with the drilling operations will stay clear of the lane;

Figure II.20. Example of Original situation and Adapted situation



3. Temporary local interruption of the scheme or part of the scheme in the area of location of the drilling rig. Such an interruption could be made a precautionary area;

Figure II.21. ***Example of Original situation and Adapted situation***



4. Temporary suspension of the whole scheme.

c. In each case, exploration sites should be reviewed and such conditions specified as the responsible Government may deem necessary to ensure safety of navigation in the area.

d. Details of these temporary adjustments should be forwarded to IMO and to appropriate hydrographic offices at least four months before the rig is positioned within an adopted traffic separation scheme so as to allow ample time to inform shipping. When the duration of such temporary adjustments is expected to be six months or more, this should be made known to the relevant hydrographic authorities in order to allow appropriate action to be taken in notifying mariners.

e. In the event of a temporary adjustment to a traffic separation scheme remaining in force for more than one year, the responsible government should consider whether permanent amendments to the scheme may ultimately become necessary and, if appropriate, initiate timely procedures for IMO to adopt such amendments.

7. THE USE OF ROUTEING SYSTEMS

a. Routeing systems are intended for use by day and by night in all weathers, in ice-free waters or under light ice conditions where no extraordinary manoeuvres or ice-breaker assistance are required.

b. Routeing systems are recommended for use by all ships unless stated otherwise. Bearing in mind the need for adequate under-keel clearance, a decision to use a routeing system must take into account the charted depth, the possibility of changes in the sea-bed since the time of the last survey, and the effects of meteorological and tidal conditions on water depths.

c. A ship navigating in or near a traffic separation scheme adopted by IMO shall in particular comply with rule 10 of the 1972 Collision Regulations to minimize the development of risk of collision with another ship. The other rules of the 1972 Collision Regulations apply in all respects, and particularly the rules of part B, sections II and III, if risk of collision with another ship is assumed to exist.

d. At junction points where traffic from various directions meets, a true separation of traffic is not really possible, as ships may need to cross routes or change to another route. Ships should therefore navigate with great caution in such areas and be aware that the mere fact that a ship is proceeding along a through-going route gives that ship no special privilege or right of way.

e. A deep-water route is primarily intended for use by ships which, because of their draught in relation to the available depth of water in the area concerned, require the use of such a route. Through traffic to which the above consideration does not apply should, as far as practicable, avoid using deep-water routes.

f. Precautionary areas should be avoided, if practicable, by passing ships not making use of the associated traffic separation schemes or deep-water routes, or entering or leaving adjacent ports.

g. In two-way routes, including two-way deep-water routes, ships should as far as practicable keep to the starboard side.

h. Arrows printed on charts in connection with routeing systems merely indicate the general direction of established or recommended traffic flow. Ships need not set their courses strictly along the arrows.

i. The signal YG meaning *You appear not to be complying with the traffic separation scheme* is provided in the International Code of Signals for appropriate use.

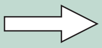
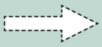
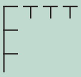
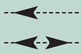
8. REPRESENTATION ON CHARTS

The legends, symbols and notes appearing in this paragraph are recommended by the International Hydrographic Organization as guidance for the representation of details of routeing systems and associated measures on nautical charts. They are included to illustrate the information likely to be found on charts and as an aid to those designing proposed routeing systems for adoption by IMO.

Table II.1. Use of legends on charts and in notes

Legend	Use of legend
Traffic separation scheme	Not usually shown on charts. Referred to un notes as *Traffic separation scheme* or its national language equivalent.
Inshore traffic zone	*Separation scheme* or its national language equivalent.
Precautionary area	*Precautionary area* or its national language equivalent may be shown no charts in lieu of the symbol and is referred to in notes.
Deep water-route	*DW* is shown on charts to indicate the deep water, "DW" or deep-water route is referred to in notes.
Area to be avoided	*Area to be avoided.* or its national language equivalent is shown on charts and is referred to in notes
Two-way route	*Two-way route.* is not usually shown on charts but is referred to in notes.
Recommended route	*Recommended route* is not usually shown on charts but is referred to in notes.
Recommended track	*Recommended track* is not usually shown on charts but is referred to in notes.

Table II.2. Symbols for basic elements of routering measures. Unless otherwise specified, symbols are printed on charts in colour, usually

Routeing term	Symbol	Description	Applications	Notes and paragraph references
1. Established direction of traffic flow		Outline arrow	Traffic separation schemes and deepwater routes (when part of a traffic lane)	(1) (2)
2. Recommended direction of traffic flow		Dashed outline arrow	Precautionary areas, two-way routes, recommended routes and deep-water routes	(1)
3. Separation lines		Tint, 3 mm wide	Traffic separation schemes and between traffic separtion schemes and inshore traffic zones	(3) (4) and Table II.3
4. Separation zones		Tint, may be any shape	Traffic separation schemes and between traffic separtion schemes and inshore traffic	(4) (5) and Table II.3
5. Limits of restricted areas (charting trem)		T-sahaped dashes	Areas to be avoided and defined ends of inshore traffic zones	(6) y Table II.3
6. General maritime limits (charting term)		Dashed line	Traffic separtion schemes, precautionary areas, two-way routes and deep-water routes	
7. Recomended tracks: one-way, two-way		Dashed line with arrowheads (colour black)	Generally reserved for use by charting authorities	(7)
8. Recommended routes		Dashed line and dashed outlined arrow	Recommended routes	
9. Precautionary areas		Precautionary symbol	Precautionary areas	(8)
For examples of routeing measures using these basic symbols see figures II.1 to II.21.				

NOTES:

1. Arrows dispersed over width of route. arrows may be curved. Where the traffic lane is converging, arrows should be oriented to the approximate average directions of the side boundaries.
2. Arrow omitted at intersections (other than roundabouts) to avoid implying priority of one lane.
3. Separation line 3mm wide where chart scale permits.
4. Tint light enough not to obscure detail beneath it.
5. If traffic lanes are separated by natural obstacles, may be replaced by the symbol for general maritime limits at the boundaries of the lanes.
6. Stems of dashes point towards the area in question.
7. Symbol intended for tracks to be followed cosely through inadequatey surveyed areas.
8. Legend Precautionary area or its national language equivalent may also be used within the precautionary area instead of the symbol.

Table II.3. **Boundary symbols in detail**

Example: Boundary symols 8 means that the boundary indicated by the line, between a precautionry area and an inshore traffic zone is to be shown by T-shaped dashes, whit the stems of the Ts pointing towards the ITZ.		
1. Traffic separation scheme (ends). Open sea	No boundary	
2. Traffic separation scheme (sides). Open sea	---------------- Or Or	(zone)
3. Traffic separation scheme. Inshore traffic zone	Or Or	(zone)
4. Traffic separation scheme next to Traffic separation scheme	No boundary	
5. Inshore traffic zone (ends). Open sea	⊥ ⊥ ⊥ ⊥ ⊥ ⊥ ⊥ ⊥ or no boundary where limits are undefined	
6. Precaution area. Open sea	----------------	
7. Precaution area. Traffic separation scheme	----------------	
8. Precaution area. Inshore traffic zone	T T T T T T T T	
9. Deep-water route (sides). Open sea	----------------	
10. Deep-water route (ends). Open sea	----------------	
11. Deep-water route (ends). Traffic separation scheme	----------------	
12. Deep-water route next to deep-water route.	No boundary	
13. Deep-water route (ends). Precautionary areas	----------------	
14. Deep-water route. Separation zone/line	(Separation zone/line acts as boundary)	
15. Two-way route. All other areas	----------------	
16. Area to be avoided. All other areas	⊥ ⊥ ⊥ ⊥ ⊥ ⊥ ⊥ ⊥	

Table II.4. **Caution and explantory notes on charts**

Traffic separtion schemes and other routeing measures	The existence of special provisions applying to particular measures should be mentioned on the charts affected, if necessary referring mariners to the full text in sailing sirections.
Deep-water routes	Where maintenance of a minimum depth can be guaranteed, the least depth (e.g. 22m) may be given after the addreviation DW. In other cases charted soundings will indicate the least depth, prefarably in conjunction with a note giving the date of the latest survey.
Areas to be avoided	Notes on conditions governing avoidance of areas (classes and sizes of ships, nature of cargoes, etc.) Should preferably be given on charts and should always be given in sailing directions

Part II

General design criteria

GENERAL DESIGN CRITERIA

Part II

2.1. DESIGN PHASES

2.1.1. The design lifetime of a Navigation Channel or a Harbour Basin is defined as the period of time elapsing from the beginning of its construction to its decommissioning, abandonment or change of use.

2.1.2. The design lifetime is divided into the following phases:

a) CONSTRUCTION PHASE

This phase covers the period elapsing from the beginning of the construction of a Navigation Channel or a Harbour Basin to its commissioning.

In view of the fact that as far as this Recommendation is concerned, Navigation Channels and Harbour Basins do not refer to the structural features of their boundaries, an analysis of the Construction Sub-phases specified in ROM 02.90 referring to such structures is not of interest since they are covered in the said Recommendation.

Provisional use of Navigation Channels or Harbour Basins Areas during their construction, modification or maintenance phases, which are habitual cases (for example, performance of maintenance dredging in a pre-existing Harbour Basin) which may affect water spaces available, will be considered as particular cases in the Service Phase.

b) SERVICE PHASE

This phase covers the period elapsing from the time when the whole Navigation Channel or Harbour Basin is commissioned to it is decommissioning, abandonment or change of use. This period will also be called useful lifetime.

The following working hypotheses will be considered in this phase:

S1. Normal Operating Conditions:

- Navigation Channels or Harbour Basins operate without restrictions, and are not affected by maritime or environmental conditions.

S2. Extreme Conditions:

- Navigation Channels or Harbour Basins have to stop or limit their operability whilst environmental conditions above operational limits persist. This condition is associated to the worst environmental conditions for which the structures of their boundaries will be designed.

S3. Exceptional Conditions:

- As a result of accidents, misuse or exceptional environmental or working conditions, Navigation Channels or Harbour Basins are subject to extraordinary, unusual but predictable restrictions.

S4. Maintenance:

- This includes the maintenance of water or above water space requirements of Navigation Channels or Harbour Basins, as well as cases which can be assimilated thereto (modifications of spaces because of changes in operating criteria, changes in use, etc.).

2.1.3. All phases, sub-phases and working hypotheses possible will be taken into account for designing the Navigation Channels or Harbour Basins included in the scope of application of these Recommendations, provided they affect dimensioning, taking into account that the most usual procedure for solving sub-phases S3 and S4 will consist on establishing more restrictive conditions for Operation, normally accompanied by temporary improvements in navigation marking without the need to modify the dimensions of these areas.

2.1.4. The Designer shall set the maximum duration time for each of the design phases affecting dimensioning, in view of their special significance in assessing:

- Risk/safety levels deriving from the use of these areas.
- Operational levels associated to the marine climate in the area and foreseeable traffic in the Design Phase.
- Economic feasibility of the design and its possibility of future development.

2.2. USEFUL LIFETIME

2.2.1. The useful lifetime will be chosen for each design adjusted to the time in which it is foreseen that the Navigation Channel or Harbour Basin under consideration will be in service.

The possibility, facility and economic feasibility of altering the dimensions, the probability and possibility of changes in the circumstances and conditions of use as provided for in the design as a result of variations in operations or port traffic and the feasibility of readaptations to new service needs will be taken into account in order to determine this lifetime.

Due to the random nature of a fair number of parameters affecting the conditions of use of these maritime works, it is not realistic to strictly apply the foregoing criteria to works with foreseeably very short lifetimes. The values as given in table 2.1. will be adopted as a minimum for works definitive in nature and with no specific justification, depending on the type of work and safety level required. Warning is given as to how inappropriate may be shortening the Useful Lifetime of this type of work, based on the argument that subsequent dredging can correct an initial under-dimensioning. Even though a change in an area's water depth is relatively simple, especially if structures on the boundaries are dimensioned for it, the geometric layout configuration of a Navigation Channel or a Harbour Basin may result in a practically inalterable physical restriction for many years.

When different useful lifetimes are accepted in parts of the same work, each will have to be calculated separately depending on the pertinent assessment, whilst taking the precaution of ensuring that unwanted throttling will not occur in the overall work.

2.3. ELEMENTS DEFINING A NAVIGATION CHANNEL AND HARBOUR BASIN

2.3.1. A correct definition of a Navigation Channel or a Harbour Basin requires the following elements to be determined:

- The geometric configuration of the water and above water space used, by means of the necessary layout and elevation definitions of the axes, alignments, curves, heights, levels and whatever elements may be necessary for an unequivocal determination of such spaces.
- Navigation marking planned to be installed for «in situ» identification of such spaces, the definition of which shall be especially concrete in the case whereby the design has been refined based on the accuracy of certain navigation aids.
- Maritime and atmospheric limit conditions which will allow Navigation Channels or Harbour Basins to be used under Normal Operating Conditions. These conditions may be different according to the vessel type and dimensions, the tug-boats available or as a function of any other particular condition defined in each case.
- Necessary basic towing requirements for certain types of vessel to use Navigation Channels and Harbour Basins, associated to the environmental conditions in which these manoeuvres may be performed under Normal Operating Conditions.

A Navigation Channel or a Harbour Basin is not therefore defined only by its geometric characteristics and navigation marking but also by its operational conditions and by the need to use or not to use tug boats or other navigation aids. These are circumstances which determine not just the fact of being able to avail of greater or lesser percentages of time suitable for vessel operation but also the actual dimensions of the required water spaces.

Table 2.1. Minimum useful lifetimes for definitive navigation channels or harbour basins (in years)

Type of work	Safety level required		
	Level 1	Level 2	Level 3
General infraestructure	25 (15)	50 (25)	100 (40)
Specific industrial infraestructure	15 (10)	25 (15)	50 (25)

Note: The figures in brackets may be used when plan and elevation reserve spaces that do not form practically inalterable physical restrictions are maintained, taking such to be those which force structures delimiting their boundaries to be demolished.

Legend:

GENERAL INFRASTRUCTURE:

- General Navigation Channels or Harbour Basins, not linked to the exploitation of an industrial facility or a single specific terminal.

SPECIFIC INDUSTRIAL:

- Navigation Channels or Harbour Basins in the service of an industrial facility or of a single specific terminal or linked to the exploitation of resources or deposits of a transitory nature (for instance, the service port for an industry, ore loader attached to a specific deposit, oil rig, etc.).

LEVEL 1:

- Navigation Channels or Harbour Basins in local interest or auxiliary facilities.
- Low risk of losses of human lives or environmental damage in the event of an accident. (Minor ports with no traffic of vessels carrying polluting, flammable or hazardous products, marinas, auxiliary ports for work construction equipment or for boats not having to operate under conditions worse than those of the auxiliary port's design, etc.).

LEVEL 2:

- Navigation Channels or Harbour Basins in general interest facilities.
- Moderate risk of losses of human lives or environmental damage in the event of an accident.
  (Large ports with no traffic involving polluting, flammable or hazardous products, or minor ports which, should they have this traffic, keep to the safety distances from urban centres or areas of a high environmental value specified by their particular regulations, etc., in all navigation channels and harbour basins accessible to them).

LEVEL 3:

- Navigation Channels or Harbour Basins in ports and facilities of a supranational nature.
- High risk of losses of human lives or environmental damage in the event of an accident.
  (Large ports with traffic involving polluting, flammable or hazardous products, and the highest values of Useful Lifetime must be adopted if the Navigation Channels or Harbour Basins located in urban areas or areas of a high environmental value, etc.).

2.4. DESIGN CRITERIA

2.4.1. The fundamental criterion for defining and dimensioning elements forming a Navigation Channel or a Harbour Basin is safety in manoeuvring and operations carried out in them. To this end, regardless of the general safety criteria as specified in Table 2.1, the risk/safety criteria recommended in keeping with the circumstances and characteristics of each case, are given in point 2.5 of this Section.

Once safety criteria are set, an economic analysis of alternatives may be made to determine the most suitable solution for the case under consideration, on the understanding that any alternative analysed shall respect the previously defined safety factors as a minimum.

The economic analysis and possible reduction (or increase) in investments deriving therefrom must in no event lead to a reduction in safety but a reduction (or increase) in operational times of the area under consideration. Each Port Authority, Owner or person responsible for these areas may decide whether, for example, a channel is dredged to one or another level as a function of tides, waves or any other circumstance in the area, based on economic or commercial considerations, but the consequence of this decision will not be that vessels enter with a greater or lesser risk of touching the seabed but that the channel will be open for a longer or shorter period of time for certain operations. The economic analysis therefore sets investment against operability, but not investment against risk, since the safety requirements recommended must be maintained in any event.

2.4.2. The procedure recommended to carry out the different studies leading to the definition of a Navigation Channel or a Harbour Basin is as follows:

1. Determine the Useful Lifetime as a function of the type of Work in question and the Safety Levels required, as well as the maximum acceptable risks according to the criteria defined in this Recommendation.

2. Establish the characteristics of the fleet of vessels which will operate in the area in the different target years which will be considered within the Useful Lifetime. In general, several fleet configuration hypotheses will be available and traffic forecasts will be taken into account.
   Depending on the complexity of the dimensioning procedure adopted from those defined in this Recommendation, it may suffice to specify the most unfavourable vessels or it will be necessary to know the fleet's configuration by segments, establishing the most representative vessels in each segment.

3. Quantify the number of vessel operations foreseen in the different target years. According to the complexity of the method used, it may be necessary to know only the number of most unfavourable vessel operations or that of all vessels, breaking down this information into the same number of segments as used in the previous point.
   Annual accumulated information will generally suffice for carrying out this study, unless traffic seasonality or environmental condition phenomena or others advise the use of shorter assessment periods (half yearly, quarterly, etc.).

4. Preset the maritime and atmospheric limit environmental conditions for the different vessel manoeuvres which may be carried out in the area under consideration. These conditions may be different for the different types of vessel or even vary for the same type of vessel depending on their sizes or characteristics.
   In the absence of criteria in this respect, this Recommendation gives the environmental conditions usually used as operating limits for vessel manoeuvres that may be carried out in the different areas. Should values be used not supported by local experience, their suitability for the specific case being analysed must be previously checked.

5. Preset the operating conditions of the vessels associated to the manoeuvres being considered in each area. Highly elemental aspects will have to be specified for the simplest analysis procedures shown in this Recommendation (vessel's speed, percentage of cargo, etc.). For more complex analyses, many other factors relating to the vessel's navigation will have to be considered.
   The attendance of tug boats or not in some manoeuvres will be established as part of this process and minimum requirements to be met will be assessed as a function of the vessel characteristics, the site, limit operating environmental conditions, etc.

6. Geometrically dimension the area being analysed, taking into account the navigation marking systems and navigation aids it is planned to implement in this respect. According to this Recommendation, two procedures may be used in this design:

   - *Determinist*

     The geometric dimension of the different layout and elevation of the areas is calculated with this method by adding up several factors which, in most cases, lead to a specific, true result whether using tabulations or mathematical formulas. This terminology is maintained even though the tables and mathematical formulas may be a reflection of statistical analyses and even though a statistical processing is used for some of the variables which enables dimensioning to be associated to the risk as set for the design.
     Safety factors in this determinist procedure are some of the addends being used in the quantification of geometric dimensions and in their assessment. Risk associated aspects are taken into account in their assessment, as well as in that of other factors, with which the resultant design may be adjusted to the specific characteristics of each case.

   - *Semiprobabilistic*

     Geometric dimensioning in this procedure is fundamentally based on the statistical analysis of space occupied by vessels in the different manoeuvres under consideration, which enables the resulting dimensions to be associated to the preset risk with greater mathematical accuracy in each case.
     The practical application of this method obliges simulation studies, scale model testing or real time measurements which will provide a statistical data base sufficiently representative for the method's reliability.

Safety factors could have been entered into the statistical analysis.
in this procedure, by requiring only probabilities of exceedance or smaller risks. However, it was decided to enter safety as an additional safeguard to be considered in the pertinent dimensions (plan or elevation), assessed with the same criteria of the determinist method, in keeping with other ROM programme Recommendations which use the partial safety coefficient system. The two procedures are thus made homogeneous since both use different systems to assess the space occupied by vessels under homogeneous conditions and spaces recommended as safety margins are added onto these spaces. Likewise, in case the simulators or models do not allow other factors affecting dimensions to be taken into account (navigation marking, silting up, etc.), the same assessment procedures as in the determinist method shall be adopted.
The semiprobabilistic procedure will enable the risk associated to geometric dimensions to be known more accurately than the determinist one, and, consequently, will enable the design to be more complete. The determinist method will not allow the risk to be quantified in the same numerical terms, which does not imply that this risk is not considered by adopting values on the safety side based on similar design experiences. All cases can be resolved with the determinist analysis at the level of prefeasibility studies, preliminary designs economic studies, etc. and it may even be used for the final design provided standards of good practice given in this Recommendation are adopted in the design and operation of the Navigation Channels or Harbour Basins. With the consequent resort to a study carried out on simulators or similar procedures, the semiprobabilistic method will be necessary in the event of special cases which are pointed out throughout this Recommendation, or when it is desired in normal cases to optimize the design of the elements defining the Navigation Channels or Harbour Basins in a broad sense.

7. Determine the times in which the Navigation Channels or Harbour Basins will be closed for being «below minima», depending on the environmental limit conditions set for operating under Normal Conditions, using the Average Regimes or distribution functions of the frequency of occurrence of the variables being considered. In cases where the area's operability is sensitive not only to these shut-down times expressed in percentages of the total time but also to the length of time these periods of inactivity may last, it will be necessary to have the Duration Regimes of the different variables being addressed (the duration of a certain threshold value of the parameter or variable in an interval of time is defined as the time elapsing between two consecutive crossings of its value by that threshold value).

8. In case it is desired to make an economic study of the design, to associate the operability of Navigation Channels or Harbour Basins to investments made, such study shall be carried out taking into account that effectively closing down the area would require not only that it were «below minima» environmentalwise but also that under those circumstances, there were a demand to use such spaces by vessels which might access the area and, therefore, the probability of both events occurring simultaneously shall have to be considered and the analyses made as per points 7 and 3 in this section will be used.
In the case this analysis leads to the conclusion that the design is unfeasible (whether because of high investments or because of the costs involved in effectively closing the area down, or for other reasons associated to the minimum service level required to be set for that specific area), alternative solutions would be examined, which might modify all or some of the elements defining the Navigation Channels or Harbour Basins, for example, reducing the operating limits under Normal Conditions with which a less expensive design would be attained, or improving the provision of tug boats to allow operation under more unfavourable conditions, which would improve the service level by increasing investment in navigation aids, etc.
The basic criterion for studying these alternatives and, in the end, choosing the most suitable in each case, is that safety criteria suited to the Area under consideration be kept to in each case since, as was pointed out before, economic optimisation must never involve a reduction in the safety required.

2.5. GEOMETRIC DIMENSIONS ASSESSMENT CRITERIA

2.5.1. The geometric definition of Navigation Channels or Harbour Basins is based on knowing the spaces occupied by vessels, which depend on:

- The vessel and the factors affecting its movements.
- The water level and factors affecting its variability.

For navigation to occur under safe conditions, the spaces occupied by the vessel must have sufficient room within the physical spaces available at the site, for which factors of uncertainty related to the boundaries (seabed, parametres, other vessels navigating or floating, elements affecting above water clearances, etc.) must be taken into account.

2.5.2. Additional spaces must be provided between those required by vessels and those available according to the the site's boundary conditions, with the purpose of keeping a suitable safety margin. They are entered to take into account, amongst others, those factors which cannot be suitably modelled in the calculation processes, the degree of statistical reliability of the design data, the uncertainty in methods for determining the vessel's behaviour, etc.

Safety factors in other design Standards and Recommendations are therefore, here, Safety Margins or Clearances and are thus additional spaces which are to be added to those required by vessels, to verify that these spaces, the sum of both, fit into the spaces available at the site. The equation for verifying the safety requirements for the dimensions of a Navigation Channel or a Harbour Basin is expressed by:

$$X_e \geq X_b + X_s$$

where:

X_e = Space available at the site.
X_b = Space occupied by the vessel
X_s = Safety Clearance.

2.5.3. Spaces will be assessed by quantifying the geometric dimensions of the outside surfaces delimiting their boundaries. The Characteristic Value (X_k) defined as that value of the dimension associated to a probability of exceedance during the design lifetime assigned to each of the Working Phases and Hypotheses will be used as the Representative Value for each of these geometric dimensions (which might be a height or a width).

Since that verification of Safety is not achieved by increasing the Characteristic values of the dimensions by means of a multiplying factor but by entering additional safety Margins or Clearances, the safety check will be expressed by:

$$X_{ek} \geq X_{bk} + X_{sd}$$

where:

X_{ek} = The characteristic value of the dimension defining the space available at the site.
X_{bk} = The characteristic value of the dimension defining the space occupied by the vessel.
X_{sd} = The safety clearance applicable to the dimension under consideration (width, depth, clearance, etc.).

2.5.4. The different cases of risk which may arise in keeping with the following failure mode types or Ultimate Limit States (ELU) will be taken into account for assessing Safety Clearances:

- Collision between vessels underway.
- Collision of a vessel underway with a floating object (anchored or moored boat, buoy, etc.).
- A vessel hitting a fixed, rigid object (quay, pier or bridge deck, etc.).
- Contact of a vessel with the sea bottom or sea floor slopes, taking into account the nature of the latter as well as the possibility of running aground.

Chapters VII and VIII establish the Safety Clearances recommended as a function of the nature of the Area under consideration and of the risks which may arise in each case.

2.5.5. The characteristic values of the dimensions defining the site will be determined by their nominal value when known or could be guaranteed. In the absence of data, they may be determined by a statistical analysis, adopting the value minimizing the water or above water space available corresponding to 1% of a probability of exceedance with a 95% confidence interval. Except for specific studies, it may be assumed that the dimensions fit a normal distribution. Likewise, errors which may originate in the data measuring and recording system will be taken into account.

Chapter VII gives specific recommendations in this respect, in connection with water Depth, since this is the site's dimension that, when known, is particularly important to the effects of this Recommendation.

2.5.6. The characteristic values of the dimensions defining the space occupied by vessels will be determined from statistical data, as far as possible, adopting the value associated to the acceptable risk level (E), which is defined as the probability of at least one incident occurring (contact, running aground, impact or collision as described in point 2.5.4) of at least one vessel during the useful lifetime of the design phase being analysed (L_f).

The maximum risks acceptable for the Service Phase are shown in Table 2.2. The same acceptable risks will be adopted for the Construction Phase unless smaller values are justified.

There are currently no statistical studies available on failures enabling dimensions to be calculated based on the Extreme Regime of the variable being considered. Therefore, it will be necessary to turn to procedures enabling the Risk to be calculated, taking the following aspects into account:

- The Useful Lifetime (L_f) of the Area and phase being analysed.

- The number of vessels per year (N_a) which it is foreseen will be operating in the average year representative of the whole Useful Lifetime of the area and phase being analysed.

- The frequency with which vessels appear, broken down into types or categories with homogeneous characteristics in relation to their manoeuvrability conditions for the case being analysed (f_{bi}). In this respect, Chapter III gives a classification for vessels as a function of their manoeuvrability characteristics and recommendations are given to setting up several subgroups within each group according to their dimensions and load conditions. The most unfavourable vessel be taken as representative of the vessels in each subgroup. This frequency of appearance will be expressed in «rate per one» in relation to the number of vessels per year «N_a» which it is forecast will operate in the mean year representative of the whole Useful Life and Phase being analysed.

- The frequency of occurrence of the operating conditions under which the manoeuvres being analysed can be undertaken. Establishing several subgroups is recommended for correctly assessing the Risk, until reaching the limit conditions which will define the Normal Operating Conditions, determining the frequency with which each of these subgroups appear (f_{oj}). The worst operating conditions will be taken from each subgroup at its top limit thus considered as representative of the whole interval. This frequency of occurrence will be expressed in a «rate per one» in relation to the mean year.

The possible interdependence of variables (for example, wind related waves or currents related to tidal conditions) will be considered for configuring these subgroups.

- For each type of vessel, the probable Number of manoeuvres associated to certain operating conditions which it is foreseen will be performed during the whole Useful Lifetime of the Area being analysed. This number of manoeuvres (N_{ij}) will be:

$$N_{ij} = f_{bi} \bullet f_{oj} \bullet L_f \bullet N_a$$

the product $L_f{\bullet}N_a$ in this expression represents the total number of vessel operations forecast during the whole Useful Lifetime under consideration.

Table 2.2. **Maximum acceptable risks E_{max} for determining the characteristic values of dimensions defining the space occupied by vessels from statical data**

RISK OF DAMAGE		Possibility of loss of human lives	
		Reduced	Expectable
Economic repercussion in the case of an incident (ELU)	LOW	0.50	0.30
Index = $\frac{\text{Cost of losses}}{\text{Investment}}$	MEDIUM	0.30	0.20
	HIGH	0.25	0.15

TOTAL LOSS RISK		Possibility of loss of human lives	
		Reduced	Expectable
Economic repercussion in the case of an incident (ELU)	LOW	0.20	0.15
Index = $\frac{\text{Cost of losses}}{\text{Investment}}$	MEDIUM	0.15	0.10
	HIGH	0.10	0.05

The maximum acceptable risk will be the initial damage risk or total loss risk considering the importance of the damage to the vessel or vessels affected and the effect this damage may have on the operation of the area being analysed or on other areas affected by it.

Should the foreseeable damage for vessels not affect their seaworthiness significantly or when the consequences of the incident do not lead to interrupting the area's general maritime traffic for periods above 2 days in the case of supranational ports or facilities, 5 days in the case of ports and facilities of a general interest and 10 days in the remaining cases, initial damage risk values may be adopted. Values for the total loss risk will be adopted in the remaining cases.

Legend:

POSSIBILITY OF LOSS OF HUMAN LIVES

- Reduced: When loss of human lives in an accident is not expected.
- Expected: When the loss of human lives in an accident is expected.

ECONOMIC REPERCUSSION IN THE EVENT OF AN INCIDENT

Index $_{re}$ = Cost of direct and indirect losses / Investment

- LOW : $r_e \leq 5$
- MEDIUM : $5 < r_e \leq 20$
- HIGH : $r_e > 20$

- The probability of exceedance (p_{ij}) of any space (X_o) being exceeded by a vessel of the type (*i*) under the operating conditions of the interval (*j*) in carrying out a separate manoeuvre, i.e.:

$$P_{ij} = P_{ij}\,(X_n > X_o)$$

Statistical distribution laws proven by experience may be used for assessing spaces which depend on variables for which there exists a broad statistical basis (for example, a vessel's vertical motions due to wave action). In cases where this statistical basis does not exist (for example, occupancy of spaces in plan in real time vessel manoeuvres), these statistical distributions have to be defined and specific recommendations are given in Chapters VIII and IX to this end.

Knowing the foregoing data and having preset a value of the variable (X_o), the Risk (E_{ij}) associated with the operation of vessels of the type (*i*) under operating conditions of the interval (*j*) will be:

- For useful lifetimes $L_f \geq 10$ years

$$E_{ij} = 1 - (1 - p_{ij})^{N_{ij}}$$

- For useful lifetimes L_f between 1 and 10 years, the following simplification of the foregoing equation may be used:

$$E_{ij} = 1 - e^{N_{ij} \cdot p_{ij}}$$

The risk associated to all vessels and all operating conditions provided for in the Normal Operating Conditions will be:

$$E = 1 - \prod_{ij}(1 - E_{ij})$$

where $\prod_{ij}$ is the product of all values for all types of vessel in all operative condition intervals.

Should this risk thus calculated be higher than the maximum acceptable (E_{max}), a new value of the variable (X_o) must be considered until this adjustment is achieved. This process will also have to be performed should the risk calculated be noticeably less than the maximum acceptable since, otherwise, spaces would be overdimensioned.

2.6. ACCIDENTAL CASES ASSESSMENT

Accidental cases are taken to be those events of a fortuitous or abnormal nature which do not stem from mere difficulties of handling a vessel under Normal Operating Conditions. A vessel's engine or rudder failures, faults in tug boat operations, mooring line breakages, etc. may be quoted amongst them.

They may be considered as cases varying in nature with low probability of occurring or that manifest for a short time throughout the Useful Lifetime of the area being considered but which, if occurring, have an effect that may bear heavily on safety.

Although these accidental cases should not be the basis for dimensioning the elements of Navigation Channels and Harbour Basins, it is advisable to address the circumstances of these cases, taking into consideration that Safety Margins in these cases may be reduced or eliminated according to the assessment made of the accident's consequences in each case.

Part III

Vessel manoeuvrability characteristics

VESSEL MANOEUVRABILITY CHARACTERISTICS

Part III

3.1. DESIGN VESSEL

3.1.1. Definition of the design vessel

The Design Vessel is that used for dimensioning approaches and Harbour Basins. Since these areas will normally be used by different types of vessel, whose dimensions and other manoeuvrability characteristics may be very different, a group of several vessels representative of the different types of vessel and load conditions under which they will operate in the Area being analysed will have to be defined as the Design Vessel, with the aim of ensuring that the dimensions defined will allow any of them to operate under safe conditions, as well as other vessels which have to operate simultaneously with them in such areas.

It must be pointed out that, as was defined in point 2.3, the elements defining a Navigation Channel and a Harbour Basin include not only the geometric configuration of the spaces but also other operating conditions which will not normally be the same for all types of vessel. This is why it is possible that the largest vessel to operate in an Area may not be the Design Vessel, since the operating criteria normally adopted for operating this vessel involve lesser requirements of space than those which might be necessary for smaller ships. Moreover, as will be analysed in later chapters, geometric plan or elevation dimensions of Navigation Channels and Harbour Basins basically depend on different vessel parameters (draught, length, beam, surfaces exposed to wind, manoeuvrability conditions, etc.) and it will therefore be necessary to consider Design Vessels as those associated to the worst conditions of those characteristics which will be determining factors in each case.

In summary, Navigation Channels and Harbour Basins will be dimensioned for the most demanding Design Vessels that can operate in the area under consideration, according to its operational conditions, assuming that the vessel is under the worst load conditions. In the absence of specific operating conditions, the Designer will assume the vessel with the greatest displacement as the Design Vessel in each of the types of vessel he is analysing, and will analyse the maximum and minimum load condition for each one, compatible with the basic use assigned to the maritme works being designed.

The vessel's total weight, equivalent to the weight of the water volume displaced, is defined as displacement (D).

3.1.2. The exceptional use of harbour basins by vessels with higher demands than those provided for in the initial design will require the checking of operating conditions for the new vessels, and the most limiting conditions in which the said vessel will have to operate so that the safety clearances as established in the design are not exceeded will be determined.

3.1.3. The most used parameters for defining a vessel and expressing her size and load capacity are:

- Dead Weight Tonnes (DWT). Weight in metric tons for the maximum useful load plus fuel and lubricating oil, water and storerooms, crew and supplies.

- Vessel's Gross Tonnage (GT): Overall internal volume or capacity of all the vessel's enclosed spaces determined with the provisions of the IMO's 1969 International Vessel Measurement Convention.

- Gross Registered Tons (GRT): A vessel's internal volume or capacity measured in Moorsom tons or registered tons. The Moorsom ton is equivalent to 100 feet^3, i.e., 2.83 m^3.

This parameter is a definition previously used to define a vessel's measurement, but has been replaced by the foregoing description (GT).

Some specific types of vessel are usually designated with other parameters. This is the case with methane gas and liquid gas carriers which are designated by their load capacity in m^3, or container ships which are designated by their capacity in TEUs (Twenty Feet Equivalent Units) without it being possible to establish an exact, fixed relationship between these parameters and any of the three previously mentioned.

Whilst the use of any of the aforementioned parameters (D, DWT, GRT, GT, etc.) is quite normal, none of them is sufficiently representative of the vessel's manoeuvrability characteristics to be used systematically to define the Design

Vessel. Dead Weight Tonnage (DWT) may serve as a reference index for vessels basically used for high density cargoes (oil tankers, grain carriers, etc.) whilst Gross Tonnage (GT) is more suitable for vessels carrying low density cargoes and in those whose cargo capacity is best identified by volume than by weight (ferries, passenger ships, etc.). In any case, in view of the fact that the relation between these parameters is not homogeneous for all types of vessel, and not even constant for the same type of ship as it varies with the vessel's dimensions, the recommendation is to use the relations between parameters taken from Table 3.1., using linear interpolation between vessels of the same type when required, in the case an exact definition of the vessels to be used as Design Vessels is not available.

Should the vessel's displacement under conditions other than the full load figure given in Table 3.1. need to be known, it may be considered that the Lightship Displacement (vessel's weight as it comes out of the shipyard with no cargo, ballast or fuel) is the difference between full load Displacement and Dead Weight tons, except in cases where the DWT is unknown, when it may be assumed that Lightship Displacement varies from 15% to 25% of full load Displacement. If it were necessary to know the Ballast Displacement (lightship displacement plus minimum ballast weight for the ship to be able to navigate and manoeuvre under safe conditions) it will be assumed that it is equal to the Lightship Displacement plus a ballast varying between 20% and 40% of the DWT, depending on the environmental conditions, except in cases where the DWT is unknown when it may be assumed that the Ballast Displacement varies from 30% to 50% of the full load Displacement depending on the environmental conditions (the greatest ballast is needed when the environmental conditions are most severe).

3.1.4. The Design Vessel's dimensions and characteristics must be provided to the designer by the authorities or owners of the facility according to the use as planned. When vessel dimensions are not clearly known and in the absence of more precise information (Lloyd's Register, for example), the average dimensions of vessels as taken from Table 3.1. may be used for designing maritime and port structures, with the following criteria:

- The table gives average values of all dimensions and is determined by assuming that vessels are at full load.
- The Characteristic Values of any of the data shown in the Table will be 110% when determining the Top Characteristic Value and 90% when determining the Bottom Characteristic Value.
- Dimensions with their most unfavourable Characteristic Values will be taken in each case for the subject under analysis, and some dimensions determined by their Top Characteristic Values and others by the Bottom ones may be combined in one only vessel provided the block coefficient is in the range of 90/110% of its mean value.
- Should the Design Vessel be characterized by the maximum value of one of its geometric dimensions (beam, draught, etc.), such value will be assumed as characteristic and the rest will be modified with the foregoing criteria.

When vessels are under partial load conditions, specific curves or tables must be used to obtain the draught and displacement under these conditions, regardless of the fact they can be approximated with empirical formulas of recognized validity. In the case of full form vessels (oil tankers, ore carriers, etc.), it may be assumed that the block coefficient (Displacement/Length between perpendiculars x Beam x Draught x g_w) is kept constant under any loading condition. It will be assumed, for other types of vessel, that the block coefficient remains constant for any loading condition between 60 and 100% and may have decreases of up to 10% of the foregoing value for load conditions under 60% of full load. Tables similar to table 3.1. may be worked out with these hypotheses for vessels under partial loading conditions, assuming that the length and beam remain constant and that the only variable geometric dimension is the draught. These tables will be taken as for average conditions and the same criteria as given in the foregoing paragraph will be applied to their values in order to obtain Characteristic Values.

In the case whereby some vessel whose displacement is higher than the maximum given in Table 3.1. for that type of vessel, of which specific data on its dimensions and other manoeuvrability features are not available, it is used as a Design Vessel, it is recommended to continuously and homogeneously extrapolate the curves relating the different dimensions to the vessel's displacement and use these extrapolated curves to obtain an estimate of the dimensions of the vessel needed. The values thus obtained may be considered as average Design Vessel dimensions, although in these cases, its Characteristic Values will be 115% (instead of 110%) when determining the Top Characteristic Value and 85% (instead of 90%) when determining the Bottom Characteristic Value.

Table 3.1. ***Average dimensions of vessels at full load***

Dead Weight Tons (DWT) t	Displacement (Δ) t	Lenght overall (L) M	Lenght between perpendiculars (Lpp) M	Beam (B) m	Depth (T) m	Draught (D) m	Block Coefficient
Crude oil tankers							
500.000	590.000	415.0	392.0	73.0	30.5	24.0	0.86
400.000	475.000	380.0	358.0	68.0	29.2	23.0	0.85
350.000	420.000	365.0	345.0	65.5	28.0	22.0	0.85
300.000	365.000	350.0	330.0	63.0	27.0	21.0	0.84
275.000	335.000	340.0	321.0	31.0	26.3	20.5	0.84
250.000	305.000	330.0	312.0	59.0	25.5	19.9	0.83
225.000	277.000	320.0	303.0	57.0	24.8	19.3	0.83
200.000	246.000	310.0	294.0	55.0	24.0	18.5	0.82
175.000	217.000	300.0	285.0	52.5	23.0	17.7	0.82
150.000	186.000	285.0	270.0	49.5	22.0	16.9	0.82
125.000	156.000	270.0	255.0	46.5	21.0	16.0	0.82
100.000	125.000	250.0	236.0	43.0	19.8	15.1	0.82
80.000	102.000	235.0	223.0	40.0	18.7	14.0	0.82
70.000	90.000	225.0	213.0	38.0	18.2	13.5	0.82
60.000	78.000	217.0	206.0	36.0	17.0	13.0	0.81
Oil and chemical product carriers							
50.000	66.000	210.0	200.0	32.2	16.4	12.6	0.81
40.000	54.000	200.0	190.0	30.0	15.4	11.8	0.80
30.000	42.000	188.0	178.0	28.0	14.2	10.8	0.78
20.000	29.000	174.0	165.0	24.5	12.6	9.8	0.73
10.000	15.000	145.0	137.0	19.0	10.0	7.8	0.74
5.000	8.000	110.0	104.0	15.0	8.6	7.0	0.73
3.000	4.900	90.0	85.0	13.0	7.2	6.0	0.74
Bulk and Multipurpose Carriers							
400.000	464.000	375.0	356.0	62.5	30.6	24.0	0.87
350.000	406.000	362.0	344.0	59.0	29.3	23.0	0.87
300.000	350.000	350.0	333.0	56.0	28.1	21.8	0.86
250.000	292.000	335.0	318.0	52.0	26.5	20.5	0.85
200.000	236.000	315.0	300.0	48.5	25.0	19.0	0.85
150.000	179.000	290.0	276.0	44.0	23.3	17.5	0.84
125.000	150.000	275.0	262.0	41.5	22.1	16.5	0.84
100.000	121.000	255.0	242.0	39.0	20.8	15.3	0.84
80.000	98.000	240.0	228.0	36.5	19.4	14.0	0.84
60.000	74.000	220.0	210.0	33.5	18.2	12.8	0.82
40.000	50.000	195.0	185.0	29.0	16.3	11.5	0.80
20.000	26.000	160.0	152.0	23.5	12.6	9.3	0.78
10.000	13.000	130.0	124.0	18.0	10.0	7.5	0.78
Methane Carriers							
60.000	88.000	290.0	275.0	44.5	26.1	11.3	0.64
40.000	59.000	252.0	237.0	38.2	22.3	10.5	0.62
20.000	31.000	209.0	199.0	30.0	17.8	9.7	0.54
Liquid Gas Carriers							
60.000	90.000	265.0	245.0	42.2	23.7	13.5	0.68
50.000	80.000	248.0	238.0	39.0	23.0	12.9	0.67

Table 3.1. Average dimensions of vessels at full load

Dead Weight Tons (DWT) t	Displacement (Δ) t	Lenght overall (L) M	Lenght between perpendiculars (Lpp) M	Beam (B) m	Depth (T) m	Draught (D) m	Block Coefficient
Liquid Gas Carriers							
40.000	65.000	240.0	230.0	35.2	20.8	12.3	0.65
30.000	49.000	226.0	216.0	32.4	19.9	11.2	0.62
20.000	33.000	207.0	197.0	26.8	18.4	10.6	0.59
10.000	17.000	160.0	152.0	21.1	15.2	9.3	0.57
5.000	8.800	134.0	126.0	16.0	12.5	8.1	0.54
3.000	5.500	116.0	110.0	13.3	10.1	7.0	0.54
Container Ships (Post Panamax)							
70.000	100.000	280.0	266.0	41.8	23.6	13.8	0.65
65.000	92.000	274.0	260.0	41.2	23.2	13.5	0.64
60.000	84.000	268.0	255.0	39.8	22.8	13.2	0.63
55.000	76.500	261.0	248.0	38.3	22.4	12.8	0.63
Container Ships (Panamax)							
60.000	83.000	290.0	275.0	32.2	22.8	13.2	0.71
55.000	75.500	278.0	264.0	32.2	22.4	12.8	0.69
50.000	68.000	267.0	253.0	32.2	22.1	12.5	0.67
45.000	61.000	255.0	242.0	32.2	21.4	12.2	0.64
40.000	54.000	237.0	225.0	32.2	20.4	11.7	0.64
35.000	47.500	222.0	211.0	32.2	19.3	11.1	0.63
30.000	40.500	210.0	200.0	30.0	18.5	10.7	0.63
25.000	33.500	195.0	185.0	28.5	17.5	10.1	0.63
20.000	27.000	174.0	165.0	26.2	16.2	9.2	0.68
15.000	20.000	152.0	144.0	23.7	15.0	8.5	0.96
10.000	13.500	130.0	124.0	21.2	13.3	7.3	0.70
Ro-Ro							
50.000	87.500	287.0	273.0	32.2	28.5	12.4	0.80
45.000	81.500	275.0	261.0	32.2	27.6	12.0	0.80
40.000	72.000	260.0	247.0	32.2	26.2	11.4	0.79
35.000	63.000	245.0	233.0	32.2	24.8	10.8	0.78
30.000	54.000	231.0	219.0	32.2	23.5	10.2	0.75
25.000	45.000	216.0	205.0	31.0	22.0	9.6	0.75
20.000	36.000	197.0	187.0	28.6	21.0	9.1	0.75
15.000	27.500	177.0	168.0	26.2	19.2	8.4	0.74
10.000	18.400	153.0	145.0	23.4	17.0	7.4	0.73
5.000	9.500	121.0	115.0	19.3	13.8	6.0	0.71
General Cargo Vessels							
40.000	54.500	209.0	199.0	30.0	18.0	12.5	0.73
35.000	48.000	199.0	189.0	28.9	17.0	12.0	0.73
30.000	41.000	188.0	179.0	27.7	16.0	11.3	0.73
25.000	34.500	178.0	169.0	26.4	15.4	10.7	0.72
20.000	28.000	166.0	158.0	24.8	13.8	10.0	0.71
15.000	21.500	152.0	145.0	22.6	12.8	9.2	0.71
10.000	14.500	133.0	127.0	19.8	11.2	8.0	0.72
5.000	7.500	105.0	100.0	15.8	8.5	5.4	0.74
2.500	4.000	85.0	80.0	13.0	6.8	5.0	0.77

(Continued)

Table 3.1. Average dimensions of vessels at full load

Dead Weight Tons (DWT) t	Displacement (Δ) t	Lenght overall (L) M	Lenght between perpendiculars (Lpp) M	Beam (B) m	Depth (T) m	Draught (D) m	Block Coefficient
Car carriers							
30.000	48,000	210.0	193.0	32.2	31.2	11.7	0.66
25.000	42,000	205.0	189.0	32.2	29.4	10.9	0.63
20.000	35.500	198.0	182.0	32.2	27.5	10.0	0.61
15.000	28,500	190.0	175.0	32.2	26.5	9.0	0.56
Warships							
16.000 (1)	20.000	172.0	163.0	23.0	–	8.2	0.65
15.000 (2)	19.000	195.0	185.0	24.0	–	9.0	0.48
5.000 (3)	5.700	117.0	115.0	16.8	–	3.7	0.80
4.000 (4)	7.000	134.0	127.0	14.3	–	7.9	0.49
3.500 (5)	4.600	120.0	115.0	12.5	–	5.5	0.58
1.500 (6)	2.100	90.0	85.0	9.3	–	5.2	0.51
1.500 (7)	1.800	68.0	67.0	6.8	–	5.4	0.73
1.400 (8)	1.800	89.0	85.0	10.5	–	3.5	0.58
750 (9)	1.000	52.0	49.0	10.4	–	4.2	0.47
400 (10)	5000	58.0	55.1	7.6	–	2.6	0.46
Ferries (conventional)							
50.000	25.000	197.0	183.0	3.6	16.5	7.1	0.63
40.000	21.000	187.0	174.0	28.7	15.7	6.7	0.63
35.000	19.000	182.0	169.0	27.6	15.3	6.5	0.63
30.000	17.000	175.0	163.0	26.5	14.9	6.3	0.62
25.000	15.000	170.0	158.0	25.3	14.5	6.1	0.62
20.000	13.000	164.0	152.0	24.1	14.1	5.9	0.60
15.000	10.500	155.0	144.0	22.7	13.6	5.6	0.57

Notes:
(1) Attack vessel
(2) Aircraft carrier
(3) Landing craft
(4) Missile launching frigate
(5) Destroyer
(6) Fast frigate
(7) Submarine
(8) Corvette
(9) Minesweeper
(10) Patrol boat

Gross Tonnage (GT) t	Displacement (Δ) t	Lenght overall (L) M	Lenght between perpendiculars (Lpp) M	Beam (B) m	Depth (T) m	Draught (D) m	Block Coefficient
Fast Ferries (provisional values)							
40.000	640	83.0	73.0	23.2 (1)	4.0	2.0 (3)	0.43 (4)
5.000	800	88.0	78.0	24.7 (1)	4.2	2.1 (3)	0.44 (4)
6.000	960	95.0	84.0	26.6 (1)	4.4	2.2 (3)	0.44 (4)
Single hull							
8.000	1.280	102.0	87.5	15.4 (2)	5.0	2.5 (3)	0.45
10.000	1.600	112.0	102.0	16.9 (2)	5.2	2.5 (3)	0.45
15.000	2.400	128.0	120.0	19.2 (2)	5.4	2.7 (3)	0.47
20.000	3.200	140.0	133.0	21.0 (2)	5.8	2.9 (3)	0.49

(Continued)

Notes:
(1) The effective waterline breadth of each of the twin hulls is approximately 45/50% of that given which corresponds to the maximum beam at deck.
(2) The waterline breadth is approximately 80/90% of that given, which corresponds to the maximum beam at deck.
(3) The draught shown is without stabilizers (slow navigation or at rest) The draught with stabilizers is approximately 70/80% greater (fast navigation).
(4) The block coefficient is calculated with the effective waterline breadth of the twin hulls.

Table 3.1. ***Average dimensions of vessels at full load***

Gross Tonnage (GT) t	Displacement (Δ) t	Lenght overall (L) M	Lenght between perpendiculars (Lpp) M	Beam (B) m	Depth (T) m	Draught (D) m	Block Coefficient
Passenger cruise ships							
80.000	44.000	272.0	231.0	35.0	20.0	8.0	0.68
70.000	38.000	265.0	225.0	32.2	19.3	7.8	0.67
60.000	34.000	252.0	214.0	32.2	18.8	7.6	0.65
50.000	29.000	234.0	199.0	32.2	18.0	7.1	0.64
40.000	24.000	212.0	180.0	32.2	17.3	6.5	0.64
35.000	21.000	192.0	164.0	32.2	17.0	6.3	0.63
Fishing boats							
3.000	4.200	90.0	85.0	14.0	6.8	5.9	0.60
2.500	3.500	85.0	81.0	13.0	6.4	5.6	0.59
2.000	2.700	80.0	76.0	12.0	6.0	5.3	0.56
1.500	2.200	76.0	72.0	11.3	5.8	5.1	0.53
1.200	1.900	72.0	68.0	11.1	5.7	5.0	0.50
1.000	1.600	70.0	66.0	10.5	5.4	4.8	0.48
700	1.250	65.0	62.0	10.0	5.1	4.5	0.45
500	800	55.0	53.0	8.6	4.5	4.0	0.44
250	400	40.0	38.0	7.0	4.0	3.5	0.43
Pleasure Power boats							
–	50.0	24.0	–	5.5	–	3.3	–
–	35.0	21.0	–	5.0	–	3.0	–
–	27.0	18.0	–	4.4	–	2.7	–
–	16.5	15.0	–	4.0	–	2.3	–
–	6.5	12.0	–	3.4	–	1.8	–
–	4.5	9.0	–	2.7	–	1.5	–
–	1.3	6.0	–	2.1	–	1.0	–
Pleasure Sailing boats							
–	60.0	24.0	–	4.6	–	3.6	–
–	40.0	21.0	–	4.3	–	3.0	–
–	22.0	18.0	–	4.0	–	2.7	–
–	13.0	15.0	–	3.7	–	2.4	–
–	10.0	12.0	–	3.5	–	2.1	–
–	3.5	9.0	–	3.3	–	1.8	–
–	1.5	6.0	–	2.4	–	1.5	–

(Continued)

3.2. FACTORS AFFECTING VESSEL MANOEUVRABILITY

The way in which a vessel behaves when underway or manoeuvring depends on many factors, amongst which the following may be mentioned: their means of propulsion, steering system, shape of the underwater hull, layout of their upperworks and superstructures, their draught, their trim, loading conditions, shallow waters or restrictions of the mass of water in which they move, the action of tug boats and wind, current and wave effects.

A vessel's behaviour may differ a great deal from another's of a different type, but there are always basic manoeuvring principles which apply to all of them in general. The nature and magnitude of forces acting on a vessel must be known in order to determine the movement it will make with some accuracy. There are multiple forces which influence or may influence a vessel's movement: those applied in propulsion, rudder, anchor and mooring lines, those caused by the action of tug boats and propellers in manoeuvres, those caused by wind, current and waves, those generated by suction from the bank or interaction between vessels, etc. Some of these forces are typical of the vessel or of the boats aiding in manoeuvring. The vessel's handler may dominate them at will and, depending on how he uses them, will take the maximum advantage from them or not. Other forces are caused by nature and are beyond the handler's control but can and should be used by him or her to bring the manoeuvre to a successful end.

Each of the aforementioned forces may cause major effects on the vessel being handled, but it must be borne in mind that they are only forces and their resulting action on the vessel's movement will be demonstrated by taking the effects of inertia into account. Whether at rest or once under way, any ship has great inertia for opposing linear accelerations, due to its mass, whilst at the same time offering a considerable moment of inertia opposing angular accelerations.

The following sections analyse the four typical elements involved in vessel manoeuvring as mentioned above. The following two chapters examine both the external and tug boat action factors.

3.3. PROPULSION SYSTEMS

3.3.1. Power plant

3.3.1.1. When moving in water, any body undergoes a force on itself which opposes such movement, i.e., resistance to advance. Assessing this resistance involves a complex process which is outside the scope of this Recommendation and usually requires scale model testing, complex formulas and numerical models. The most important factors affecting such assessment are listed hereafter as an indication:

- The shape of the vessel's underwater hull.
- The condition of the underwater hull.
- The vessel's appendages which alter the underwater hull's hydrodynamics (propellers, rudder, etc.).
- The state of the sea (currents, waves, etc.).
- Alterations to the state of the sea caused by the vessel's navigation.

In order to overcome this resistance, a mechanism exerting a force opposed to it must be available, and this mechanism is called a Propeller or Screw and the force produced by the latter is called thrust.

3.3.1.2. The mechanical propulsion system formed by engine-reducer gear-shaft-propeller is the most usual procedure for propelling vessels (Fig. 3.01) although the reduction gear is usually eliminated in larger vessels and direct transmission is used.

When the manoeuvring qualities of any vessel are analysed, the first consideration to be borne in mind, together with the number and size of the propellers and rudders, are the power and type of its propulsion plant. Other factors being equal, the greater a vessel engine's power, the easier its handling proves to be.

For a vessel to be handled well, the minimum speed at which the propellers can rotate in going ahead or astern must be known, as well as response delay due to the transmission and execution of the orders given to the engines. These features vary from one ship to another and basically depend on their propulsion systems, which is why it is of interest to summarise the most important peculiarities displayed by such systems, as follows.

a) RECIPROCATING STEAM ENGINES

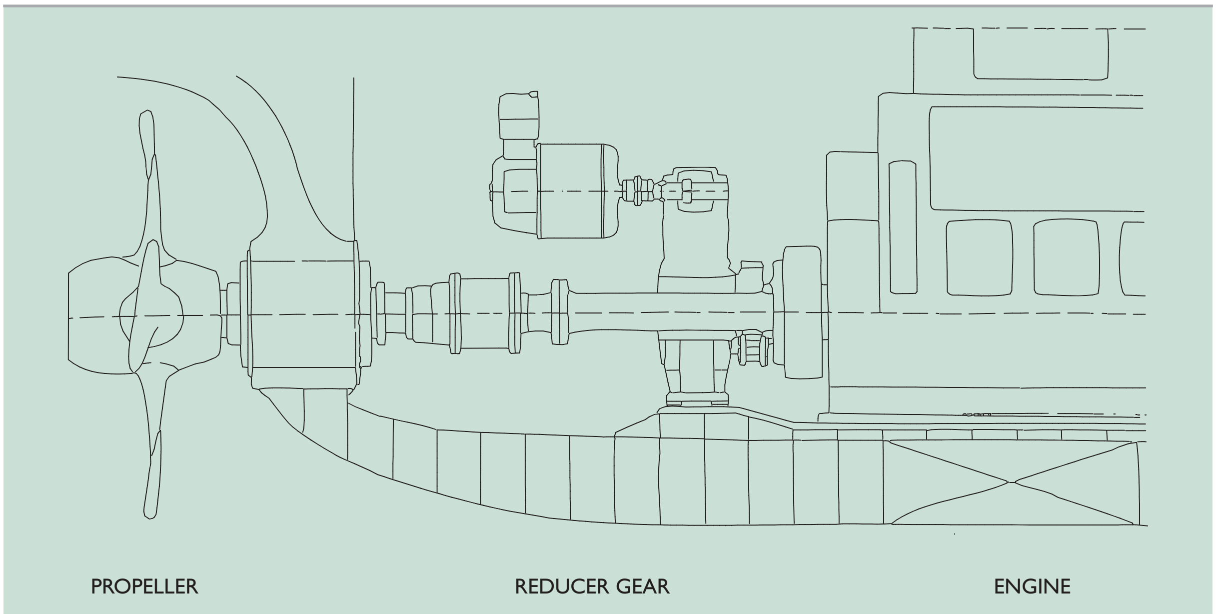
- These can rotate slowly at low revolutions going ahead and astern which provides good control over the vessel at any speed.

- They stop almost instantly, they are easy to reverse and quickly give maximum power in both directions.
- They give practically the same power ahead and astern.
- The economic speed is equal or very close to that of the propeller's highest efficiency.
- They start up well.

b) *STEAM TURBINES*

- These have a small starting torque.
- They take a long time to stop if not braked.
- They cannot be braked rapidly without the risk of damage.
- Their power astern is very low, in the order of 1/3 of their power ahead and therefore they generally need a special lower power turbine for going astern.

Figure 3.01. **Mechanical propulsion**



- They use much more steam in reverse.
- Their economic speed is far higher than that of the propeller's highest efficiency.

c) *DIESEL ENGINES DIRECTLY COUPLED TO PROPELLER SHAFTS*

- They cannot rotate below a certain, relatively high speed, usually corresponding to about 4 or 5 knots in light vessels.
- They have the same power ahead and astern.

- They stop almost instantly.
- They have a very good starting torque.

d) *DIESEL ENGINES WITH REDUCTION GEAR*

- Apart from slow engines, high-speed engines (over 500 rpm) and medium-speed engines (between 150 and 500 rpm) can be used because of the reduction gear.
- These engines are reversible and give practically the same power ahead and astern.
- They stop almost instantly.
- They have a very good starting torque.
- They take up little room.
- They can be built in a range from a very low to a very high power rating.
- Their specific consumptions ar lower than those of steam turbines.

e) *DIESEL-ELECTRIC AND TURBO-ELECTRIC PROPULSION*

- Propellers can rotate at very low revolutions ahead or astern.
- They respond quickly to orders given.
- They can be stopped easily.
- Propellers cannot be reversed quickly.
- They have a very good starting torque.

f) *DIESEL ENGINES WITH CONTROLLABLE PITCH PROPELLER*

- Minimum pitch can be used ahead or astern.
- Practically the same power is available ahead and astern.
- The propulsion direction can be almost immediately stopped or reversed with normal shaft revolutions.

g) *GAS TURBINES WITH CONTROLLABLE PITCH PROPELLER*

- Minimum pitch can be used ahead or astern.
- Practically the same power is available ahead and astern.
- The propulsion direction can be almost immediately stopped or reversed with normal shaft revolutions.

The different propulsion systems show differences from the point of view of their flexibility, force, response delays, etc. Diesel-electric, turbo-electric and reciprocating engines are the propulsion systems offering greatest general advantages and safety for manoeuvring out of those mentioned above. Turbines show most disadvantages and diesel engines occupy an intermediate position. The most used are diesel engines followed by steam turbines, gas turbines and diesel-electric propulsion; reciprocating steam engines are practically no longer used.

3.3.1.3. For studying vessel operation in models or on simulators, the propulsion plant must be known in order to know what possibilities and limitations it offers during manoeuvres and the reserve available in emergency cases. The following must be available, amongst other information:

- Number of revolutions or pitch angle of the propeller to be applied to obtain different speeds, knot by knot, for different loading and trim conditions and, if such be the case, percentage correction for a dirty hull due to the time elapsing since the last careening.
- Maximum speed attainable with certain gas turbines or boilers in service.
- Speeds obtained for different r.p.m. and/or pitch angles when navigating with a single propeller.
- Number of revolutions from which the turbines are allowed to be braked, if established for certain manoeuvres.
- Minimum number of r.p.m. which the engine can give working uninterruptedly with no danger of having to stop.

3.3.1.4. The power W necessary for propelling a vessel depends on a large number of factors and, in particular, on the geometric characteristics of its underwater hull. In general, it can be expressed by the following equation, valid for the vessel's service speeds:

$$W = K_{VD} \cdot \Delta^{2/3} \cdot V_f^3$$

where:

W = Effective power supplied by the engine.
K_{VD} = Coefficient mainly depending on the vessel's characteristics and the operating conditions considered, which is usually determined by model tests.
Δ = Vessel's displacement
V_f = Vessel's speed relative to the water.

The correct application of this equation for all possible cases exceeds the scope of this Recommendation. The power may be assessed using an approximate procedure based on the power required to propel a similar 1,000 t displacement model vessel at a speed of 10 knots. For service speed, a valid expression would be:

$$w = w_o \cdot \left(\frac{\Delta}{1.000}\right)^{2/3} \left(\frac{v_r}{10}\right)^3$$

where:

W = Effective power supplied by the engine
W_o = Power of the similar vessel model. See Table 3.2.
Δ = Vessel's displacement in tonnes.
V_r = Vessel's speed in knots relative to the sea.

3.3.1.5. If the effective power supplied by the engine under service conditions is known the thrust T_p applied in the propeller under such conditions may be determined by using the equation:

$$W = T_p \cdot V_r$$

and the following general expression thus results:

$$T_p = K \cdot \Delta^{2/3} \cdot V_r^2$$

where the different symbols have the expressions as given above.

The propeller's thrust for running speeds other than the service speed could be determined by the same procedure, assuming the vessel's steady speed with which it would navigate under the regime being analysed were known.

Table 3.2. ***Model vessel power W_0***

Rate of speed	Type of vessel	W_o (HP)
$V_r \cdot L_{pp}^{-1/2} < 1.2$	Slow vessels (bulk carriers, oil tankers, etc.)	200-250
$1.5 < V_r \cdot L_{pp}^{-1/2} < 1.7$	Moderately fast vessels (merchant ships, container vessels, etc.)	250-400
$1.9 < V_r \cdot L_{pp}^{-1/2} < 2.2$	Large fast ships (cruise liners, aircraft carriers, etc.)	300-400
$2.4 < V_r \cdot L_{pp}^{-1/2} < 3.4$	Very fast ships (warships, ferries, etc.)	500-650
$V_r \cdot L_{pp}^{-1/2} < 5.0$	Fast patrol boats, coastguard vessels	800-1.200
$1.8 < V_r \cdot L_{pp}^{-1/2} < 2.7$	Fast, small sized boats (tug boats, fishing boats, etc.)	600-1.200

Notes:
V_r = Vessel's relative speed to the water in knots.
L_{pp} = Length between perpendiculars in metres.

3.3.2. Propeller action

3.3.2.1. The propeller is the propulsion element typical of vessels and the most used at the present time (fig. 3.02). The propeller's applicability for this purpose is based on the physical phenomenon of lift: the movement of a blade in a fluid due to the propeller's action generates a thrust in the blade whose component on the vessel's longitudinal axis may be used to cause the vessel to move forward.

A propeller is characterized by its diameter, its pitch, the number of its blades and the thrust it can generate when rotating at a certain speed. Most propellers have 4 or 5 blades, but those of 2, 3, 6 and 7 blades also exist. The most used in merchant ships are the 4 and 5 bladed. The 3 bladed are currently used only in certain warships and small fishing boats.

There is normally only one propeller per vessel. Should the ship have a high installed power (high speed vessels) the propulsion plant may have to be divided into two or more groups which leads to two or more shafting lines. If there are space limitations because of the vessel's stern shape or in the engine room, the propulsion plant is also usually divided and there are two or more propellers. Thrusters are doubled or tripled in warships and some passenger ships to increase the propulsion system's reliability, with the consequent doubling or tripling of propellers. Summarising the foregoing, it may be said that in general oil tankers, bulk carriers, general cargo merchant ships, medium and small container ships and fishing boats usually have one propeller whilst warships, passenger ships, ferries, Ro-Ro and large container ships usually have two propellers.

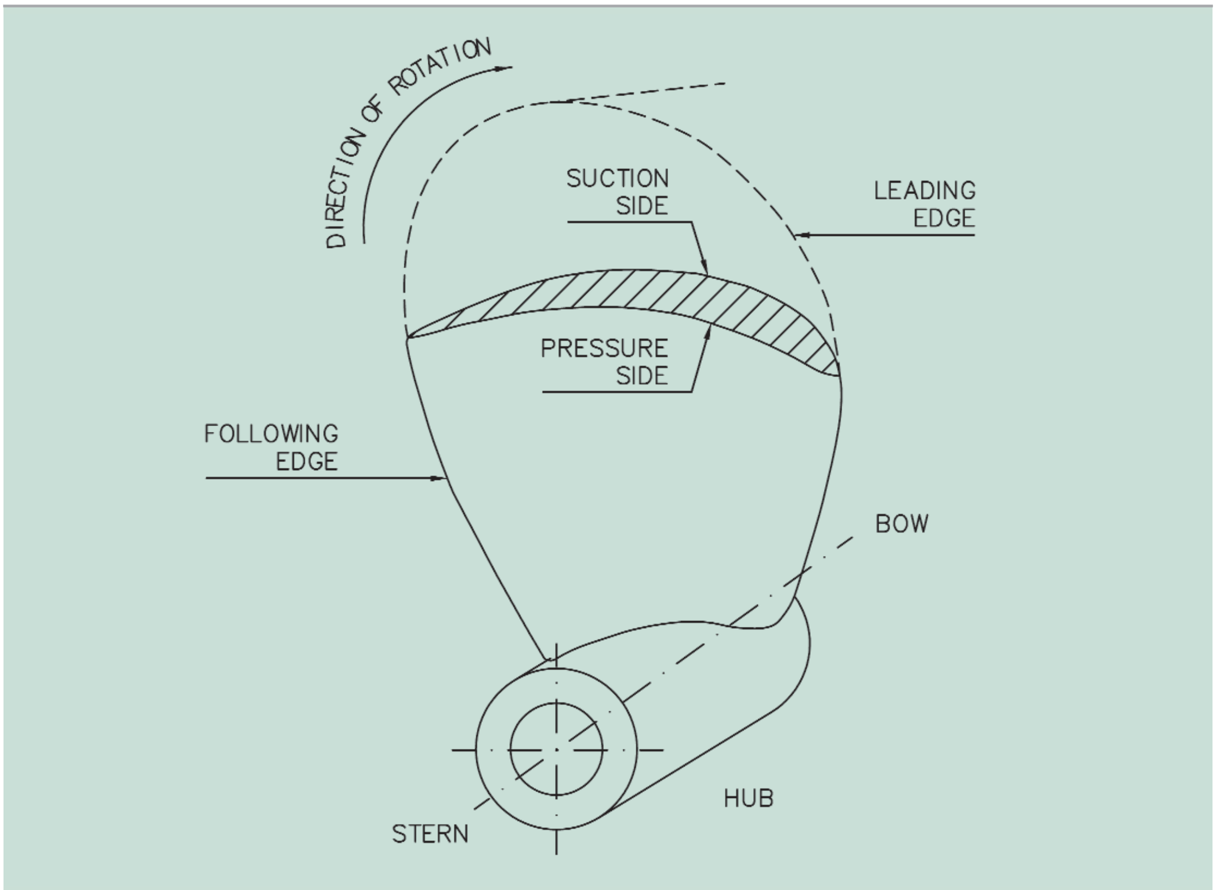
Single propeller vessels are almost always fitted with right hand pitch propellers, i.e., the blades rotate in a clockwise direction looking from the stern when going ahead. The propeller shaft rotation direction is reversed for going astern.

Propellers in the vast majority of two propeller ships rotate when going ahead with their high blades outwards, i.e., the starboard one has a right hand pitch and the port one a left hand.

The three propeller system, one in the centre and two at the sides, has not given good results in any type of vessel which is why it is practically not used at the present time.

In the case of four propeller ships, two are located on each side. In general, the four propellers rotate outwards and the two centre ones are located more astern than the others.

Figure 3.02. **Typical propeller**



3.3.2.2. The aim pursued when designing a propeller is to achieve the maximum thrust along the direction of the shaft for the vessel running ahead at service speed but in practice, an acceptable performance is also obtained at other speeds within a wide range of revolutions. The propeller also works well when engines astern is ordered, but with very low efficiency since the blades are rotating in reverse and the pertinent wing sections are working under different conditions to those used to optimize their design. In addition, the shape of the vessel's underwater body is more efficient for running ahead than astern, and, therefore, more revolutions are required in running astern to obtain the same effect as going ahead.

Despite a propeller being designed to produce a force acting in the direction of its axis, the net force resulting exerts its action by forming a certain angle with the vessel's centre line, for various reasons related to the shapes of the hull at the stern, propeller and rudder arrangement and differences in flow occurring on the propellers different blades. This resulting force may be broken down into two perpendicular components:

- The thrust force acting ahead or astern, in the direction of the vessel's longitudinal axis, producing the purely ahead or astern propellant effect.
- The transverse component acting towards starboard or port producing a turning effect.

Therefore, due to the propeller's rotation, a lateral force applied to the vessel's stern tending to turn it to one side or the other is generated (ignoring other effects produced by the fact of these forces not passing through the vessel's centre of gravity) as a secondary effect, apart from the main direct effect of the thrust exerted along the propeller axis. This lateral force must always be taken into account by the ship's handler and may be the determining factor of whether a certain low speed or going astern manoeuvre can be carried out or not.

The magnitude of this lateral force varies with the type of vessel and shapes of the underwater body and elements close to the propeller, but its direction depends only on the propeller shaft's direction of rotation. In most cases, when ordering engine ahead in a vessel with a single right hand pitch propeller, the lateral force pulls the stern towards starboard and tends to turn the ship, making its bow veer towards port, but it does not always happen like this. On the contrary, when giving engine astern, the lateral force usually takes the stern to port and tends to turn the vessel, making it veer its bow to starboard. The tendency mentioned is more notable the greater the propeller's diameter is and is far more noticeable in going astern than going ahead in a given vessel.

The effect of this lateral force in single propeller ships running ahead can easily be corrected with the rudder, since the propeller's slipstream is thrown directly onto its blade and a few degrees of rudder to the pertinent shipside to offset this force suffice. However, this resource is much less efficient in reverse not only because the lateral force is greater, but also because the rudder's correcting effect in reverse is only felt when the vessel has taken appreciable headway.

This fact is a great problem in handling single propeller ships, as shown by the following disadvantages:

- Starting from rest, it is not possible to turn it in little space, except in one direction only: normally veering the bow to starboard.

- There is a handling problem in running astern when required to backing in a straight line.

In twin screw ships, the lateral force's action persists for each of the propellers taken individually, but its effect is considerably reduced due to their having a comparatively smaller diameter, being more submerged in the water and being quite some distance from the hull. Moreover, if both screws rotate in different directions, they balance each other, apart from the offsetting turning effect which may be obtained by making each of the propellers work at a different rate of revolutions.

3.3.3. Other types of propeller

a) CONTROLLABLE PITCH PROPELLERS

The use of propellers whose blades may be oriented at will, which is why they are called controllable pitch or alterable pitch propellers (Fig. 3.03) have become increasingly widespread with excellent results. These propellers allow the thrust they provide to the vessel to be reversed without needing to change the direction of rotation of the propeller shaft. The blades are fitted such that they can rotate on themselves by means of a special hydraulic mechanism turning round a shaft which is fitted onto the propeller's hub. This type of propeller is an efficient means of propulsion and makes the manoeuvre easier and faster as shafts do not have to be stopped to go into reverse. Another of these propellers' advantages lies in making it possible for the vessel to turn at low speed in a completely controlled manner as they rotate at a high rate with minimum pitch, which result is impossible to achieve in any other way with other systems.

b) DUCTED PROPELLERS

This system consists in fitting a fixed nozzle around the propeller, which increases performance as it aligns the flow entering and leaving the propeller despite the increase in friction resistance (see fig. 3.04). This is a propulsion device requiring a rudder behind for steering the vessel.

The prime function of the fixed nozzle is to considerably increase the propeller's thrust in certain circumstances (bollard pull, trawling in fishing boats, tug boat pull, etc.).

Figure 3.03. **Controllable pitch propeller**

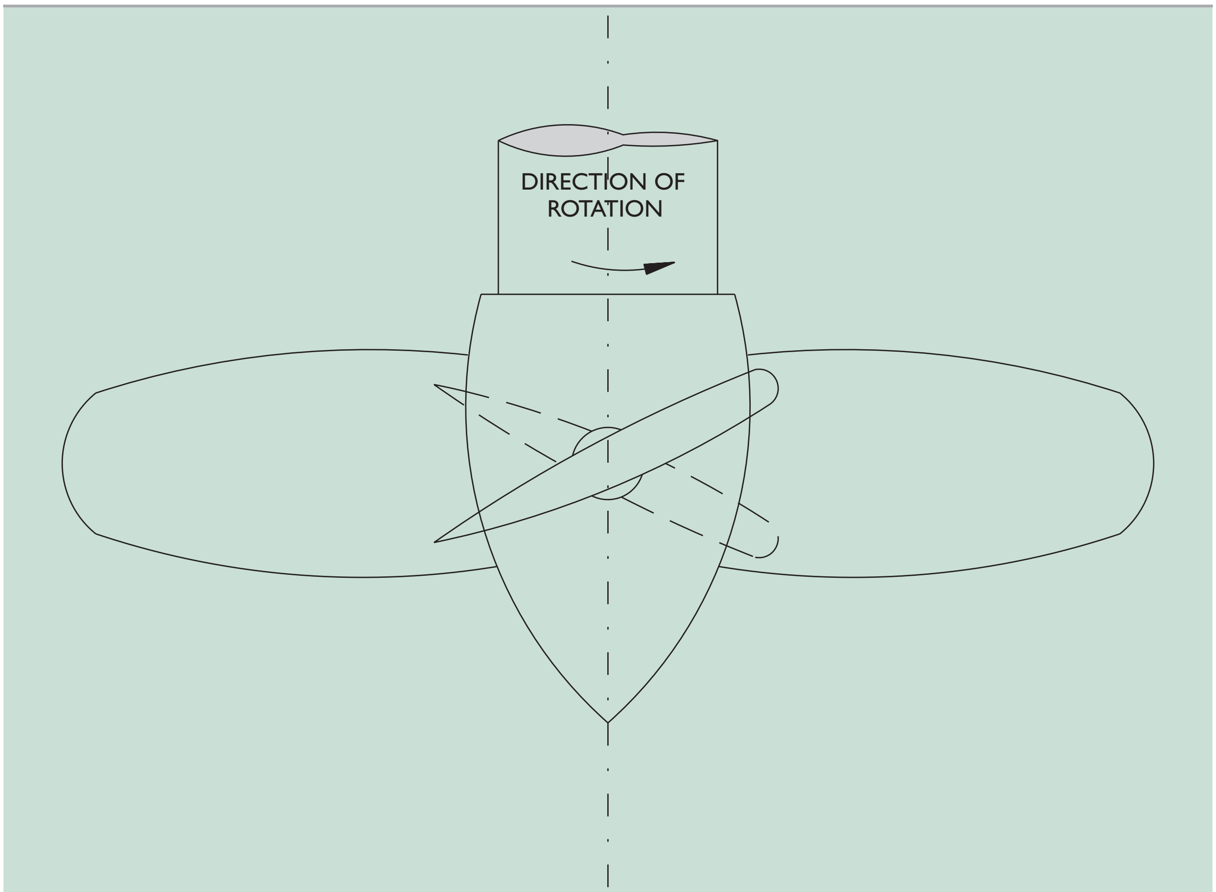
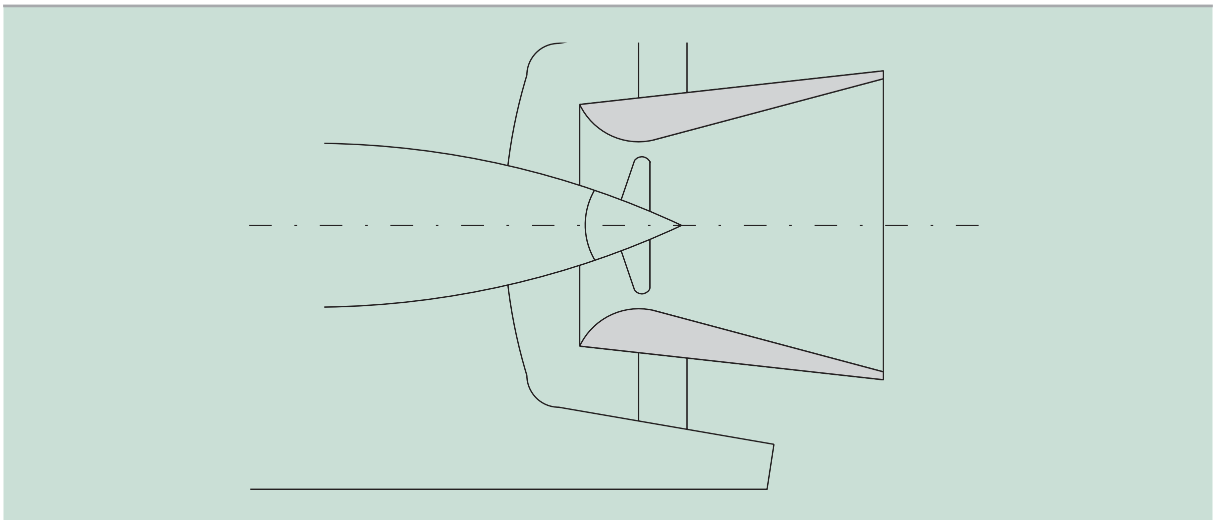


Figure 3.04. **Ducted propeller**



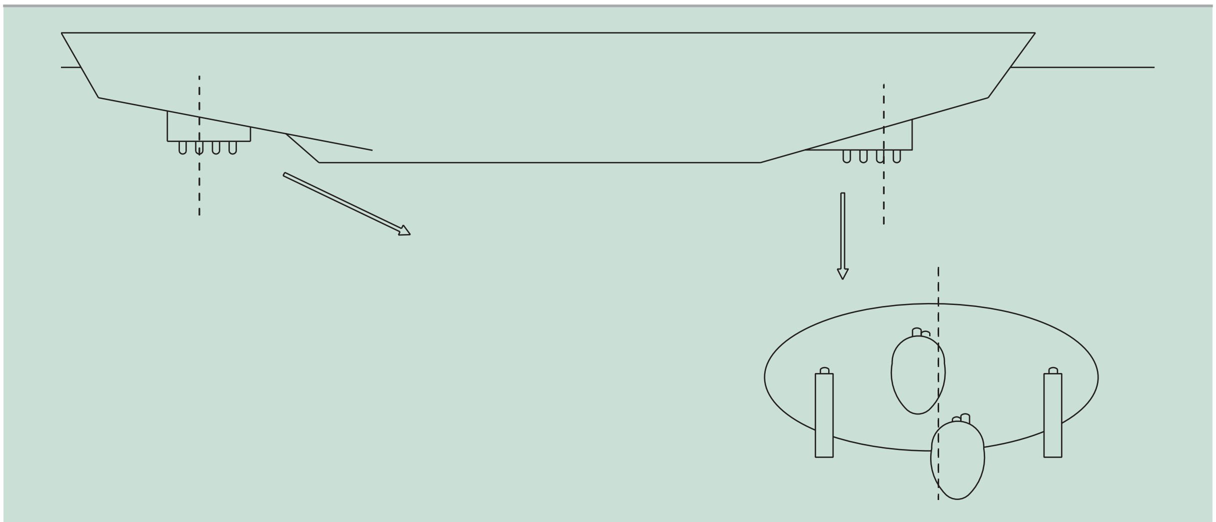
c) SWIVEL NOZZLE

This system derives from the foregoing and provides the possibility of turning the nozzle and directing the jet, eliminating the need for a rudder. Thus, it is a propulsion-steering device contributing to the vessel's manoeuvrability.

d) VERTICAL SHAFT OR CYCLOIDAL PROPULSION PROPELLERS

This thruster is formed by a hull housed rotor and rotates constantly around a vertical shaft. Two or three pairs of hydrodynamic profile fins are secured in the periphery of the disc shaped, rotor's bottom. Located in diametrical opposite positions, these fins share the rotor's circular movement and may, in turn, revolve on their respective vertical shafts (fig. 3.05). On modifying the pitch of the fins and their eccentricity, the resulting thrust force acts in any desired direction. By keeping the rotor rotating in the same direction at a constant speed, going ahead may be changed to astern and vice-versa and, what is still more important, a kind of lateral movement allowing the stern to move to one or the other side may also be achieved with the bow remaining practically at rest.

Figure 3.05. ***Vertical shaft propeller***



The cycloidal propeller makes it possible to manoeuvre the vessel without the need for a rudder by combining the propulsion and steering effects in a single organic device. It has the great advantage of noticeably improving the vessel's turning qualities, particularly when it has little or no headway. This is why it is used in small vessels operating in restricted, heavy traffic waters, such as tug boats, river pleasure, pilot or fire fighting boats.

The most widespread designs used are the Voith-Schneider and Kirsten Boeing makes.

e) PADDLE WHEELS

Very much used in the past, this type of thruster is based on the action of two wheels, symmetrically located on each ship side and revolving separately on horizontal shafts housed above the water line, perpendicular to the centre line.

This method of propulsion has been abandoned in vessels navigating in the open sea as it is liable to breakdown with bad weather. Only certain harbour tug boats and small vessels plying the coastal trading service or in sheltered roads use it nowadays.

f) SPECIAL THRUSTERS

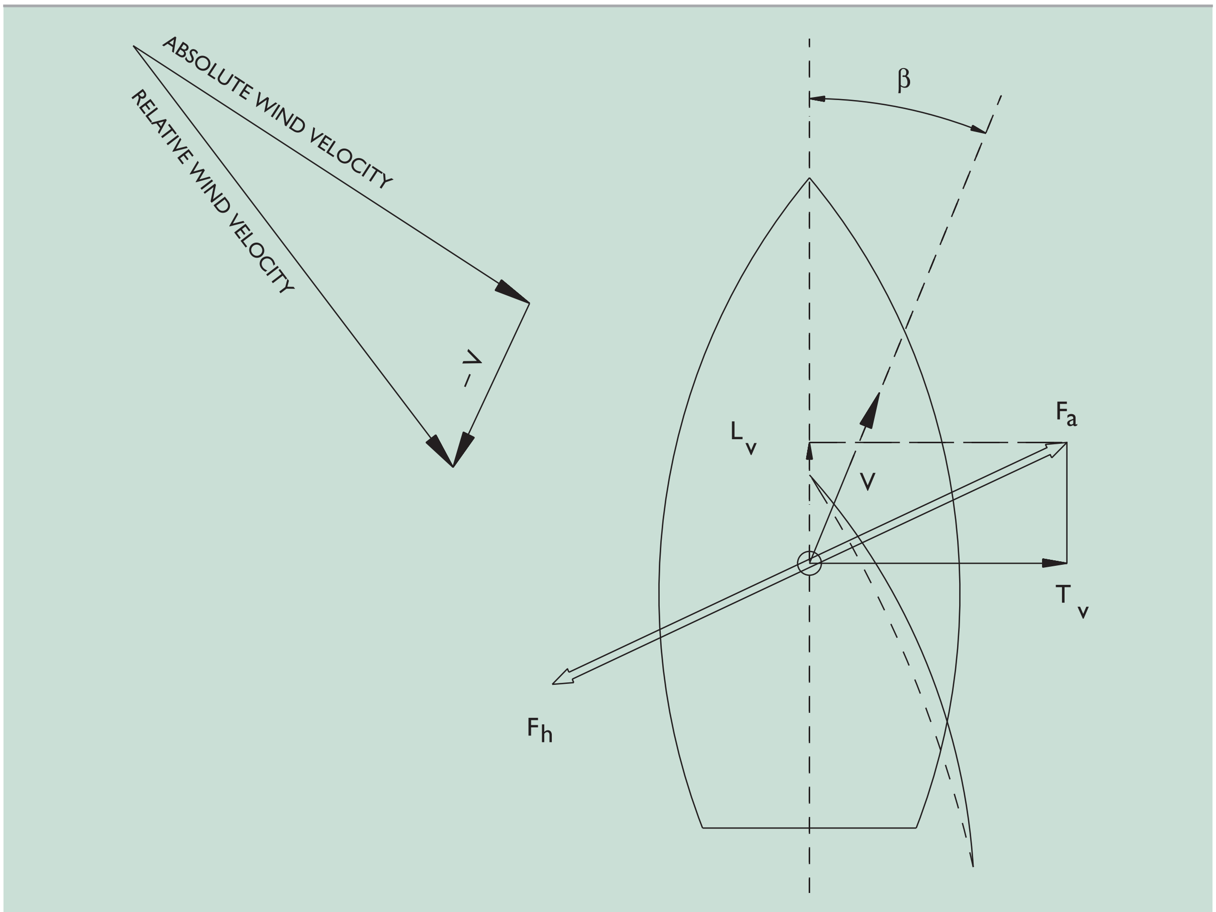
Other special propulsion methods have been developed apart from the foregoing systems for fast boats (hovercraft, jet-foil, hydrofoil, etc.), whose analysis is beyond the scope of this ROM.

3.3.4. Sailing

Sailing is the intelligent use of wind propulsion based on the physical phenomenon of lift on the sail's surface such that it enables a route oblique to the wind's direction to be followed and chosen at will. The sail's propulsion working scheme is given in a simplified manner in figure 3.06 where the following are shown:

- F_a, which is the horizontal aerodynamic force resulting from the wind's action on the sails, forming the propulsion force applied at a point known as centre of effort.

Figure 3.06. ***Sailing***



- F_h, which is the horizontal hydrodynamic force resulting from the water's action on the vessel's underwater hull which forms the resistance to the manoeuvre and is applied at a point called the underwater centre of lateral resistance or centre of drift. The position of this point may be modified within certain limits by orienting the elements that steer the vessel.

For the vessel to be balanced, the sail must be positioned so that the centre of effort, assuming the ship to be horizontal, is noticeably on the vertical of the underwater centre of lateral resistance. When the boat is running at an absolute speed V constant in direction and intensity, F_a and F_h are balanced in intensity and direction, allowing the ship to fetch to the wind. It must be pointed out that should there be a current of water, the aerodynamic force F_a will be caused by the speed of the wind relative to the vessel (V_{vr}), and the hydrodynamic force F_h by the current's speed relative to the vessel (V_{cr}).

The propulsion speed F_a may be broken down into a force L_v directed forwards and a transverse force T_v and, as the underwater hull will normally offer less resistance to the longitudinal movement than the to transverse, the vessel's resulting speed will be at an angle b with the underwater hull's longitudinal symmetry plane called drift angle, which will normally be small.

Based on this system, a direct navigation route may be followed in any direction, except upwind inside the limit beating angle (30-45 degrees on each side), in which circumstances, sailing must be close to the wind in order to arrive at the required point, with zig-zag tacks, thus increasing the space required.

3.3.5. Towing

Being towed is the simplest propulsion procedure, used for moving boats in canals and navigable rivers. The pull is provided by a means external to the vessel and is generally transmitted obliquely to the vessel's longitudinal axis which calls for course correcting measures to be taken in order to achieve balanced navigation.

3.4. RUDDER ACTION

3.4.1. Rudder function

3.4.1.1. The rudder is the main steering item of the ship by means of which the latter can maintain its course or alter it at will. The rudder is schematically formed by a plate called a blade, which revolves at the will of the ship's handler, on a usually vertical shaft called a stock or main piece, with which forces are generated due to water flow falling on it. These forces are used to steer the ship. The rudder therefore has two main functions:

- To produce the steering movement necessary to start turning the vessel to one side or another.
- To keep the vessel turning in that direction, if so required, overcoming the water pressure resistance acting on the hull which tends to prevent this movement.

In practice, the rudder also enables a vessel to keep navigating over a straight line track when the wind or sea's effect tend to alter its heading whilst at the same time it serves for making it turn during port, channel or open water manoeuvres.

The rudder's efficiency depends on a flow incident on it forming a certain angle with the blade's orientation. If the incident flow's speed is low or null, the rudder's performance is minimal. If the rudder is amidship forming no angle with the incident flow, the forces generated in the rudder will be only in the vessel's longitudinal direction, unable to provide steering actions. The incident flow speed is given by the vessel's speed in going ahead or astern, modified at the rudder location by the shapes of the underwater hull, plus the flow induced by the propeller, the influence of which will vary depending on the rudder's position relative to the propeller and whether the propeller is rotating in a go ahead or go astern direction.

3.4.1.2. There are several types of conventional rudder, the classic or unbalanced and the balanced, and various types of special rudders. The unbalanced rudder has its rotation shaft at the end of the blade and therefore requires a greater force to turn it, whilst in the balanced rudder, its vertical revolving shaft has been moved towards the blade's pressure centre so that 25% to 30% of its area is to the bow of the said shaft. This arrangement reduces the energy necessary to turn it when the vessel has much headway. The balanced rudder is conventional in all merchant vessels nowadays, whilst the unbalanced rudder is most usual in small sport boats. Special rudders (Schilling, Becker or with flap, etc.) improve the rudder's efficiency at large angles, increasing manoeuvring capability in vessels with them fitted, which may double that of a ship fitted with a conventional rudder.

Single-screw vessels normally have a single rudder located directly astern of the propeller. Twin propulsion shaft ships may have one or two rudders. When fitted with a single rudder, it is installed with its vertical shaft in the centre line and, consequently, being placed amidship, it does not receive the direct effect of the propellers' slipstream. Therefore, most modern twin-screw vessels are fitted with two rudders installed immediately astern of each propeller. Thus each rudder directly receives a propeller's slipstream. The great advantage of twin rudders lies in their higher effectiveness at low speeds and for small blade angles.

Three-propeller vessels normally have a single rudder located astern of the centre screw and ships with quadruple propellers normally have two rudders fitted astern of the inner propeller shafts.

3.4.2. Forces generated in the rudder. Turning moment

An analysis of the forces generated at the rudder blade by a flow of water incident on it with an angle a may be divided into its two components: one in the rudder's direction due mainly to friction forces, which is negligible, and the other perpendicular to the blade «P_T», called normal pressure force or rudder force, whose point of application is called the blade's pressure centre. The effect of this «P_T» force referred to the vessel's centre of gravity may be broken down into two components in the vessel's longitudinal and transverse directions, «P_{TL}» and «P_{TN}» respectively, and a moment M_e called «turning moment» which tends to turn the vessel in the horizontal plane (ignoring other secondary moments on other axes).

If these effects are analysed in a vessel navigating ahead with engines running ahead (see fig. 3.07), the longitudinal component «P_{TN}» is seen to make the vessel cast to the side opposite to which the rudder blade was turned and the evolution moment M_e tends to rotate the vessel making its bow veer to the side where the rudder was turned. If this analysis is carried out for a ship moving astern with engines astern (see fig. 3.08), the longitudinal component «P_{TL}» also tends to slow down the vessel, the transverse component «P_{TN}» makes the vessel cast to the same side as that to which the blade was turned and the evolution moment M_e makes the bow veer to the side opposite to that to which the rudder was turned.

Figure 3.07. **Rudder's action (vessel moving ahead with engines ahead)**

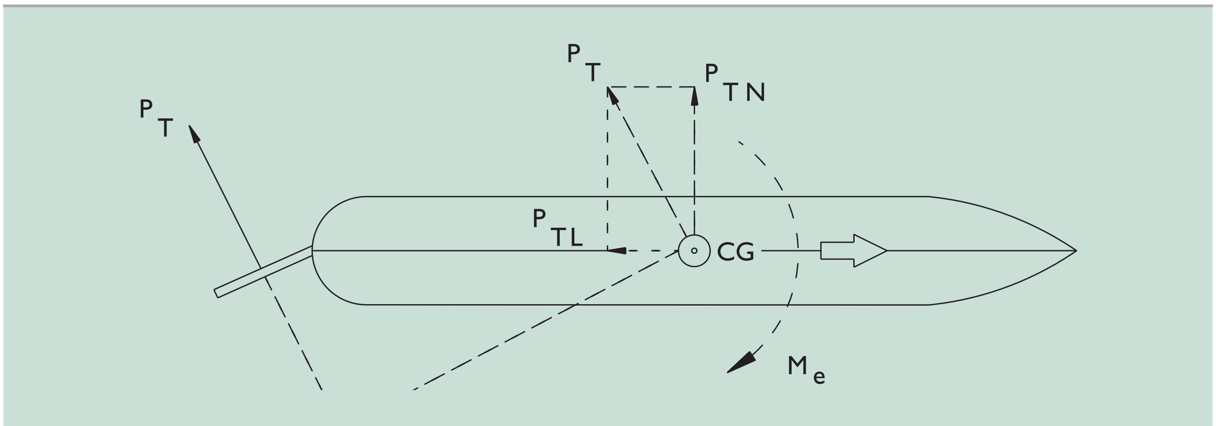
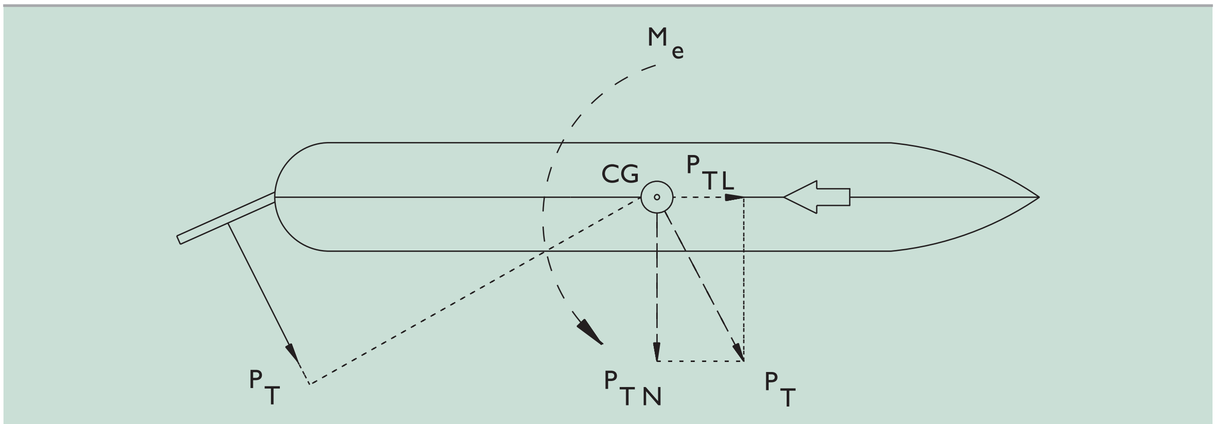


Figure 3.08. **Rudder's action (vessel moving astern with engines astern)**



The foregoing forces may be calculated approximately for conventional rudders using Joessel's formulas which determine the value of force «P_T» perpendicular to the rudder's blade, produced by a horizontal, even current with a velocity V_T inclined at an angle α_T to the rudder plane (see fig. 3.09).

$$P_T = \frac{K_T \cdot S_T \cdot V_T^2 \cdot \sin\alpha_T}{0.2 + 0.3 \cdot \sin\alpha_T}$$

where:

P_T = Component of the resulting loads on the rudder in the direction perpendicular to the blade.
K_T = Constant of a value 41.35 for the units indicated.
S_T = Area of the rudder's blade (m^2)
V_T = Speed of flow incident on the rudder (m/s).
α_T = Rudder angle to the current's speed direction.

The pressure centre will be located at an approximate distance:

$$d_T = (0.2 + 0.3 \bullet \sin\alpha_T) \bullet l_T$$

where:

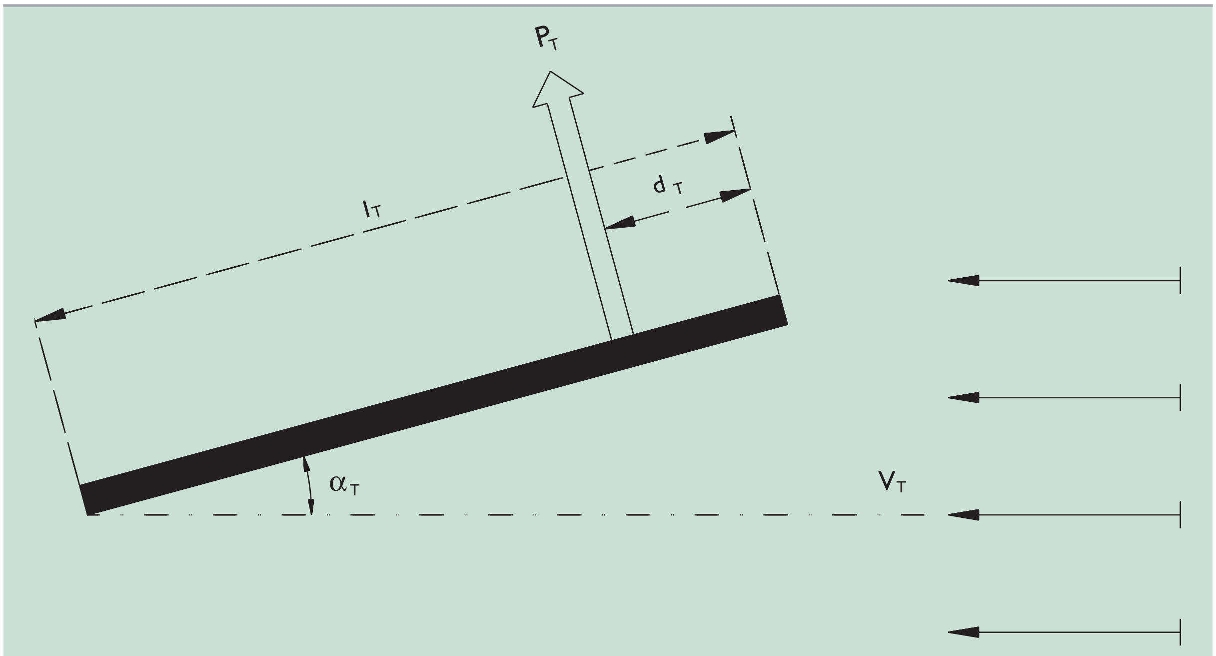
l_T = Chord of the rudder's blade.
d_T = Distance of the pressure centre to the blade's leading edge.

Using these expressions, the value of the Turning Moment (M_e) can be simply obtained from the following equation:

$$M_e = \frac{41.35 \cdot S_T \cdot V_T^2 \cdot L_{pp} \cdot sen\alpha_T \cdot \cos\alpha_T}{0.4 + 0.6 \cdot sen\alpha_T}$$

where M_e is the Turning Moment expressed in kg.m and L_{pp} the length between perpendiculars expressed in m.

Figure 3.09. **Load on rudder**



The characteristics of the vessel must be known in order to apply these equations, in particular the rudder blade area «S_T». In the absence of this value, the following equation from Det Norske Veritas may be used, applicable to vessels fitted with a single conventional rudder directly astern of the propeller (for other rudder arrangements this area must be increased at least 30%):

$$S_T = \frac{D \cdot L_{pp}}{100}\left[1 + 25\left(\frac{B}{L_{pp}}\right)^2\right]$$

where:

S_t = Rudder blade area.
D = Draught of vessel at full load.
L_{pp} = Length between perpendiculars
B = Vessel's beam.

The turning moment for conventional rudders is theoretically maximum when the rudder angle is 45°. In practice, it has been proven that the maximum effect is reached with a lesser angle, about 35° approximately, value up to which Joessel's equations are acceptable. With greater angles, there is a mass separation of the viscous boundary layer on the suction side of the blade, which makes the pressure on that side increase and, consequently, greatly diminish the rudder's useful force. Some types of special rudders have been precisely developed to prevent this effect. They boundary layer from separating and increase the rudder's efficiency with large angles (40 or 45 and even greater).

3.4.3. Heeling effect due of the rudder

Considering that the forces intervening in a vessel's navigation are not all located in the same horizontal plane, pitching and rolling effects will occur, the most important being the latter. For the case of a vessel moving ahead, as soon as full rudder is given to one side and before the vessel commences to turn, it is likely to list somewhat to that side because the rudder blade's pressure centre is always located below the centre of gravity of the vessel. The initial heeling angle is normally small. As the vessel commences and continues its turning, an acceleration towards the centre of curvature is established, caused by the centripetal force exerted on a point called the centre of lateral resistance or centre of drift located lower than the centre of gravity where the latter applies the centrifugal force balancing it. Since the centripetal force is far higher than the rudder's, its action not only cancels out the initial listing but causes further listing towards the other side, i.e., towards the side opposite to the veering's, with a greater amplitude than the first.

When a vessel moves astern, these two listings or heelings do not offset each other but add together. However, their effect is less important because of the lower speed at which the vessel moves under these conditions.

3.5. COMBINED PROPELLER AND RUDDER ACTION

The foregoing sections have separately analysed the propeller's thrust and lateral force, as well as the rudder action, which are produced at the stern and almost in one only place. To practical effects for single-screw vessels, both may be composed into a single resulting force, applied to the propeller, which would enable its effect on the behaviour of the vessel to be predicted, taking into account that the vessel is handled by controlling this resulting force applied astern. When the handler moves the engine and/or the rudder, he is only altering the linear direction, side direction or magnitude of that force acting on the vessel's stern, and his skill depends precisely on knowing how to choose the most suitable combination to achieve the turning effect desired.

In vessels with 2 or more propellers and several rudders, the study may be carried out in a similar way, taking into account that the possibility of intervening with different forces applied at different points provides the vessel with a higher turning capacity, especially when one of the thrusters is giving ahead and the other astern.

Analysing all the cases which may occur is beyond the scope of this ROM. As an example, Table 3.3. gives a summary of the behaviour of a normal single, right hand pitch propeller vessel fitted with a single rudder and under windless conditions and a calm sea. The influence of adverse weather conditions on this behaviour will be effected with the criteria given in Chapter IV. Similar tables suited to the specific characteristics of another type of vessel may be drawn up in a way similar to this one.

Table 3.3. ***Bow veering when handling a single right hand pitch propeller vessels***

	Engine ahead		Engine astern		Vessel under headway and engine astern	Vessel moving astern and engine ahead
Helm	Vessel at rest	Vessel moving ahead	Vessel at rest	Vessel moving astern		
Amidship	First veers slightly to Port; on getting under way, this effect disappears	Keeps to heading or veers very little to port	Veers to Starboard, clearly	Veers to Starboard, slowly	Keeps to heading then veers to Starboard slowly	Indeterminate: whether veering to Port or to Starboard cannot be forecast
To port	Veers to port, clearly	Veers to Port, quickly	Veers to Starboard, quickly	Veers to Starboard, quickly	Veers little to Port, very slowly and then to Starboard, more quickly	Veers to Port slowly
To starboard	Veers to Starboard, slowly	Veers to Starboard, quickly	Veers to Starboard very slowly	First veers to Starboard, if it has little headway, then amidships and, when picking up speed, may veer somewhat to Port	Veers somewhat to Starboard, very slowly. Then indeterminate. May keep amidship or veer to Port, slowly	Veers to Starboard, slowly
Rudder effectiveness	High	Very high	Very low	Low. Improves with propeller stopped	See remark (1)	High

Remarks:
(1) The instant full rudder is given is very important. The table includes the typical behaviour of the vessel when the blade is turned at the same time as the propeller is reversed.

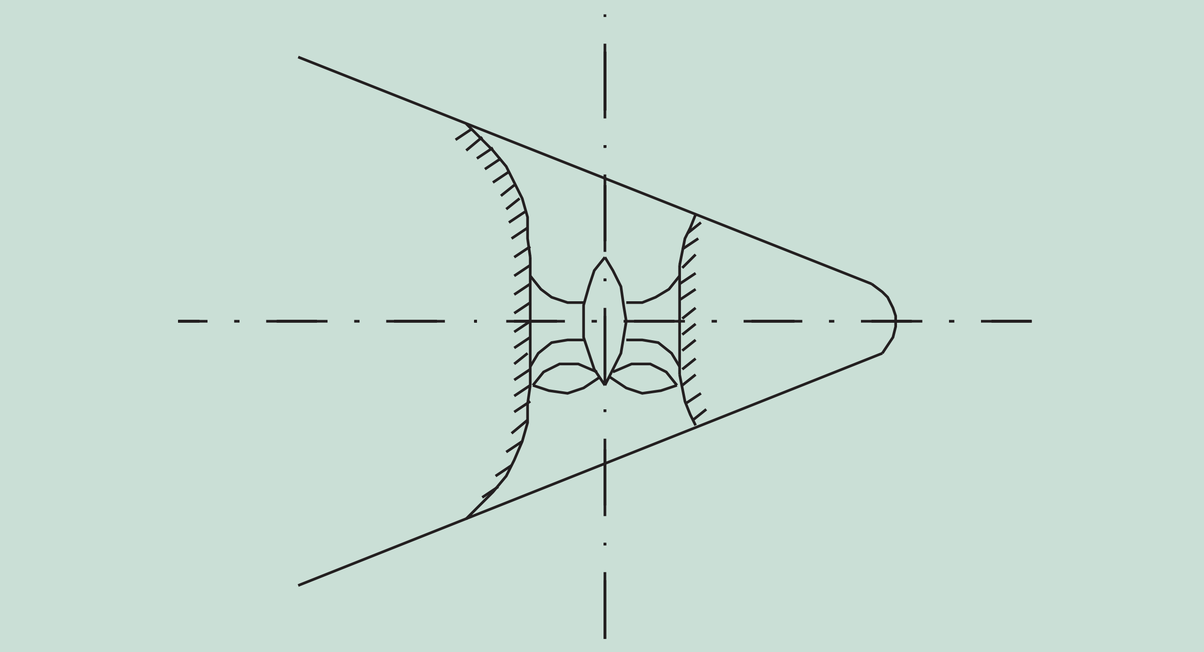
3.6. TRANSVERSE THUSTERS ACTION

Some vessels are fitted with propellers at the bow and also, in some cases, at the stern, whose shaft is perpendicular to the centre line. They are installed in transverse tunnels, which allows them to push the bow or stern to one or the other side (see fig. 3.10).

The main aim of bow thrusters is to enable vessels to manoeuvre when stopped or navigating at low speed (a circumstance in which the conventional rudder's effectiveness is very low), allowing the need for tug boat assistance to be reduced. When the vessel's speed increases, the lateral force due to the thrusters and, therefore, the turning torque generated, diminish since the flow is not diverted to enter into the thruster's tunnel, and becomes insignificant when the vessel's speed exceeds 3 knots, with efficiency decreasing from 1.5 knots.

The following criteria, which are those usually employed for designing thrusters, may be used for assessing their effect with the vessel at rest.

Figure 3.10. **Bow Thruster**



	Propeller thrust (kg/m2)	
	For lateral area of underwater body	For lateral area of upper work
Oil tankers, Bulk carriers	4-8	4-8
General cargo	6-8	4-8
Ferries. Passengers	12-16	4-8
Fishing boats	16-18	4-8
Dredgers	10-12	4-8

3.7. MOORING LINES ACTION

For the purpose of this ROM, mooring lines are manoeuvring elements used for facilitating vessel mooring or casting-off at quays, buoys or the alongside other ships. They are also used for keeping vessels secured in a steady, safe position whilst staying in port, as well as for some manoeuvres in the vessel's movement along the quay (shifting on ropes or warpings).

Mooring lines are given different names depending on the direction in which they work when exiting the vessel through chocks, fairleads or warp holders and depending on the location of these elements.

Mooring lines leaving the bow to work frontwards or leaving the stern to work backwards are called length lines. Mooring lines leaving through one end of the vessel to work obliquely in the direction of the other end, or those which are arranged longitudinally to the vessel's side are called spring lines or lashings. Ropes or cables working in a direction approximately perpendicular to the centre line plane are called breast lines.

An adequate use of mooring lines largely contributes to the speed and safety of in-port manoeuvres; that is why it is important to know the effect occurring on the vessel when hauling on a mooring line or making it work with the headway the vessel has or is given.

The effect of any mooring line can be seen in schematic form in figure 3.11 where the vector T_M represents the horizontal stress component applied at the warp holder when a rope fastened on a quay bollard is hauled in. This vector T_M moved to the centre of gravity CG causes the following main effects (ignoring moments on horizontal axes).

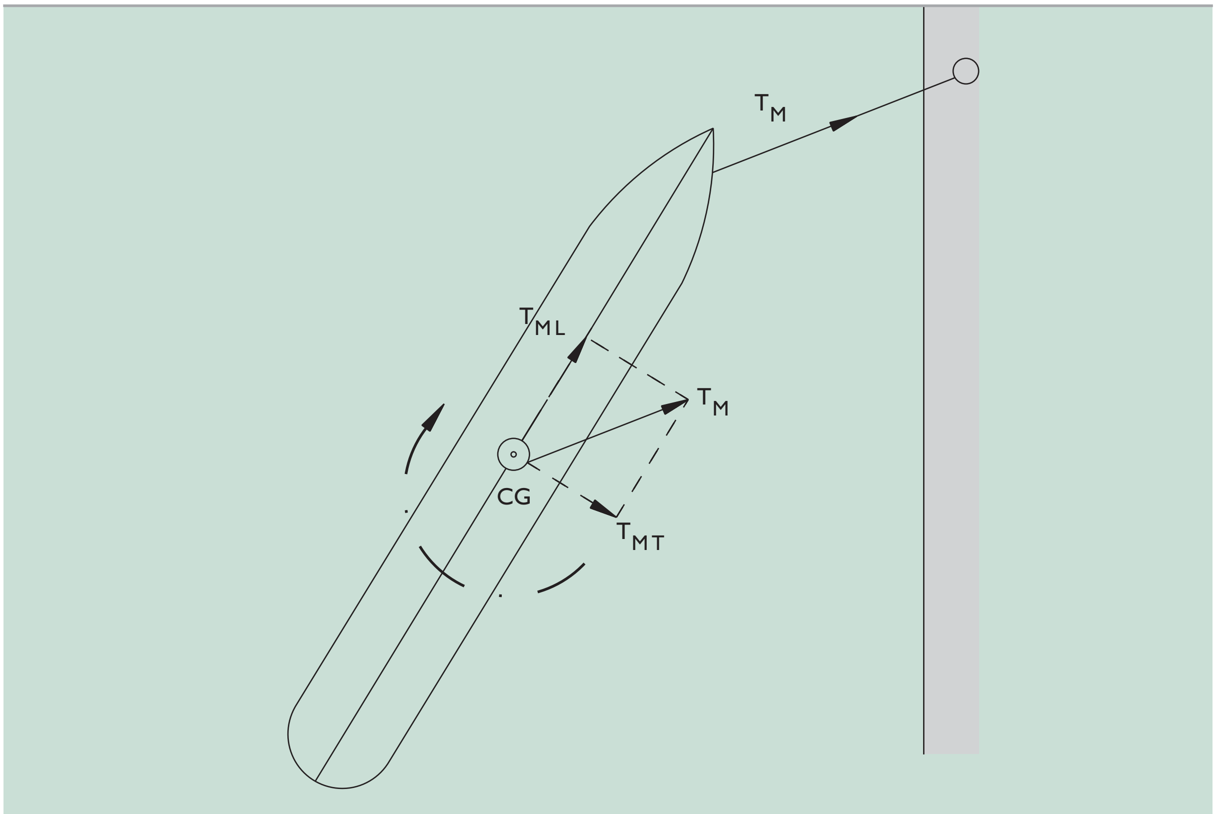
- The longitudinal component T_{ML} tends to make the vessel advance.
- The transverse component T_{MT} tends to make the vessel move sideways, approaching it to the quay.
- The moment on the vertical shaft due to the force's eccentricity tries to make the vessel turn rotating it in the direction of its bow veering landwards.

Generalizing this effect, it could be said that the three effects can be obtained from the action of a mooring line: one of evolution, another of propulsion or slowing down and a third of drift or sway, which vary depending on the place on the vessel where the force is applied and the direction in which the mooring line is working.

The closer the warp holder is located to one of the vessel's ends and the more perpendicular the mooring line is oriented to the centre line the greater will be the moment.

The propulsion effect due to the longitudinal component will be haigher the closer the mooring line works to the centre line's direction. Should the latter be under stress due to the vessel's headway, slowing down occurs rather than propulsion.

Figure 3.11. ***Effect of a mooring line***



The effect of casting or sideways movement towards the quay will be all the greater the more the angle the mooring line forms with the vessel's longitudinal axis approaches 90°.

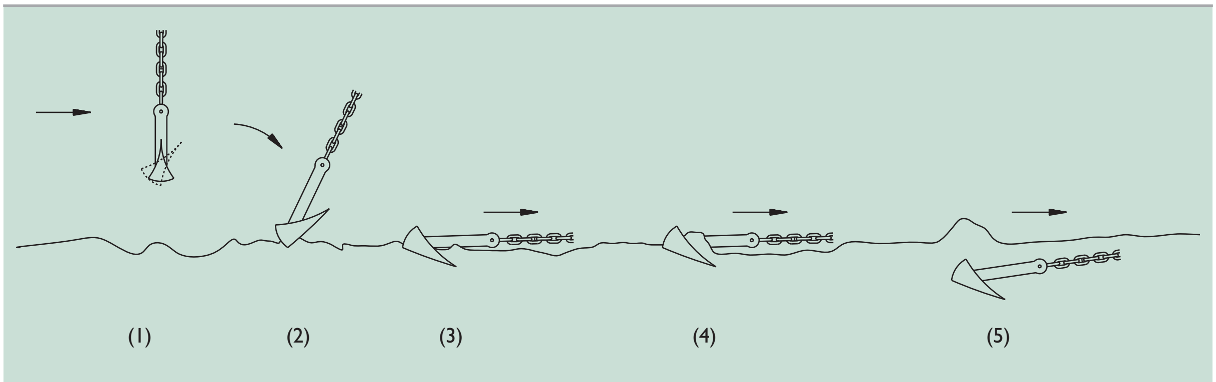
3.8. ANCHOR AND CHAIN ACTION

A vessel in relatively shallow water can be secured firmly to the sea bottom by an anchor and its chain with the main purpose of keeping it secure in a certain place or anchorage, preventing it from being dragged away by wind, sea or current action. Moreover, the anchor is the only element available which allows the movement of the vessel's bow to be fixed or controlled when there is no mooring line passing over that end, and can be used for the vessel's mooring and casting-off manoeuvres. In combination with the wind and/or current effect, the anchor can solve manoeuvring problems which could not be solved if there were only engines, rudder and mooring lines available. Finally, the anchor is a recourse usable in an emergency.

Almost all modern vessels are provided with stockless anchors also known as 'patent' type anchors which have replaced the old ones because of their advantages in stowage and handling, weight saving and efficiency. Modern anchors have articulated arms which can turn 30 to 35° and they are designed to bite into the sea bottom with their flukes and bury deeply into it. Figure 3.12 shows the sequence of how a stockless anchor works. When commencing the manoeuvre, the anchor descends almost vertically (1) and once it hits the seabed, inclines in the direction the chain is working (2) until lying on its side on the bottom (3). Due to the chain's pull, the anchor begins to drag along the bottom and digs its flukes in (4) through the action of the heels. As it continues to be dragged, the anchor sinks in deeper until it is totally buried (5). It is easily understood from the foregoing that the chain must exert its pull force as horizontally as possible for the anchor to initially dig well into the seabed and for this to happen, it must be paid out in a sufficient amount for its last stretch to be working practically resting on the sea bottom.

The magnitude of an anchor's holding power is normally expressed as a multiple of its weight and depends on the type and weight thereof, on the direction the chain is pulling in the vertical plane and on the type or nature of the seabed. As a guide, the holding power of the different models of anchor varies between 3 and 10 times their weight, under conditions of pull parallel to the sea bottom and in good holding ground. However, the fact that an anchor holds well depends less on its weight than the way in which it was dropped and only thus can it be understood that a relatively light anchor can hold vessels whose displacement is thousands of times its heavier.

Figure 3.12. ***Stockless anchor's working sequence***



The chain not only functions as an item joining or linking the vessel to the anchor but, because of its weight, acts as a damper or spring improving the possibilities of holding a vessel at its anchorage. The chain lying on the bottom provides additional holding power which is added to the anchor's holding capacity. The chain is arranged forming a catenary between the hawse hole and the anchor: The heavier the wind, the waves or the current acting on the vessel, the greater the distance between the chain's end points will be, with the portion thereof resting on the sea bottom diminishing so that the possibility of dragging increases.

The effect the chain produces corresponds to the direction in which it works and the place where the force is applied, i.e., the vessel's hawse hole. Recalling what was analysed in the foregoing paragraph as regards mooring lines, it may be said that, with this approach, the chain will act as a bow, breast or spring line, depending on each case, and may be considered as an extremely strong mooring line passed through a portable mooring point which is the anchor.

3.9. OTHER VESSEL MASS AND INERTIA CHARACTERISTICS AFFECTING ITS MOTION

The following mass and inertia characteristics of the vessel must be considered for a correct analysis of all the factors described in the foregoing sections:

- Vessel's mass, equal to its displacement divided by «g», the acceleration of gravity.
- Added mass of water, which is the mass of water moving with the vessel in its movement. The amount depends on the hull shapes, speed of motion and, basically, the water depth.

  For longitudinal motions in shallow or limited depth areas, it may be assumed that it varies between 0 for low speed motions and 10% of the vessel's mass for speeds close to service speeds. The added mass of water for low speed transverse motions in an area of shallow or limited depth can be assessed as a percentage of the vessel's mass, determined by the expression:

  $$\% = 100\frac{2D}{B}$$

  where:

  D = Vessel's draught
  B = Vessel's beam

- Vessels moments of inertia. Of the three elemental rotations possible (yawing, pitching and rolling), that with the most important effect on the dimensions of harbour basins is the rotation of the vessel around a vertical axis passing through the centre of gravity (yawing), for which the moment of inertia can be determined by knowing its radius of gyration «K_z» that may be found from the following equation:

  $$K_z = (0.19\ C_b + 0.11).L_{pp}$$

  where:

  K_z = Vessel's radius of gyration about a vertical axis passing through the centre of gravity, in m.
  C_b = Vessel's block coefficient.
  L_{pp} = Vessel's length between perpendiculars, in m.

- Vessel's moment of inertia due to added water. The mass of water moving with the vessel under way affects the value of the moments of inertia. In particular, for the vessel's yawing turn, the turning radius added may range between 20% and 25% of the length between perpendiculars (L_{pp}), reaching the lowest values when the vessel's block coefficient is higher.

  The vessel's inertia features may be assessed also by its consequences. The following factors are usually considered in particular:

  - Rudder inertia: the distance travelled by the vessel between the moment when full rudder is ordered with a certain angle and the moment the vessel has turned 10° in that direction.
  - Turning inertia: the number of degrees the vessel continues yawing to the side from the time when the helm was put amidships.

Part IV
External actions on a vessel

EXTERNAL ACTIONS ON A VESSEL

Part IV

4.1. WIND ACTION AND EFFECTS

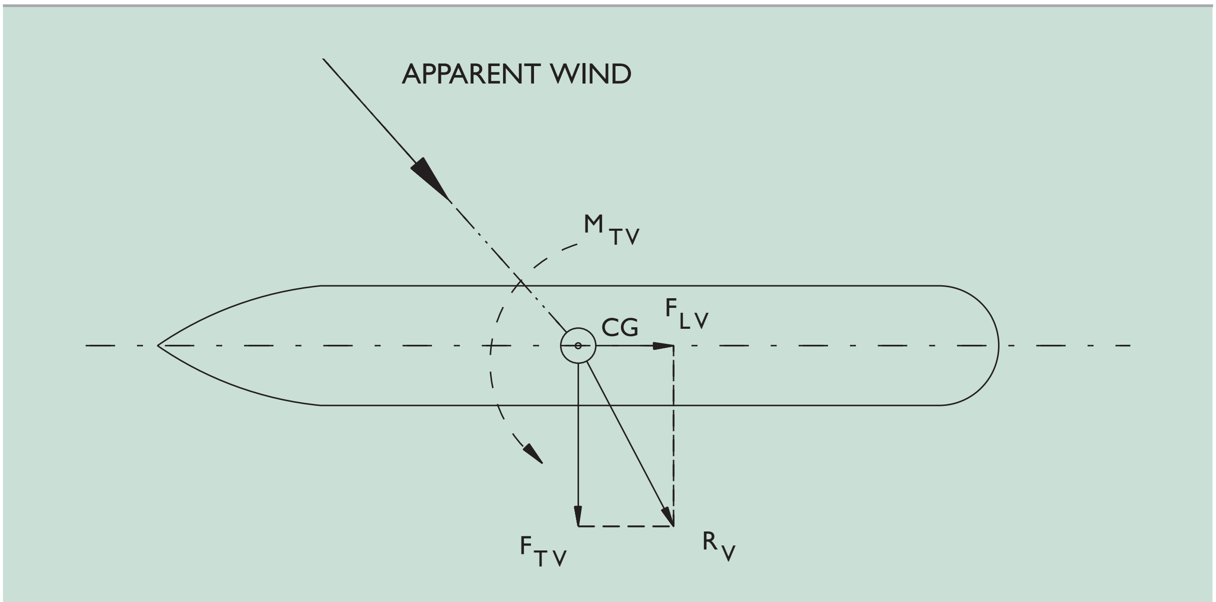
4.1.1. General concepts

The wind is one of the main factors to be considered in all manoeuvres since it is almost always blowing, with lower or higher intensity. If a heavy wind, it has a marked influence on the action of the rudder and propellers when going ahead and alters the turning laws with the vessel going astern.

The action of a steady wind is shown schematically in fig. 4.01 which shows the horizontal force R_v resulting on the vessel's upper works, whose line of action will not normally pass through the vessel's centre of gravity and, therefore, the force system referred to this point may be broken down into the following partial effects:

- A component F_{LV} in the longitudinal direction which tends to make the vessel advance or go back depending on the wind's angle of incidence.
- A component F_{TV} in the vessel's transverse direction which tends to displace it with a drift motion.
- A Resulting Moment M_{TV} which tries to make the vesselturn by rotating it in the pertinent direction on a vertical axis.

Figure 4.01. ***Wind action on a vessel***



In addition to these three main forces, consideration may be given to the component in the vessel's vertical direction which would cause heave motions and to the two moments on the longitudinal and transversal axes which would cause pitching and rolling motions (see fig. 7.04), some of which may have to be considered to determine the vessel's additional draughts due to wind action.

The effect of the wind action will tend to take the vessel to leeward with a form of casting which will depend on the resulting force R_V and the system of forces balancing the latter. In the case of a moored vessel, wind force would be resisted by mooring lines and fenders which will be dimensioned as per ROM 02 «Actions in the Design of Maritime and Port Structures». In the case of a vessel at rest without mooring, the resistance of the water acting on the underwater hull (see section 4.2) opposes the wind force on the vessel's upper works trying to make it cast until reaching an equilibrium position which will be the resultant of both partial effects. In the most general case, the position in which the forces of the propellers, rudder, sea and any other external ones are offset in such a way that the vessel moves in a straight line is called the equilibrium position. In all these cases where the vessel is in motion, the fact that the wind actually acting on the vessel is the apparent or relative wind, whose direction and intensity are the resultants of the absolute, actual wind and of a velocity equal and opposite to the vessel's absolute speed shall be taken into account.

When there is no wind, waves or other external forces, the equilibrium position of a vessel moving forward will be reached by keeping the rudder practically amidships. If there is wind and/or sea, the vessel will tend to yaw to one side or the other and in order to sail on a steady course, a few degrees of the helm to the opposite side should be set to counteract this tendency. The blade's angle of deflection will be all the greater the more intense the action of the external forces is, and the rudder will have to be kept constantly hard over to keep the vessel in equilibrium on the track planned.

The way in which a vessel reacts to wind force mainly depends on the direction and intensity of the apparent wind, on the shape and layout of the superstructure and its upper works, on the shape of the underwater hull, on the difference in draught between bow and stern (trim) and on the direction and speed of the vessel's motion through the water. The equilibrium positions for a vessel adrift, going forward and going astern are analysed hereafter.

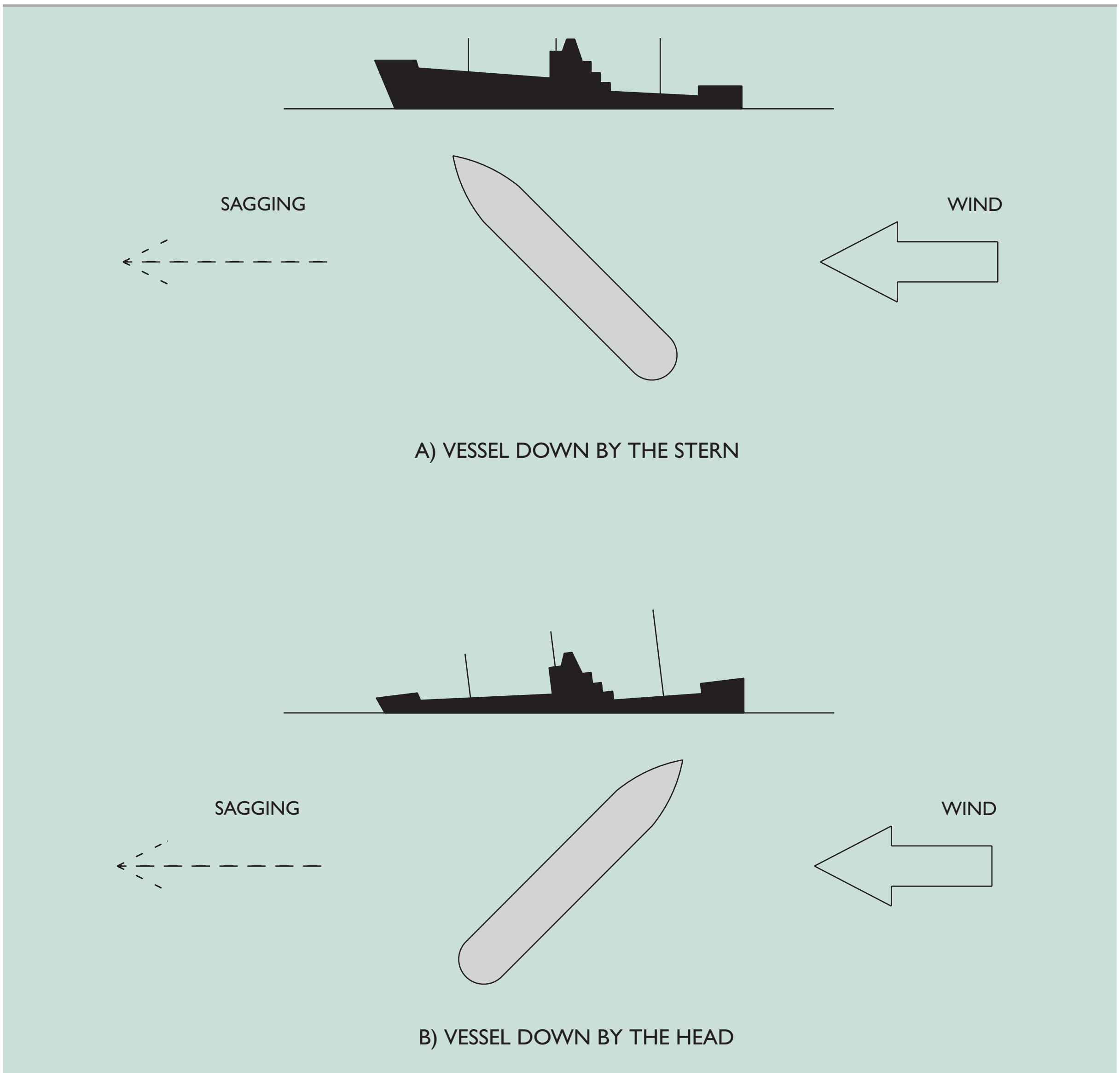
4.1.2. Equilibrium position with vessel at rest

The way in which a vessel will bear on the wind mainly depends on the layout of the superstructure, shape of the underwater hull and the difference between the bow and stern draughts.

If it has more stern draught, its bow will cast relatively more to leeward than the other end of the ship, because the water will oppose less resistance and vice-versa (see fig. 4.02 a) and b). If the vessel has the same bow and stern draught, the layout of the upper work along the whole length will have a predominant influence and the part generating the greatest forces will cast becaquse it has the larger area exposed to the wind. The vessel's orientation to the wind in the equilibrium position will thus depend on the ratio between the bow's and stern's areas exposed to the wind. Passenger vessels and some cargo ships and oil tankers bear approximately on the wind as they have their superstructures mainly in the centre of their length or with a certain amount of symmetry and, consequently, cast to leeward almost side on (see fig. 4.03a). Having bow forecastle and superstructure, warships, tug boats and some merchant ships receive the wind somewhat abaft the beam; consequently, they cast with a small component of headway (see fig. 4.03.b). Some tanker vessels, bulk carriers and coasters who have their superstructures astern take up the equilibrium position receiving the wind somewhat before the beam and cast with a slight component of sternway (see fig. 4.03.c). In vessels with a high freeboard and low draught, the wind force action will be heavy and the resistance offered by the water will be low. Therefore, they will respond quickly to the wind effect and will cast much. If a vessel has a deep draught or is heavily loaded and offers a small, streamlined surface to the wind, the water will offer considerable resistance and the wind effect will be minimum.

When a vessel is in its equilibrium position at rest and receives wind action, it requires an turning moment other than the normal to start veering to one or the other side. With vessels which, because they have more stern than bow draught or larger upper works fore and bearing on the wind somewhat abaft the beam, it will be much easier and quicker for them to go about by turning them leeward. On the contrary, it may prove impossible to turn if trying to make them turn in the opposite direction, taking the bow to the wind, and this can only be achieved if good headway is gained for rudder action to be effective. If the vessel's superstructure is predominantly laid out bowards, a really heavy lateral force may be required at the stern to achieve this purpose. If the lateral force of the propellers proves insufficient, considerable headway must be gained until the additional turning force from the rudder action enables the wind effect to be overcome.

Figure 4.02. ***Equilibrium of a vessel at rest to the wind as a function of trim***

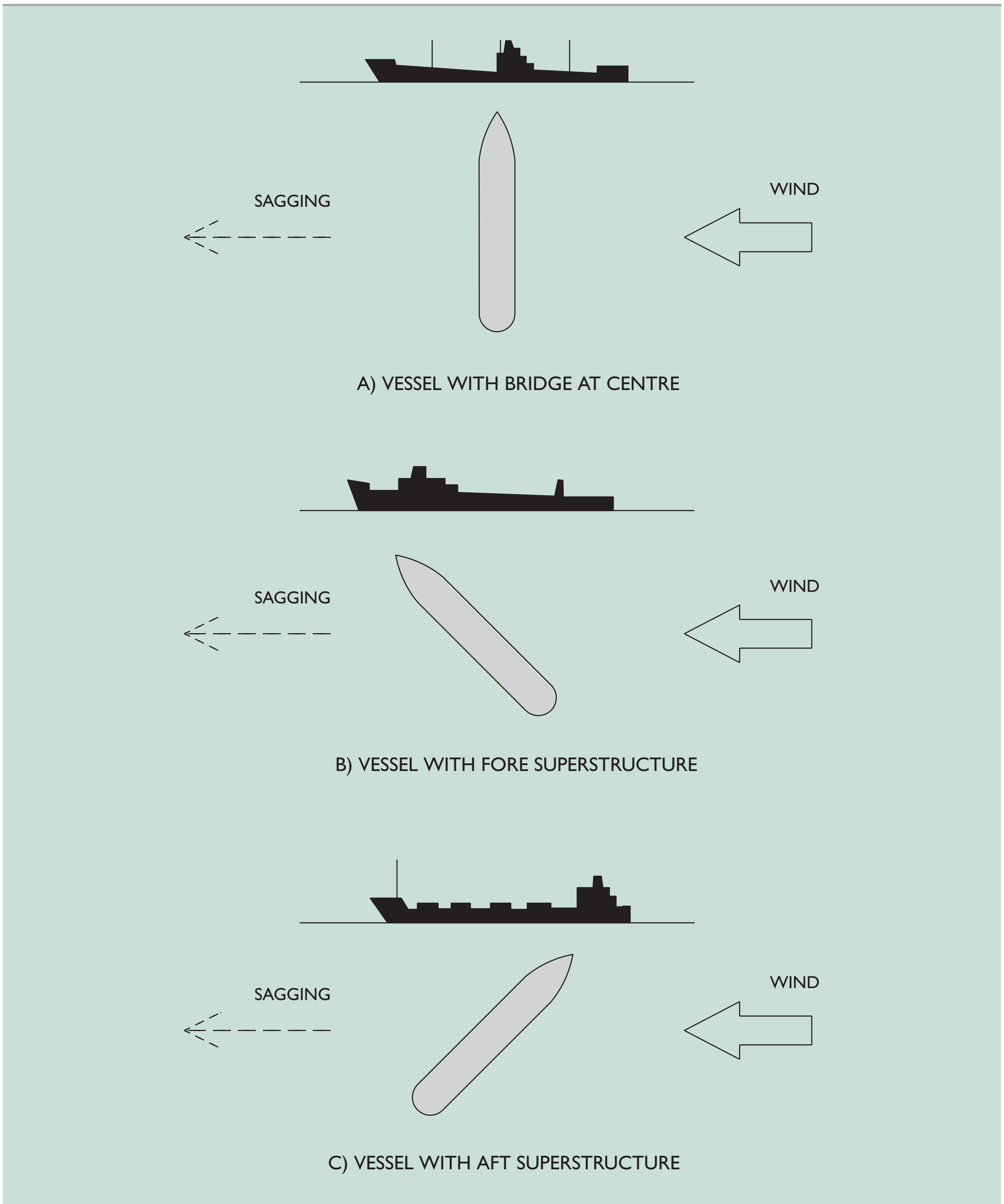


4.1.3. Equilibrium position with vessel going ahead

If, starting from the equilibrium position at rest, engine is put ahead with the rudder amidships, the vessel is subject to wind thrust lee tacking action on the upper work, to luffing action due to underwater hull resistance and to the action of waves which will normally act in the same direction as the wind. The vessel then veers somewhat seeking the wind, receiving it from a before the beam direction until reaching an equilibrium position which depends on the type of vessel, its speed, the wind intensity and the state of the sea, if there were any.

This effect may also be understood by knowing (see chapter 6) that the pivot point or apparent centre of gyration of most vessels making headway during turning is very much bowards, which is why the pressure exerted by the wind on the area exposed astern of this point is greater than that acting before it, and, consequently, it tends to make it luff, veering with its bow to the wind until bringing its tack to bear on it. The degree to which this effect makes itself felt basically depends on the shape and layout of the superstructure, which is why different types of vessel react differently when going ahead, but any tendency will be noticed more at moderate than at high speed and in merchant vessels when in ballast or in light load conditions.

Figure 4.03. ***Equilibrium of a vessel at rest to the wind as a function of the superstructure***



4.1.4. Equilibrium position with vessel going astern

The only position in which the wind and sea effects and the underwater hull's resistance are balanced for any type of vessel going astern is taking the stern to the wind. This is due to the fact that when a vessel is under sternway, its pivot point moves to trhe stern and is closer to that end than the bow and will therefore come to the wind.

This rule is invariable and the stern goes to the wind more rapidly the greater the wind's intensity and the vessel's speed astern are. The tendency is more noticeable when the vessel in its original orientation is farthest from that final equilibrium position, and once the latter has been reached it will try to keep to it within small variations. This tendency may be reduced or, at most, almost balanced by the effect of the propellers when the vessel is making little or null sternway. If the wind is strong breeze, the stern will seek it, even though the helm is fully turned against it.

It is indispensable to take this principle into account in any manoeuvre obliging the vessel to go astern, especially in restricted roads or inside harbours.

When turning in open waters with somewhat of a moderate sea, making too much sternway must be avoided, since vessel hulls are less suitable for action from stern waves because of their design and their structural strength. To take the stern to the wind, it suffices to order engines astern very slowly with the leeward propeller and the turning will be made by making very reduced sternway.

4.2. CURRENT ACTION AND EFFECTS

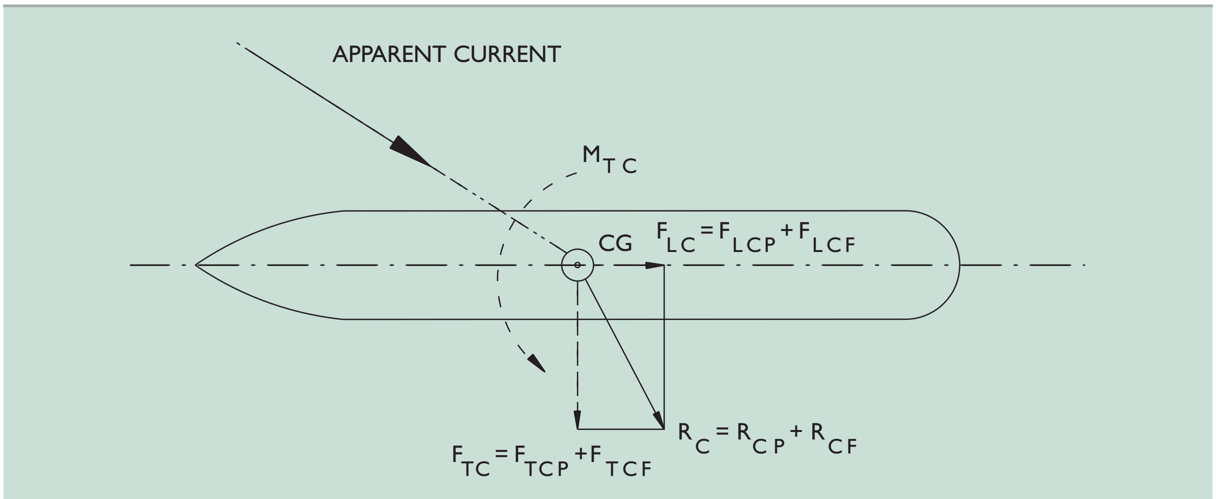
4.2.1. General concepts

The resistance offered by the vessel's underwater body to the current flow is similar to that offered by the upper work to the wind, but the resulting force is much greater for a given speed due to water density being far higher than air's.

The force of a steady current acting on a vessel is shown in fig. 4.04, where the horizontal force resulting on the vessel's underwater body, R^C will not generally pass through the centre of gravity, and may be broken down into the following partial effects:

- A component F_{LC} in the vessel's longitudinal direction, the sum of the forces produced by pressure and by friction respectively ($F_{LCP} + F_{LCF}$).
- A component F_{TC} in the vessel's transverse direction, the sum of the forces produced by pressure and friction respectively ($F_{TCP} + F_{TCF}$).
- A resulting moment M_{TC} due to the eccentricity of the pressure forces about the vessel's centre of gravity.

Figure 4.04. ***Current action on a vessel***



Apart from these three main forces, the component in the vessel's vertical direction and the two moments on the longitudinal and transverse axes whose effects may have to be taken into account for determining the vessel's additional draughts due to this current action could be considered.

The effect of this current action, when steady, will tend to move the vessel as a whole in the same direction and at the same as the current flows. In the case of a moored vessel, the current action will be resisted by mooring lines and fenders, which will be dimensioned as per the criteria of ROM 02.09 «Actions in the Design of Maritime and Port Structures». In the case of a vessel at rest and not moored, the vessel will drift according to the aforementioned effect, i.e., in the same direction and at the same speed as the steady current's flow. In the more general case of a vessel in motion, all the ship's external and internal forces must be taken into account for determining its path, taking into account that in all these cases, the current actually occurring on the vessel is the apparent or relative current in relation to it, the direction and intensity of which are the resultants of the absolute, real current and a speed equal and opposite to the vessel's absolute. The three most usual are analysed out of the multiple cases which may be submitted in this respect.

4.2.2. Navigation in a steady current transversal to the vessel

As the current represents the movement of the whole mass of water in a certain direction, it will move the vessel in its same direction and at its same speed when acting on the underwater body.

The helmsman cannot, in general, generate a current relative to the vessel other than in the bow or stern direction unless the ship has an external load applied to it. Consequently, if a vessel receiving a current across is being manoeuvred, it must be expected to be dragged to a side by this current's action, unless external means are resorted to for controlling the drifting effect and in that case, relatively large forces are required. There will be no solution in certain situations with a heavy current across other than using the aid of the anchor, mooring lines and even tug boats to be able to perform the manoeuvre required.

The helmsman must therefore always have the action of currents in mind and more so when manoeuvring the vessel in restricted waters, with the purpose of being able to counteract their effects or use them to the manoeuvre's benefit if so advisable. The current's vector must be added to that of the vessel's propulsion movement over the water to determine the direction and speed with which the vessel will actually move with respect to the seabed.

A vessel's manoeuvring qualities are not at all affected if the whole mass of water covering the area where it is turning moves at a constant speed. However, when manoeuvring in restricted waters or near fixed obstacles, the distance the ship will drift away from the route planned because of the current's action must be taken into due consideration for adopting the pertinent safety margin.

4.2.3. Navigation in a steady current longitudinal to the vessel

In general, the effect is the same as that described in the foregoing paragraph, although some aspects on the vessel's manoeuvrability must be pointed out, especially on the widely held criterion that vessels manoeuvre relatively better with a current against than in favour. When a bow current is taken, the vessel travels at a lower speed relative to the seabed but keeps the steering efficiency for its propulsion rate, and the case may even be reached where, by suitably regulating its speed, it is kept practically stationary next to fixed objects, easily obeying the rudder's action. Under these circumstances, when setting the rudder, the radius of the path for the first 45° turn is substantially reduced (see section 6.3.), which is a great advantage from the manoeuvrability standpoint. For example, a ship navigating with engines ahead slowly advancing at 5 knots through the water and receiving a 3 knot head current, will move at a very low speed of 2 knots with respect to fixed obstacles such as buoys, quays or anchored ships, but it will steer well, responding to the rudder which will receive the streamlines of water current with a flow of 5 knots.

When a vessel is advancing with a stern current and engine slow ahead, its speed relative to the sea bottom is greater than the propulsion's, but its manoeuvring conditions are the same as for slow moving engines, since its headway with respect to the water is small and the rudder action is not increased by the current's effect, as happened in the case of a bow current. Under these conditions, the radius of the path to turn the first 45° (see section 6.3) is disproportionately increased and great precision and special vigilance will be required of the helmsman during the turning.

4.2.4. Navigation in unsteady currents

On certain occasions, particularly in Approach Channels with restricted dimensions or close to the coast, the current's flow is frequently not steady and varies much in direction and velocity in short distances. Currents can also have non steady effects because of differences in salinity, density or for the different depths of water existing in different areas. The effect on the manoeuvre in these cases is significant since the bow may be subjected to a current other than the one acting on the stern or to equal currents producing forces of a different magnitude and it may well happen that the vessel's ends are subjected to the effects of opposing currents which would cause a situation difficult to steer through.

Should such cases occur, every effort shall be made as regards the accuracy of the study and determining the environmental conditions in which the manoeuvre could be made. The result could be the closing of the area during those periods of time or conditions under which the manoeuvre's safety cannot be guaranteed.

4.3. WAVE ACTION AND EFFECTS

4.3.1. It is indispensable to analyse wave influence in all the vessel's manoeuvres considered, since in any Approach Channels or Harbour Basins, although possibly sheltered, it will always be possible for waves to arise, frequently associated to the presence of a wind.

A vessel's hull is studied and designed for its displacement to be optimal under normal navigation conditions. Any movement, whether pitching or rolling, which is very characteristically associated with the presence of waves, alters the water flow round the hull and, by destroying the harmony of the current lines, a slowing down effect occurs through an increase in resistance.

Moreover, the wave which does not break drags that part of the vessel on a crest in the direction of its propagation, and in the opposite direction that nearest its trough. As a result, a ship moving through this water suffers alternating turning forces tending to make it follow a ziz-zag path. This effect is more pronounced with higher waves and the closer the vessel's length approaches a half wave length.

In the case of broken waves or those breaking on the vessel's hull, the sea acts both on the vessel's underwater body and upper works and generates forces far higher than those of unbroken waves. If waves are received from a direction before the beam, they will be more directly and effectively incident on the vessel's fore part than on the stern and, in consequence, a tendency towards increasing casting due to the wind which normally accompanies a storm will be manifest. The ship will reduce its speed in relation to the seabed and will try to veer its bow towards the wave troughs, crosswise to the sea, especially if moving with engine slow ahead.

When waves are received from a direction abaft the beam, their action will tend to increase the vessel's headway and make it luff, veering its bow towards the wave troughs and this latter effect is the more noticeable when navigating on the descending slope than on the ascending one. If waves are received from the stern, the vessel will tend to yaw and go crosswise and a heavy helm is required for steering, which will retard its advance and this may counteract the effect of the sea's increasing the vessel's speed in relation to the sea bottom.

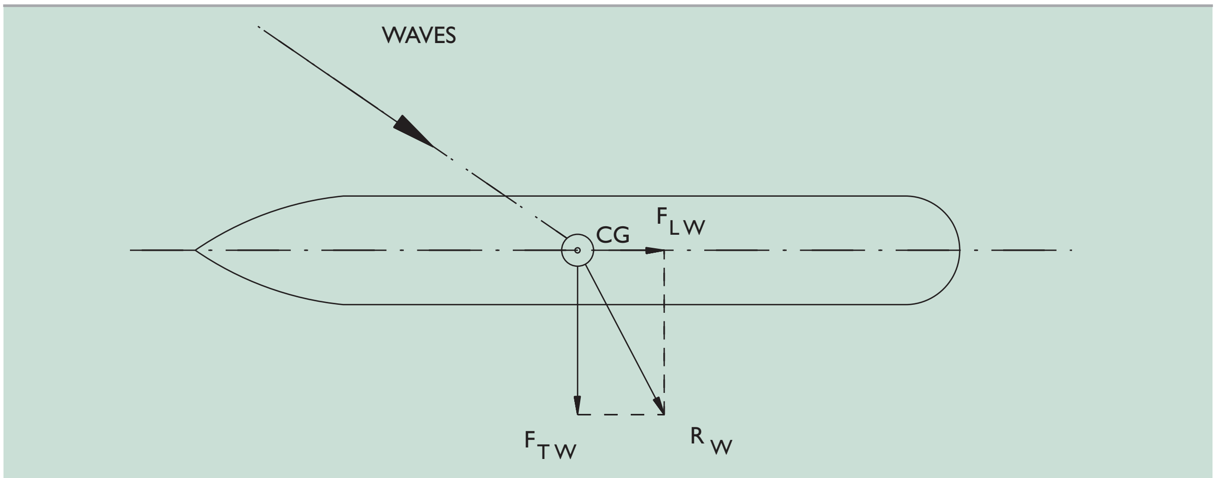
Consequently, the sea's general effect on a vessel's steering is to tend to cross it on to the waves and whether these come from side bow or quarter, the helm will have to be applied to keep to the heading planned, which will cause an additional loss of speed.

The sea effects as described above are higher the lower the vessel's propulsion speed is, and may change if wind and waves are received from different directions.

4.3.2. With respect to the study of the layout, wave action may be simplified with the scheme shown in fig. 4.05 where the resulting horizontal force R_W is shown which, in a first approximation, may be assumed to pass through the vessel's centre of gravity and so may be broken down into the following effects:

- A component F_{LW} in the longitudinal direction which tends to make the vessel advance or retreat depending on the wave angle of incidence.
- A component F_{TW} in the vessel's transverse direction, which tends to displace it with a drift motion.

Figure 4.05. ***Wave action on a vessel***



In addition to these two main forces which produce straight line movements, the swinging motions caused by the vessel's longitudinal and transverse axes (respectively rolling and pitching) must be considered. The most significat effect of these motions is to increase the additional draughts of the vessel and water depths necessary for navigating under conditions of safety.

4.3.3. Depending on their type, dimensions and loading conditions, all vessels have a well defined natural period of pitching and rolling independent of their amplitudes.

The rolling period is the time interval a ship takes in going from the upright position to maximum heeling on one side, back to another maximum on the other side and returning to the upright. A vessel's rolling period is directly proportional to its beam and inversely proportional to its metacentric height; consequently, the wider a vessel and the lower the metacentric height, the greater its rolling period will be.

The pitching period is the time the vessel's bow takes in lifting from the horizontal, rising and then descending below that position until reaching the horizontal again.

If either one of these natural periods coincides with wave periods, resonance phenomena may occur which will considerably increase the vessel's swinging motions. Nevertheless, if the vessel is in motion, the wave period to be considered will be what is known as the period of encounter or apparent or relative period, which is the time interval between two successive crests passing through the same point of the vessel. Therefore, it depends not only on the actual wave period but also on the vessel's speed and the angle it forms with the wave direction. This consideration allows a vessel in motion to modify its conditions of response to waves by altering its course, its speed or both.

4.3.4. Rolling and pitching motions of a vessel at sea depends, therefore, on the size of the waves and the ratio between the period of encounter and its rolling and pitching periods, and maximum motion will develop when there is synchronism between those values. The following cases may occur, with respect to this relation:

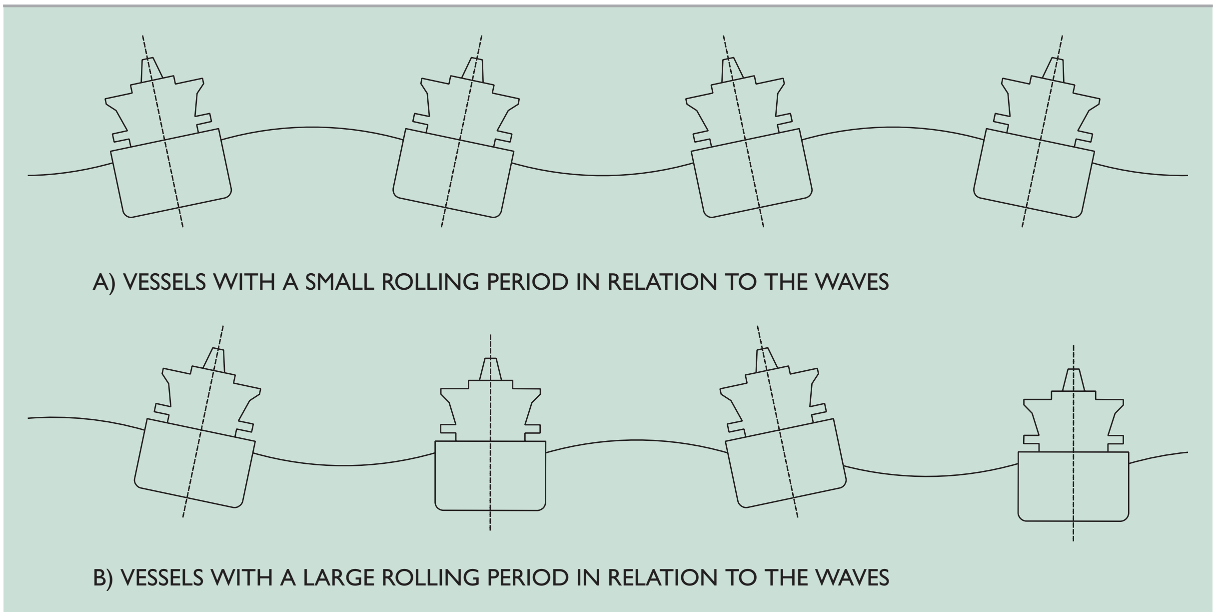
1. When the vessel's period is shorter than the period of encounter, the ship will tend to mount the waves keeping its deck parallel to the wave slope. With a beam sea, the vessel will always lean towards the opposite part of the crest (see fig. 4.06a). At the crest and the trough, it will be vertical, acquiring a greater rolling motion the less the difference between the wave period and vessel's vertical rolling period is. With a bow sea, a small pitching period with respect to the period of encounter will produce a comfortable, gentle motion of the vessel without shipping water.

2. When the vessel's period is longer than the period of encounter, the vessel will pitch or roll regardless of the waves. With a beam sea, this will mean that the ship will heel towards the crest with relatively calm rolling (see fig. 4.06b), even though the waves hitting the windward side may manage to keep the deck wet. If the difference in period is very large, the vessel will keep upright almost continuously. With a bow sea, a comparatively large pitching period may cause the ship to sink its bow into the sea and draw its propellers and rudder out of the water.

3. When the period of encounter is approaching synchronization with the rolling or pitching period, the vessel will move violently. Pitching will be very severe with a bow sea and it may cause the propellers to frequently race, producing damaging stresses in the vessel's structure. With a beam sea, synchronism will produce dangerously intense rolling. Very low board vessels or ships with a poor reserve of stability may well roll completely over, but those suitably designed and undamaged will not capsize because there are resistant forces opposing rolling until reaching an equilibrium between forces contributing to rolling and the resistant ones opposing it. The vessel will thus keep rolling to the maximum limit until something is done to break the situation of synchronism. If the vessel is making headway, this can be achieved by changing the period of encounter, for which the course or speed or both must be altered. The apparent wave period will then separate from the vessel's actual rolling period and the rolling amplitude will diminish.

4.3.5. Since, with other conditions being equal, rolling and pitching periods are strictly linked to vessel size, the following general considerations on rolling and pitching motions can be made.

Figure 4.06. ***Effects of beam waves on vessels***



4.3.5.1. Rolling

When synchronism occurs, the situation must be overcome by altering course, speed or both. In luffing towards the sea's direction, the period of encounter diminishes whilst when bearing away, it increases.

Large ships, characterized by having a very large rolling period, rarely come across waves. Since their periods are generally higher than the waves' they make them to roll excessively. Despite this, coming to the wind with respect to the sea must be performed carefully, because the increase in the period of encounter causes them to roll more violently.

Light, small rolling period vessels behave fairy well in storms and therefore tend to keep their deck parallel to the wave slopes. In this operation, the more they turn the bow away from the sea's direction, the more eased they are because in increasing the period of encounter, it differs more from the vessel's rolling period. These short rolling period vessels have the disadvantage of substantially rolling even with relative good weather, because the sea's normal motion has a period which may be very similar to theirs.

Vessels with medium period require special attention because synchronism frequently occurs in them. Since it is not always advisable to luff against the sea with them, rolling can be reduced by coming to the wind and increasing speed somewhat if necessary.

4.3.5.2. Pitching

A vessel's natural pitching period is generally clearly shorter that of the waves which induce its pitching motion. At a moderate speed, the vessel will keep its longitudinal axis parallel to the wave slope and will navigate fairly comfortably. When navigating in a bow sea, if the speed is increased, synchronism may well occur and the resulting pitching will be very violent. Coming to the wind and increasing speed at the same time, the period of encounter will increase and pitching will diminish. When descending the wave slope, it is possible for the bow to partially emerge from the water and a tendency to go crosswise to the sea will always occur, as was mentioned before.

4.3.6. From the foregoing, it may be deduced that special care must be taken in steering cargo vessels during storms because correct handling depends on the cargo's stowage and the actual pitching and rolling periods of the vessel, which vary according to the nature and conditions of the cargo.

Rolling periods depend on the metacentric height the vessel has under certain circumstances. With a vessel without load, the reduction in metacentric height may produce a long rolling period and in this case a manoeuvre opposite to that recommended when the same vessel is fully loaded, when its rolling period diminishes on increasing the metacentric height. In the first case, it may be more advisable to receive the sea before the beam and, in the second, on the quarter. Special attention must be paid to liquid cargoes.

The free movement of water from one side to the other, whether in tanks or compartments located below the centre of gravity or on deck, will increase the rolling period and amplitude. This effect will be more noticeable when the liquid surfaces are at the vessel's high parts.

4.3.7. Summarising the content of the foregoing paragraphs, wave action may have one or several of the following effects on a vessel:

- Violent pitching and/or rolling motions affecting its stability, increasing its draught, reducing crew efficiency and comfort and even causing damage in merchant vessel cargoes.
- Abnormal hull vibrations causing excessive stresses on the vessel's structure.
- Vibrations in the propulsion system through a continuous change in the working depth of the propellers which may even «race» when emerging above the sea surface.
- Damage in the upper works or cargo stowed on deck from direct wave action.

- Shipping large mass of sea water that affect floatation and stability
- Reduction in real speed and steering effectiveness.

4.4. STORM EFFECTS

When navigating in storms, effects may be analysed by a combination of the foregoing cases (winds, waves and currents). However, general considerations could be made on the overall effects of these cases.

When a vessel has been forced to reduce its speed to slow ahead during a storm, the wind pressure on its upper works will have a greater effect on the manoeuvre's qualities. This effect is increased in the case of vessels with little cargo and in those with shallow draught or large superstructures. When travelling very slowly or engines are stopped, most vessels tend to swing crosswise to the wind and when the latter is not exceptionally high, it may be difficult to turn them by taking the bow to the sea (luffing), though it can be possible to make them veer by coming to the wind. It may be impossible in a typhoon or hurricane to turn certain vessels by taking their bow to the wind. This is a good reason to explain why all mariners avoid navigating under such conditions when they have land or hazards to leeward.

The magnitude by which a vessel casts during a storm depends on its speed, draught, freeboard and heading with respect to the wind and seas's direction. With hurricane and gale winds, casting with cross winds may be very considerable and may reach two or three knots, particularly if the ship is navigating at low speed.

4.5. EFFECT OF SHALLOWS WATERS

The effect of shallow water in general is to increase resistance to propulsion and reduce the manoeuvring qualities of vessels when moving at a considerable speed. The cause of this phenomenon lies in the fact that when the vessel enters shallow water the distance between the sea bottom and the keel reduces, and with it the space allowing current lines to flow normally until a moment when the pattern of flow lines is altered in the vicinity of the hull and pressures diminish. As a result, cross waves are formed on the surface at the bow and stern which appear to accompany the vessel in its movement. The increase in stern wave dimensions is a clear sign of the vessel navigating in shallow water. The loss of energy spent by the vessel in forming these waves results in a reduction in the power available to propel it (less real thrust) and, in addition, the perturbations caused in the water flow affect the propellers' efficiency; as a result, the vessel's speed is reduced.

The effects of shallows on vessel steering are usually more noticeable in vesels where the propeller slipstream does not act directly on the rudder. Such effects are normally more pronounced when navigating in restricted waters (rivers, ports or canals) than when doing so in open waters with a similar depth and it is also likely that they also have more dangerous consequences in the former case. When losing control of the vessel because of the effect of shallow waters the only way to recover it is to reduce speed immediately and drastically.

When manoeuvring at speed in shallow, restricted waters, or when trying to turn a vessel by acting on the engine, it is possible that not all the turning effects normally expected of the rudder and propellers will be fulfilled. The water cannot flow freely from one side or the other under the vessel and it may even occur that the lateral propeller forces behave in an opposite manner to that expected. Sometimes vortices are formed which counteract the effect of the rudder or the lateral force.

4.6. EFFECT OF BANK SUCTION AND REJECTION

When a vessel is navigating ahead in a straight path in a homogeneous medium, the water flow around the hull is practically symmetrical on the starboard side and on the port side and no unbalancing forces occur except those which may derive from the propellers.

If this navigation occurs close to shore or a bank, the water flow around the hull stops being symmetrical and alterations occur in the distribution of pressures on the hull which depend not only on the different water velocity on one side and the other but also on the generation of vortices and separation of water flow on the side closest to the bank. The practical consequence of this effect is the appearance of the following two phenomena:

- A transverse suction of the vessel towards the bank causing the ship to drift in that direction.
- A moment on the vessel's vertical axis passing through its centre of gravity, which causes a yawing motion that separates the vessel's bow from the bank.

Both effects depend on the navigation speed, the distance of the vessel from the bank and the configuration of this bank and it will be greater for a vertical wall than an inclined slope.

The foregoing phenomena may be corrected by using the rudder, although in the case of navigating through a canal, it may occur that the result of this manoeuvre were a movement to the opposite side which might not be subsequently controlled and the helmsman must therefore be ready to immediately use the engines or drop anchor if necessary.

4.7. EFFECT OF PASSING VESSELS

A vessel may undergo other influences in canals or restricted navigation areas due to the interaction with other moored or moving vessels. In both cases, the phenomenon is the same and can be seen schematically in fig. 4.07 where the effect of vessels passing can be seen: as they approach, the water pressure between them both will try to separate their bows, when passing abeam, they will tend to stay parallel and as their sterns pass each other, there will be mutual attraction. This effect may be corrected by a proper use of the rudder. Fig. 4.08 shows the effect of a vessel passing another one moored and the forces generated in the latter. The phenomenon also occurs in the case of vessels overtaking where a collision risk situation may arise.

In addition, the effect on each vessel of the wave train associated to the other vessel in motion would have to be considered.

4.8. ASSESSMENT OF EXTERNAL FORCES ON A VESSEL

The assessment of external forces on a vessel will be calculated by applying the criteria of the ROM 02 Recommendation, "Actions in the Design of Maritime and Port Structures" and ROM 04, "Environmental Actions II: Wind", using the maximum relative values with respect to the vessel in motion worked out from the absolute values of the operational limit conditions established for the pertinent port or facility as values of the variables (wind velocity, current velocity and wave characteristics). Therefore, the following criteria will be used.

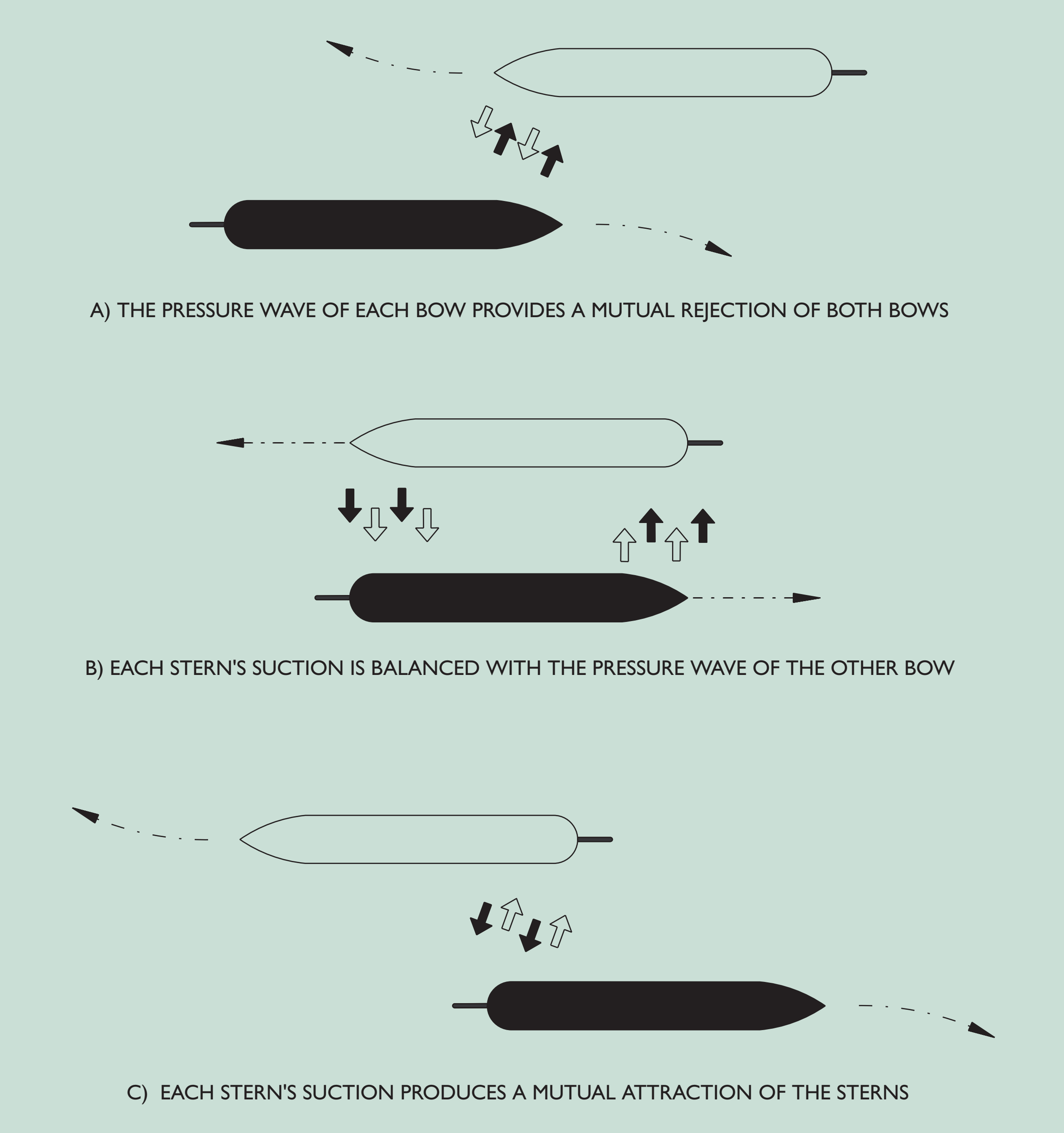
4.8.1. Wind

The forces resulting from wind pressures on vessels may be decomposed into a horizontal force in the vessel's longitudinal direction, another in the transverse direction and a vertical axis moment, all applied at the vessel's centre of gravity. They will be determined by the formulas shown in Table 4.1., regardless of other existing methods of validity recognized for specific vessels. It is reminded that the calculation shall be made for the apparent or relative wind, the direction and intensity of which are the resultants of the absolute real wind and of a speed equal and opposite to the vessel's absolute speed as is shown schematically in fig. 4.09.

4.8.2. Current

The action of currents on a vessel may cause three types of stresses: pressure stresses, friction stresses and stressed induced by dynamic instability phenomena leading to self-excited lateral oscillations («flutter» effect).

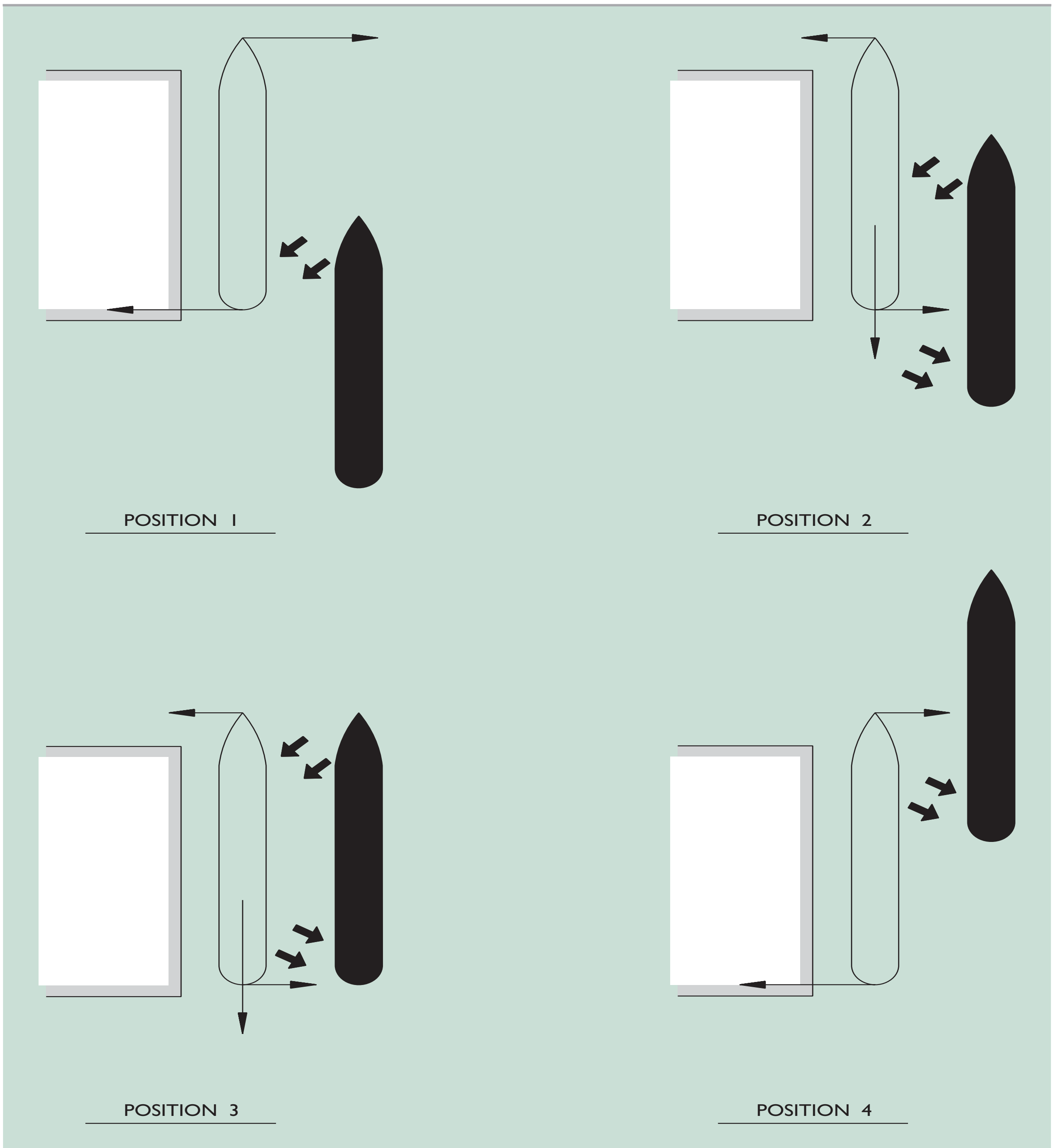
Figure 4.07. **Vessels passing each other**



The resulting pressure and friction stresses caused by currents on vessels, respectively R_{CP} and R_{CF}, may be discretized into a horizontal force in the vessel's longitudinal direction, another in the transverse direction and a vertical axis moment, all applied at the vessel's centre of gravity. They may be determined by using the formulas given in tables 4.2 and 4.3, regardless of other methods of acknowledged validity for specific vessels. It is reminded that the calculation should be made for the apparent or relative current, whose direction and intensity are those resulting from the absolute real current and from a current equal and opposite to the vessel's absolute, as schematically shown in fig. 4.10.

The stresses induced by the "flutter" effect are difficult to formulate mathematically and they have to be determined by scale model testing or measurements on a prototype. This effect is important only in particular cases referring to moored vessels, which is why it will not be taken into account in navigation and floatation areas.

Figure 4.08. ***Effects of a vessel passing another one moored***

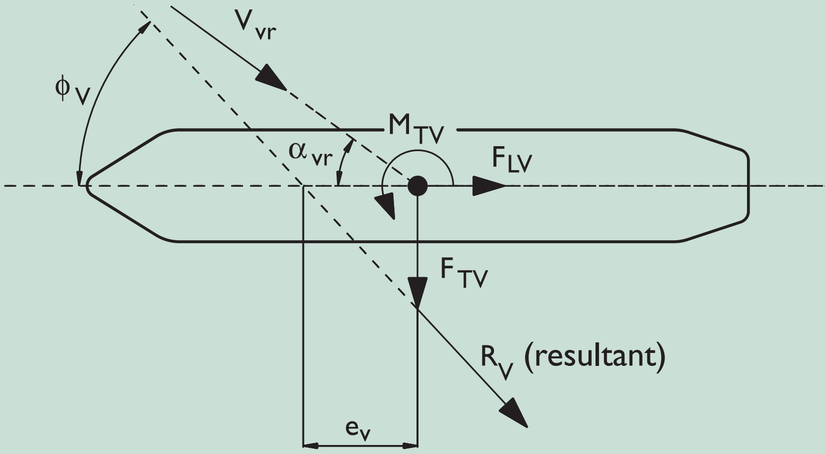


4.8.3. Waves

It is a highly complex matter to analytically quantify the stresses caused by waves on a vessel since they depend on many variables, amongst which are:

- The characteristics of the incident waves: type (progressive or stationary), height, period and direction.
- The vessel's characteristics: type, displacement, underkeel clearance, etc.
- Type of movement of the vessel.

Table 4.1. ***Stresses resulting from wind pressures on vessels***



General formula

$$R_V = \frac{\rho}{2g} \cdot V_{Vr}^2 \cdot \frac{C_{VL} \cdot A_{TV} \cdot \cos^2 \alpha_{Vr} + C_{VT} \cdot A_{LV} \cdot sen^2 \alpha_{Vr}}{\cos(\phi_V - \alpha_{Vr})}$$

Simplified formula (applicable when more precise information on the shape factors «C_{VT}» *and* «C_{VL}» is not available)

$$R_V = \frac{\rho}{2g} \cdot C_{VF} \cdot V_{Vr}^2 \left(A_{TV} \cdot \cos^2 \alpha_{Vr} + A_{LV} \cdot sen^2 \alpha_{Vr}\right) = \frac{C_{VF} \cdot V2_{Vr}^2}{16.000} \left(A_{TV} \cdot \cos^2 \alpha_{Vr} + A_{LV} \cdot sen^2 \alpha_{Vr}\right)$$

Formulas applicable in both cases (general and simplified)

$$\mathrm{Tg}\ \phi_V = \frac{A_{LV}}{A_{TV}} \cdot \mathrm{tg}\alpha_{vr} \qquad F_{TV} = R_V \cdot \mathrm{sen}\ \phi_V$$

$$F_{TV} = R_V \cdot \mathrm{sen}\ \phi_V \qquad M_{TV} = F_{TV} \cdot e_v = F_{TV} \cdot K_{ev} \cdot L$$

where:

R_V = *Horizontal force resulting, in t.*

f_V = Angle formed between the vessel's longitudinal axis, taken as from bow to stern, and the direction of the resultant force, in degrees.

F_{TV} = Component of the resultant force in the vessel's transverse direction, in t.

F_{LV} = Component of the resultant force in the vessel's longitudinal direction, in t.

M_{TV} = Resulting moment applied on a vertical axis passing through the vessel's centre of gravity, in m.t.

r = Specific weight of air ($1.225 \bullet 10^{-3}$ t/m^3).

g = Acceleration of gravity (9.81 m/s^2).

C_{VF} = Shape factor (non dimensional).
May vary between 1.0 and 1.3. In the absence of a more precise figure by means of model studies, 1.3 will be adopted for any shape of vessel and wind action direction.

C_{VL} = Shape factor for calculating the resultant of the wind force on the vessel, acting in the direction of its longitudinal axis. It is highly variable depending on the vessel's characteristics and shape and its loading condition; the following values may be taken as a first approximation:
0.80 for a bow wind (a_{vr} = 0)
1.00 for a stern wind (a_{vr} = 180°)

C_{VT} = Shape factors for calculating the resultant of the wind action on the vessel, acting in the direction of its transverse axis. They are highly variable depending on the vessel's characteristics and shape and its loading condition and, as a first approximation, a figure of 1.25 (a_{vr} = 90°) may be adopted.

(Continued)

Table 4.1. Stresses resulting from wind pressures on vessels

a_v = Angle formed between the vessel's longitudinal axis, considered from bow to stern, and the direction of the absolute wind's action (incoming), in degrees.

a_{vr} = Angle formed between the vessel's longitudinal axis, considered from bow to stern, and the direction of the relative wind's action (incoming), in degrees.

V_v = Wind's basic horizontal absolute speed at 10 m above sea level height in m/s, assumed to be constant for any height.

The wind's mean velocity, determined in the shortest interval (gust) able to overcome the vessel's inertia will be adopted as the absolute basic velocity. A mean absolute velocity for the following gusts may be adopted:

1 minute for vessels of a length equal to or greater than 25 m.

15 seconds for vessels with a length less than 25 m.

The maximum value for the limit operating conditions established for the pertinent port or facility will be taken as the absolute basic speed (V_v). This value may be different depending on the action directions if the characteristics of the site or manoeuvre under study justify so.

For facilities in which the operating criteria established do not allow vessels to stay at all times or in all situations, the absolute basic velocity which will be adopted for the study of departure manoeuvres will be that which corresponds to that expressly defined as a limit condition for vessels to stay moored at berths, associated or not to a certain vessel configuration (e.g., ballasting of the vessel to reduce its sail area). In the absence of operativity criteria, the following will be adopted as the limit velocity to stay without adopting reducing measures for variation in the vessel's configuration:

$$V_{v1min} = 22 \text{ m/s } (\approx 80 \text{ km/h})$$

provided tug boats are available with a bollard pull of 125% of the maximum resulting wind force on the vessel.

V_{vr} = Relative wind velocity referred to the vessel determined by calculating the resultant of the absolute velocity vector of the wind «V_v» quantified as indicated in the foregoing definition, with a vector equal and opposite in direction to the vessel's absolute speed «V»

b = Vessel's drift angle.

A_{TV} = Area of the vessel's transverse projection exposed to wind action, in m^2.

A_{LV} = Area of the vessel's longitudinal projection exposed to wind action, in m^2.

In the absence of known values, these areas may be approximated by means of the following expressions:

$$A_{TV} = B \bullet (G + h_T)$$
$$A_{LV} = L_{pp} \bullet (G + h_L)$$

where:

B = Vessel's beam.

G = Vessel's freeboard = Depth - Draught.

L_{pp} = Vessel's length between perpendiculars

h_T = Mean height of superstructure surface above the vessel's deck, projected onto a transversal plane.

h_L = Mean height of superstructure area above the vessel's deck, projected onto a longitudinal plane.

The usual values of B, G and L_{pp} for the full load design vessel may be obtained from Table 3.1. When vessels are partially loaded, specific tables must be used for obtaining the draught and the remaining dimensions under these conditions, although they may be approximated by empirical formulas of a recognized validity. In the case of very full form vessels (oil tankers, ore carriers, etc.), it may be assumed that the block coefficient [displacement/(length between perpendiculars x beam x draught x γ_W)] is kept constant under any load condition. For other types of vessel, it would be assumed that the block coefficient is kept constant for any load condition between 60% and 100% and may have decreases of up to 10% of the foregoing value for load conditions below 60% of full load.

The usual values of h_T and h_L could be approximated from the following table, according to the type of design vessel:

(Continued)

Table 4.1. ***Stresses resulting from wind pressures on vessels***

Type of vessel	DWT Tons	Mean height (m)		Type of vessel	DWT Tons	Mean height (m)	
		h_T	h_L			h_T	h_L
Oil Tankers	500.000	32.00	4.00	**Liquid gas carriers**	60.000	15.00	4.00
	400.000	29.00	3.80		50.000	14.00	4.00
	300.000	25.00	3.70		30.000	13.00	4.00
	275.000	24.00	3.70		20.000	11.00	4.00
	250.000	23.00	3.60		10.000	9.00	4.00
	225.000	22.00	3.50		5.000	7.50	6.20
	200.000	21.00	3.40		3.000	7.00	5.00
	175.000	20.00	3.30				
	150.000	19.00	3.20				
	125.000	17.50	3.10				
	100.000	16.50	3.00				
	80.000	15.00	2.90				
	70.000	14.50	2.80				
	60.000	14.00	2.70				
Oil and chemical product carriers	50.000	13.00	2.60	**General cargo merchant ships**	40.000	17.00	5.00
	40.000	12.00	2.40		35.000	16.50	5.00
	30.000	11.00	2.20		30.000	16.00	5.00
	20.000	10.00	2.00		25.000	15.00	5.00
	10.000	9.00	2.00		20.000	14.00	5.00
	5.000	8.50	2.00		15.000	13.00	5.00
	3.000	8.00	2.00		10.000	11.50	5.00
					5.000	8.50	5.00
					2.500	7.50	5.00
Bulk and multipurpose carriers	400.000	29.00	5.00	**Container and ro-ro vessels**	70.000	22.50	12.00
	350.000	27.00	5.00		65.000	21.00	11.00
	300.000	25.00	5.00		60.000	20.00	10.50
	250.000	23.00	5.00		55.000	19.00	10.00
	200.000	21.00	5.00		50.000	18.00	9.00
	150.000	19.00	5.00		45.000	17.00	8.50
	125.000	18.00	5.00		40.000	18.00	8.50
	100.000	16.50	5.00		35.000	16.00	8.50
	80.000	15.50	5.00		30.000	13.50	8.50
	60.000	14.00	5.00		25.000	12.00	8.50
	40.000	12.00	5.00		20.000	10.50	8.00
	20.000	10.00	5.00		15.000	9.00	7.50
	10.000	9.00	5.00		10.000	8.00	7.50
Methane carriers	60.000	19.00	10.00	**Car carriers**	30.000	13.00	5.00
	40.000	14.00	8.00		25.000	12.00	5.00
	20.000	12.00	6.00		20.000	10.50	5.00
					15.000	9.00	5.00

Type of vessel	GT Tons	Mean height (m)		Type of vessel	GT Tons	Mean height (m)	
		h_T	h_L			h_T	h_L
Conventional ferries	50.000	22.00	18.00	**Fishing boats**	3.000	9.00	5.00
	40.000	21.00	17.00		2.500	8.00	5.00
	35.000	20.00	16.00		2.000	7.50	5.00
	30.000	19.00	15.50		1.500	7.20	5.00
	25.000	18.50	15.00		1.200	7.00	5.00
	20.000	18.00	14.50		1.000	6.80	5.00
	15.000	17.50	14.00		700	6.20	5.00
					500	5.90	5.00
					250	5.60	5.00

(Continued)

Table 4.1. ***Stresses resulting from wind pressures on vessels***

Type of vessel	GT Tons	Mean height (m)		Type of vessel	Displacement (t)	Mean height (m)	
		h_T	h_L			h_T	h_L
Fast ferries (provisional figures)				**Sport boats**			
Catamaran type	4.000	13.5	11.9	**Power**	50.0	5.50	4.00
	5.000	14.6	12.4		35.0	5.00	3.50
	6.000	15.2	12.9		27.0	4.40	3.00
					16.5	4.00	2.80
Single hull type	8.000	14.4	13.0		6.5	3.40	2.40
	10.000	16.9	14.6		4.0	2.70	2.00
	15.000	20.8	18.4		1.3	2.10	1.50
	20.000	24.6	22.3				
Passengers cruise liners	80.000	23.00	21.00	**Sailing**	60.0	4.60	5.50
	70.000	21.00	18.00		40.0	4.30	5.00
	60.000	19.50	16.50		20.0	4.00	4.80
	50.000	18.00	15.00		13.0	3.70	4.50
	40.000	17.00	14.00		10.0	3.40	4.20
	35.000	16.00	13.00		3.5	3.00	4.00
					1.5	2.70	3.00

e_v = Eccentricity of the Resultant Wind Force with respect to the vessel's CG measured along the centre line plane. Considering the moments shown in the figure heading this table as positive, positive eccentricity will be taken as that occurring towards the vessel's bow.

K_{ev} = Coefficient of eccentricity (non-dimensional). The values of the coefficient of eccentricity may be approximated from the following table, failing specific data:

Vessels with centred superstructure

α_{VT} (in °.)	K_{ev}	
	In ballast	Full load
0	0	0
30	0.15	0.10
60	0.05	0.03
90	–0.02	0.02
120	–0.10	0.10
150	–0.20	0.10
180	0	0

Vessels with fore superstructure

α_{VT} (in °.)	K_{ev}	
	In ballast	Full load
0	0	0
30	0.33	0.37
60	0.18	0.27
90	–0.04	0.16
120	–0.05	0.12
150	–0.16	0.10
180	0	0

Vessels with aft superstructure

α_{VT} (in °.)	K_{ev}	
	In ballast	Full load
0	0	0
30	0.16	–0.10
60	0.05	–0.12
90	–0.04	–0.16
120	–0.18	–0.27
150	–0.33	–0.37
180	0	0

L = Vessel's length overall, in m.

(Continued)

Nevertheless, in a first approximation and in the absence of other more specific studies such as a model analysis or measurements on a prototype, the formulas as given in Table 4.4. arising from considering the wave stresses as the resultant of fluid pressures on the vessel's hull caused by a regular incident wave action may be adopted. This resultant may be broken down into a horizontal force in the vessel's longitudinal direction and another in the transverse direction, assuming, in a first approximation, that the resultant passes through the vessel's centre of gravity.

It is remided that the calculation should be made for the apparent or relative wave, the characteristics of which will be determined as a function of those of the absolute wave and of the vessel's absolute speed as shown in Fig. 4.11.

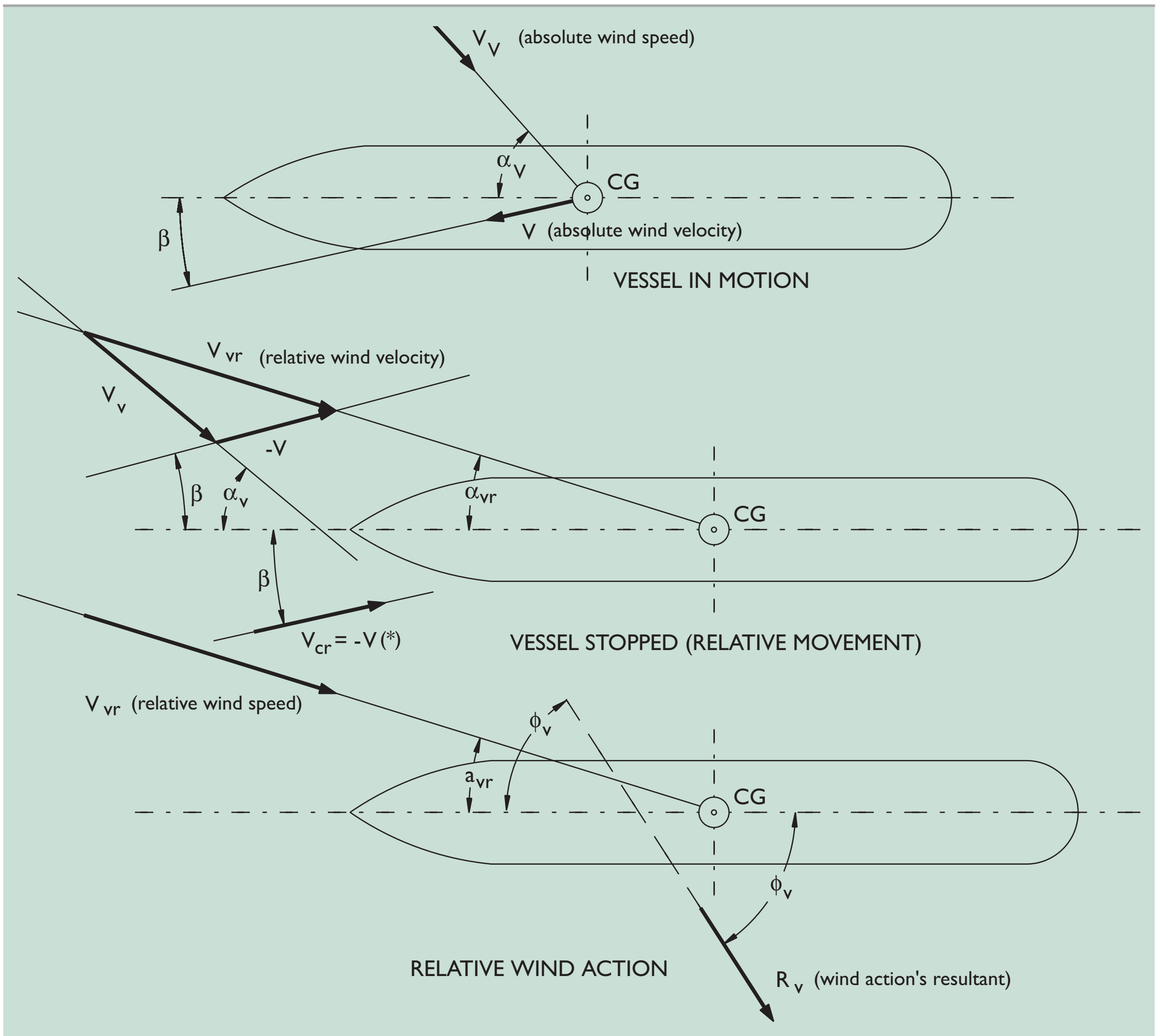
4.8.4. Effect of shallow waters

The effect of shallow waters may be determined with the formulas for waves and currents in which the parameters intervening in the calculation are determined as a function of the existing water depth. In the case whereby the water depth is not homogeneous under one or another part of the vessel, its effects may be approximated by considering partial forces applicable to each part of the vessel, determined for the water depth existing at each part.

4.8.5. Effect of bank suction and rejection

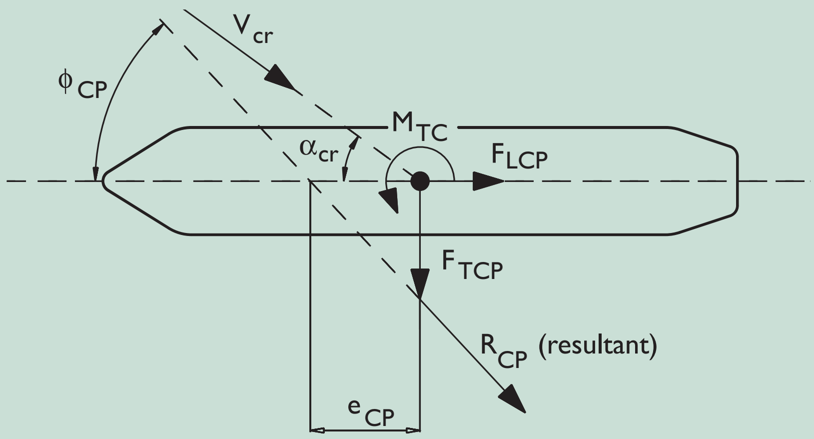
This force may be determined by using studies already performed in model testing or specific tests for the vessel under consideration. However, the effect may be ignored when the clearances recommended in chapter 8 of this ROM are kept to, so as to prevent this phenomenon appearing in the layout analysis of Access Channels and Harbour Basins.

Figure 4.09. ***Determining the apparent wind relative to a vessel***



—: See table 4.1. for notation and terminology.
—: In the pointed outt that when consideering the relative movement, a relative current «Vcr» appears equal and opposite in direction to the vessel´s absolute speed «V», which does not take part in the calculation of «Rv».

Table 4.2. **Stresses resulting from current pressures on vessels**



$$R_{CP} = \frac{\gamma_w}{2g} \cdot V_{cr}^2 \cdot \frac{C_{CL} \cdot A_{TC} \cdot \cos^2 \alpha_{cr} \cdot C_{CT} \cdot A_{LC} \cdot sen^2 \alpha_{cr}}{\cos\left(\phi_{CP} - \alpha_{cr}\right)}$$

$$tg\phi_{CP} = \frac{A_{LC}}{A_{TC}} \cdot tg\alpha_{cr} \qquad F_{LCP} = R_{CP} \cdot \cos\alpha_{CP}$$

$$F_{TCP} = R_{CP} \cdot sen\alpha_{CP} \qquad M_{TC} = F_{TCP} \cdot e_{CP} = F_{TCP} \cdot K_{ec} \cdot L$$

Where:

R_{CP} = Horizontal force resulting from the action of current pressures on the vessel in t.

$Ø_{CP}$ = Angle formed between the vessel's longitudinal axis, considered from bow to stern, and the direction of the resultant of current pressures in degrees.

F_{TCP} = Component of the resultant force in the vessel's transverse direction, in t.

F_{LCP} = Component of the resultant force in the vessel's longitudinal direction, in t.

M_{TC} = Resulting moment applied on a vertical axis passing through the vessel's centre of gravity, in m.t.

γ_w = Specific weight of water.
(1.03 t/m³ salt water).
(1.00 t/m³ sweet water).

g = Acceleration of gravity (9.81 m/s²).

α_c = Angle formed between the vessel's longitudinal axis, considered from bow to stern, and the direction of the absolute current's action (incoming), in degrees.

α_{cr} = Angle between the vessel's longitudinal axis, considered from bow to stern, and the direction of the relative current's action (incoming), in degrees.

V_c = Current's basic horizontal absolute velocity at a depth of 50% of the vessel's draught in m/s, assumed to be constant over its whole depth.
The mean velocity of the current determined in 1 minute interval ($V_{c.1\ min}$) will be adopted as the basic velocity.
The maximum value relative to the vessel for the limit operational conditions established for the pertinent port or facility will be taken for this basic absolute velocity (V_c) thus defined. This value may be different depending on the direction of its action if the characteristics of the site or the manoeuvring being studied so justify.
For facilities in which the operating criteria established do not allow vessels to stay at all times or situations, the absolute basic velocity which will be adopted for the study of departure manoeuvring will be that which corresponds to that expressly defined as a limit condition for vessels to stay at berths, associated or not to a certain vessel configuration (e.g., ballast reduction to reduce the submerged area).

(Continued)

Table 4.2. Stresses resulting from current pressures on vessels

In the absence of defined operability criteria, the limit velocity to be adopted to stay, without adopting reducing measures for variation in the vessel's configuration, will be that corresponding to:

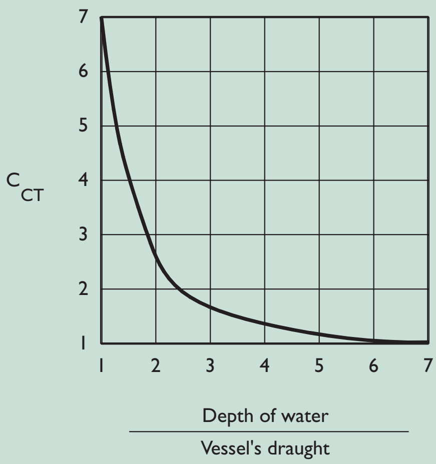
Side currents:	$0° < \alpha_c < 180°$	$V_{c1\,min}$ = 1 m/s (2 knots)
Longitudinal currents:	$\alpha_c = 0°$	$V_{c1\,min}$ = 2.5 m/s (5 knots)
	$\alpha_c = 180°$	

provided these values are less than those for the extreme value associated to the maximum risk acceptable, tug boats are available with a bollard pull of 125% of the maximum resulting current force on the vessel, and they are compatible with the site's specific characteristics.

V_{cr} = Current velocity relative to the vessel. The resultant of the absolute velocity vector of the current «V_c», quantified as indicated in the previous definition, with a vector equal and in the opposite direction to the vessel's absolute velocity «V» will be calculated for determining same.

β = Vessel's drift angle.

C_{cr} = Shape factor for calculating the resultant of the current pressures on the vessel, acting in the direction of its transverse axis (non-dimensional). It depends on the Depth of water/Design vessel draught ratio, increasing as the value of this ratio approaches 1.00. It may vary between 1.00 for deep water and 6.00 for ratios (Water depth/draught) = 1.00 according to the following graph, for any shape of vessel and current direction:



C_{CL} = Shape factor for calculating the resultant of current pressures on the vessel, acting in the direction of its longitudinal axis (non-dimensional). It basically depends on the vessel's bow geometry. It may vary between 0.2 and 0.6. In the absence of a more precise determination, 0.2 will be adopted for a bulbous bow and 0.6 for a conventional bow.

A_{LC} = Longitudinal submerged area of the hull subjected to the current's action, in m².

A_{TC} = Transverse submerged area of the hull subjected to the current's action, in m².

In the absence of values, these areas may be approximated by means of the following expressions:

$$A_{LC} = L_{pp} \bullet D$$
$$A_{TC} = B \bullet D$$

where:

L_{pp} = Length between perpendiculars.

D = Vessel's draught.

B = Vessel's beam.

The usual values of L_{pp}, D and B for the design vessel may be obtained from table 3.1.

e_{cp} = Eccentricity of the Force resulting from the current pressures on the vessel with respect to its centre of gravity measured along the centre line plane. Considering the moments shown in the figure heading this table as positive moments, positive eccentricity will be taken as that occurring towards the vessel's bow.

(Continued)

Table 4.2. Stresses resulting from the current pressures on vessels

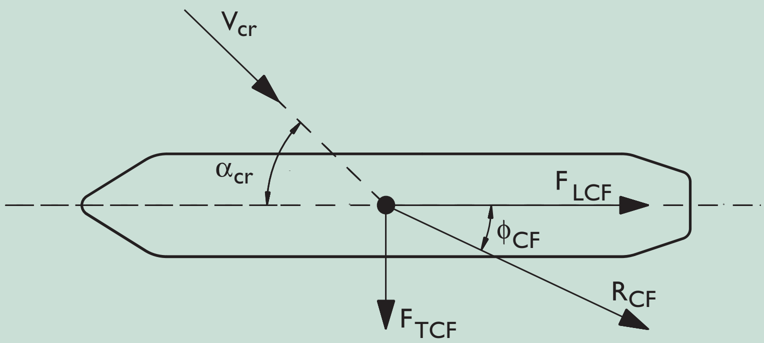
K_{ec} = Coefficient of eccentricity (non-dimensional).
The values of the coefficient of eccentricity may be approximated from the following table, failing specific data:

α_{cr} (in °)	K_{ec}
0	0
30	0.17
60	0.09
90	0
120	–0.09
150	–0.17
180	0

L = vessel's length, in m.

(Continued)

Table 4.3. Stresses resulting from the current's friction forces on vessels



$$F_{TCF} = \frac{\gamma_w}{2g} \cdot C_r \cdot V_{cr}^2 \cdot A_{TCF} \cdot \text{sen}^2 \alpha_{cr} \qquad F_{LCF} = \frac{\gamma_w}{2g} \cdot C_r \cdot V_{cr}^2 \cdot A_{LCF} \cdot \cos^2 \alpha_{cr} \qquad tg\phi_{CF} = \frac{A_{TCF}}{A_{LCF}} \cdot tg^2 \alpha_{cr}$$

where:

R_{CF} = Resulting horizontal force of the current's friction force on the vessel, in t.
$Ø_{CF}$ = Angle formed by the vessel's longitudinal axis, considered from bow to stern, and the direction of the resultant of the current's friction, in degrees.
F_{TCF} = Transverse component of the resultant force on the vessel due to friction, in t.
F_{LCF} = Longitudinal component of the resultant force on the vessel due to friction, in t.
C_r = Coefficient of Friction (non-dimensional). 0.004 may be adopted for vessels in service and 0.001 for new vessels (e.g., for shipyard designs).
A_{TCF} = Wetted hull surface transverse to the centre line direction, in m².
A_{LCF} = Wetted hull surface longitudinal to the centre line direction, in m².
In the absence of known data on these areas, they may be approximated by means of the following expressions:

$$A_{TCF} = (L_{pp} + 2D) \bullet B$$
$$A_{LCF} = (B + 2D) \bullet L_{pp}$$

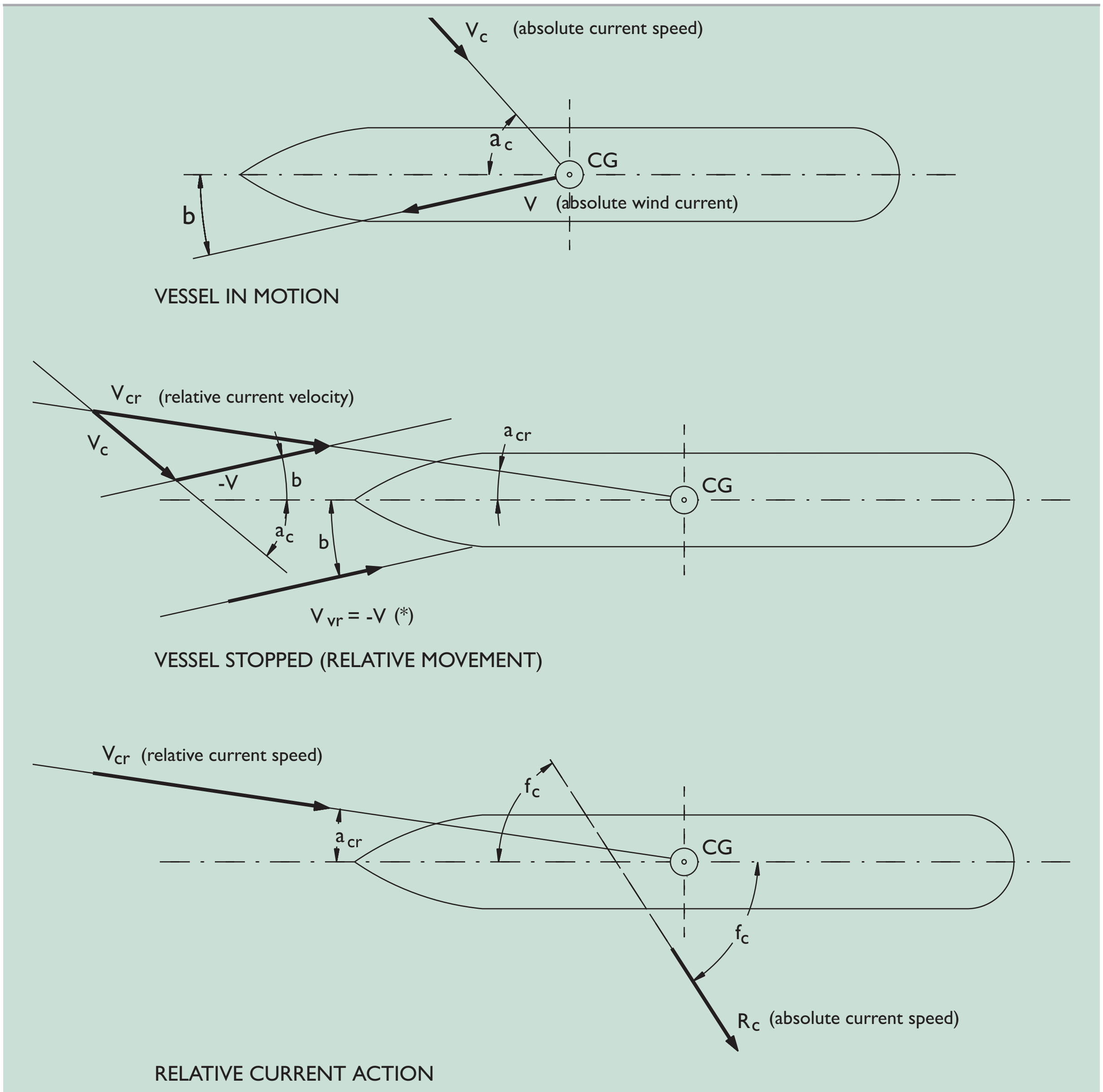
for values of $L_{pp,\ B}$ and D defined as per the criteria in table 3.1.
$\gamma_{w,\ g,\ a}$ cr and V_{cr} have meanings and values coinciding with those shown in table 4.2.

4.8.6. Passing other vessels

A vessel passing in the vicinity of another may cause an increase in wave disturbance due to the train of waves associated to any vessel in motion. This effect is not generally taken into account in the calculation. However, it must be borne in mind when excessive passing speeds are foreseen or in very narrow basins. The stresses produced may be quantified by the formulas given for wave action in the previous paragraph.

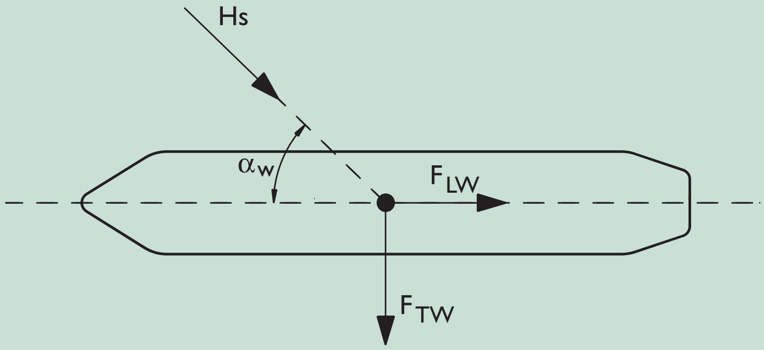
Likewise, if vessels pass or overtake or a vessel passes in the vicinity of a moored vessel, bank suction and rejection phenomena may occur, which will be dealt with by the same criteria as established in the preceding paragraph. Therefore, this effect may be ignored should the clearances as recommended in Chapter 8 of this ROM be kept to in preventing such phenomenon arising in the plan analysis of Navigation Areas and Basins.

Figure 4.10. *Determining the apparent current relative to the vessel*



*: It is pointed out that when considering the relative movement, a relative current «Vcr» appears equal and opposite in direction to the vessel´s absolute speed «V», which does not take part in the calculation of «Rc».

Table 4.4. Stresses resulting from wave forces on vessels



$$F_{TW} = C_{fw} \cdot C_{dw} \cdot \gamma_w \cdot H_s^2 \cdot L_{proy} \cdot \mathrm{sen}\,\alpha_w$$

$$F_{LW} = C_{fw} \cdot C_{dw} \cdot \gamma_w \cdot H_s^2 \cdot L_{proy} \cdot \cos\alpha_w$$

Where:

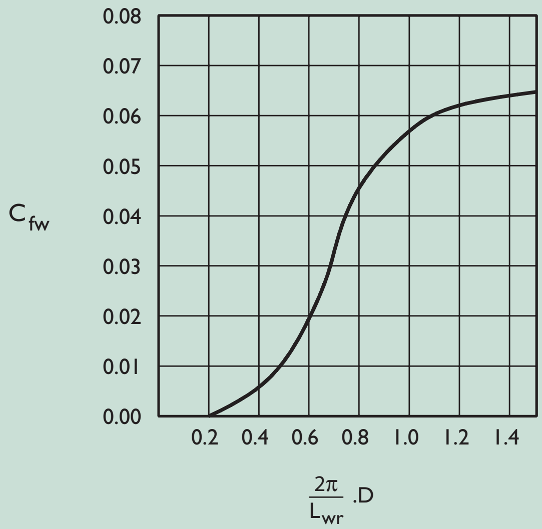
F_{TW} = Component of the resultant force in the vessel's transverse direction, in t.

F_{LW} = Component of the resultant force in the vessel's longitudinal direction, in t.

γ_w = Specific weight of water.
(1.03 t/m³ salt water)
(1.00 t/m³ fresh water)

α_w = Angle formed between the vessel's longitudinal axis, considered from bow to stern, and the direction of wave incidence (incoming), in degrees.

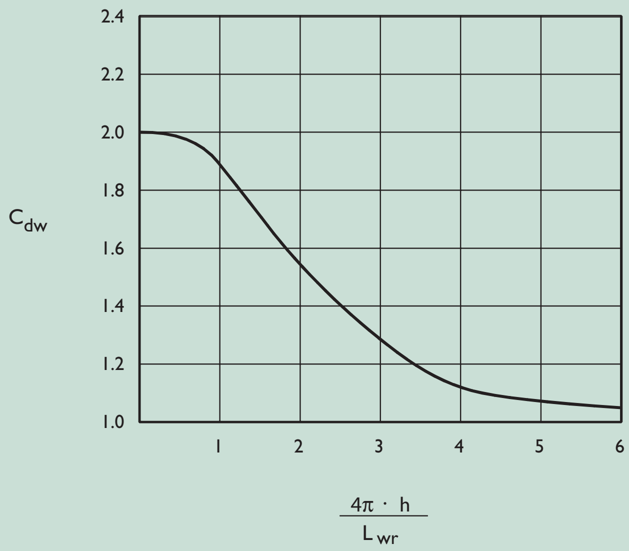
C_{fw} = Waterline coefficient (non dimensional).
The value given in the following table as a function of the relative wave length at the depth of the site L_{wr} and the vessel's draught (D) will be taken as the value of C_{fw}.



C_{dw} = Depth coefficient (non-dimensional).
The values of this coefficient will be obtained from the following table, as a function of the relative wave length at the site's depth (L_{wr}) and of the depth of water at the site (h).

(Continued)

Table 4.4. ***Stresses resulting from wave forces on vessels***



L_{proy} = Length of the vessel's projection in the direction of the incident waves, in m. In the absence of known values, this may be approximated by the following expression:

$$L_{proy} = L_{pp} \bullet sine\ \alpha_w + B \bullet cos\ \alpha_w$$

where:

L_{pp} = Vessel's length between perpendiculars, in m.
B = Vessel's beam, in m.
α_w = Direction of incident waves, in degrees.

H_s = Significant wave height for the direction determined at the site's depth, in m.
The maximum value for the limit operating conditions established for the pertinent port or facility will be taken for this wave height (H_s). This value may be different depending on the direction of action if the characteristics of the location or the manoeuvre being studied so justify.
In the absence of defined operability criteria, the significant wave heights shown in Table 8.1. in Chapter 8 will be adopted as the stay limit, unless the H_s of the extreme regime is lower, tug boats are available with sufficient pull to enable the vessel to be towed out of the facility when the aforesaid wave conditions occur (bollard pull of 125% of the maximum force resulting) and they are compatible with the site's specific characteristics.

L_{wr} = Length of apparent wave or relative to the vessel, in m at the site's depth, which may be calculated by the following expression:

$$L_{wr} = L_w \cdot \frac{T_{wr}}{T_w}$$

L_w = Absolute wave length, in m. at the site's depth.
T_w = Absolute wave period, in s.
T_{wr} = Wave period, apparent or relative to the vessel or period of encounter, in sec., which may be calculated by the following expression:

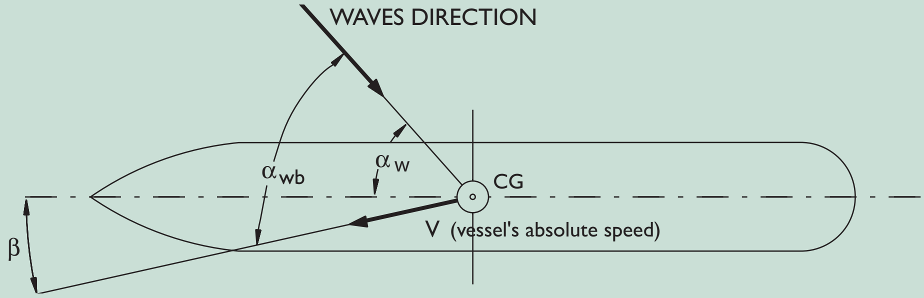
$$\frac{1}{T_{wr}} = \frac{1}{T_w} + \frac{V \cdot \cos\alpha_{wb}}{L_w}$$

In the case where T_{wr} is negative, it will be taken that the relative waves are in the opposite direction.

V = Vessel's absolute speed with respect to the sea bottom, in m/s.
α_{wb} = Angle formed between the vessel's absolute speed and the wave direction (incoming).
β = Vessel's drift angle

(Continued)

Figure 4.11. ***Determining the apparent waves relative to the vessel***



VESSEL IN MOTION

WAVE CHARACTERISTICS

	Absolute	Relative to the vessel
Significant height	H_s	H_s
Wave period	T_W	T_{wr}
Wave length	L_W	L_{wr}
Angle formed between the vessel's longitudinal axis, considered from bow to stern, and wave direction (incoming)	α_W	α_w
Angle formed between the vessel's absolute speed and the wave direction (incoming)	α_{Wb}	α_{wb}

Determining the relative wave period and lenght as a function of the abosolute ones.

$$\frac{1}{T_{wr}} = \frac{1}{T_w} + \frac{V \cdot \cos \alpha_{wb}}{L_w}$$

$$L_{wr} = L_w \cdot \frac{T_{wr}}{T_w}$$

Should Twr be negative, it should be contrued that the relative waves come from the opposite direction.

Note: For notation and terminology, see the table 4.4.

Part V

Tug boats

TUG BOATS

Part V

5.1. TUG BOAT FUNCTIONS

Tug boats are auxiliary craft for the navigation and manoeuvring of vessels and other floating bodies and are used for the following functions:

- To assist the vessel in going alongside and sheering away manoeuvres and, on certain occasions, when staying.
- To aid the vessel in turning about in a small area.
- To provide the support necessary to counteract wind, wave and current actions in situations where the vessel is moving at low speed while the propulsion engine and rudder efficiency is low.
- To aid in stopping the vessel.
- To tow, push or aid a vessel which has lost its means of propulsion or steering.
- To take lighters or floating apparatus from one place to another.
- To escort vessels with hazardous cargoes in high risk areas as a precaution for a loss of steering.

5.2. TYPES OF TUG BOAT

Tug boats can be divided into harbour tugs, harbour and sea going tugs and sea going and salvage tugs according to the type of operation and the task to be performed, although there may be tug boats which carry out all three types of operation.

Harbour tug boat: Employed in internal harbour traffic. Its horsepower may vary between 400 and 3,000 HP or more, with a 6 to 30 tonne bollard pull, a length between 20 and 30 m, a draught between 3.0 and 4.5 m and a speed ranging between 5 and 13 knots. Though this function in a harbour's internal traffic is the normal one, there are tug boats based in certain strategic ports where they operate alone and must be able to undertake harbour and sea going operations, as well as salvage work.

Harbour and sea going tug boat: Its work may be divided between harbour services to aid large vessels, mooring supertankers to single buoys, deep sea coastal towing, etc. Its length ranges from 25 to 40 m and its horsepower may vary between 1,500 and 5,000 HP with a bollard pull of 20 to 55 tonnes.

Sea going and salvage tug boat: Because of its size and power, this tug boat is able to carry out ocean going towage and provide assistance to vessels in danger on the high seas. Its main features are a length between 40 and 80 metres, 40,000 to 20,000 HP, bollard pull of 55 to 180 tonnes and a 15 to 16 knot speed.

Nowadays, most harbour tug boats have pollution and fire fighting equipment. Apart from their typical towing equipment, sea going and salvage tug boats have water and water-foam fire fighting equipment with monitors fitted on overhead platforms 15/20 m above the waterline which, remotely controlled, can extinguish large fires. They also have pumping out systems to be used in damaged vessels and, by using their auxiliary equipment, some tug boats can make the main engines of a damaged vessel work by supplying start-up air and electric power.

5.3. TUG BOAT PROPULSION AND STEERING SYSTEM

5.3.1. Propulsion system

5.3.1.1. The normal tug boat propulsion system is a diesel engine which drives conventional or special propellers. Conventional propellers may be classified into four types:

- Fixed pitch propellers
- Controllable pitch propellers

- Fixed pitch ducted propellers
- Controllable pitch ducted propellers

The most frequently used special propellers are of two types:

- Schottel system (rudder propeller)
- Voith-Schneider (cycloidal propeller)

CONVENTIONAL PROPELLERS

As was pointed out in Chapter 3, fixed pitch propellers do not vary their configuration whilst in controllable pitch propellers, each of the blades may be rotated on its axis giving the pitch required in one direction or the other and even cancelling it out by turning the blades like a disk, which allows the engine always to rotate in the same direction whilst continuously running.

Controllable pitch propellers are more efficient than fixed pitch because blade adjustment allows maximum power or any speed to be developed and this does not happen with fixed pitch which are designed for the specific conditions of ordinary operation. However, variable pitch propellers provide less thrust for going astern which may be a major limitation for tug boats where a compromise is sought for efficient operation when working in either direction.

Incorporating a nozzle into these systems, within which the propeller revolves, significantly improves the propeller's efficiency, equivalent to an increase in its effective diameter. The effect produced by the nozzle in channelling the water flow, is an increase in speed in the minimum cross section where the propeller is located. This speed diminishes when exceeding this section, thus increasing the pressure and thrust. A ducted propeller may perform from 25% to 40% better than the conventional propeller system for forward navigation.

SPECIAL PROPELLERS

Special propellers are systems where the propeller carries out the functions of propulsion and steering, thus replacing the rudder. The most developed systems are the Schottel and Voith-Schneider.

Schottel system. This system consists in a propeller suspended from a vertical Z or right angled shaft. A nozzle is secured to the shaft within which the propeller rotates and the whole unit may turn 360° on the said vertical shaft. Using this rotation, the slipstream jet can be orientated in the direction desired, providing great manoeuvrability to the tug boat which can move in all directions. Fig. 5.01.

Voith-Schneider system. Consists in a rotor turning on a vertical shaft secured to the hull approximately at its pivot point (fig. 5.02), fitted with four foils or blades pivoting on vertical shafts driven by a mechanisms called steering control which sets the leading angle of the blades in the different manoeuvring positions, and determines the position of the steering centre. When the steering centre is separated from the rotor's geometric centre, the blades move around its axis, producing a jet of water creating an opposite reaction.

The mechanism is synchronized so that the perpendiculars to the chord of each blade's profile coincide at the steering centre, with which the jet of water and the thrust resulting are perpendicular to the line joining the steering centre to the rotor's geometric centre. Thus, with a single rotor, a thrust in any direction can be obtained providing this system with a high manoeuvrability capability (see Fig. 5.03, positions 2, 3, 4 and 5). If two rotors of this type are fitted in a tug boat, as is shown schematically in diagram 6 in the same figure, the longitudinal components of both thrusts can offset each other and, adding the cross forces together would cause the tug boat to move sideways if they were applied at the centre of drift.

Figure 5.01. «Schottel» system

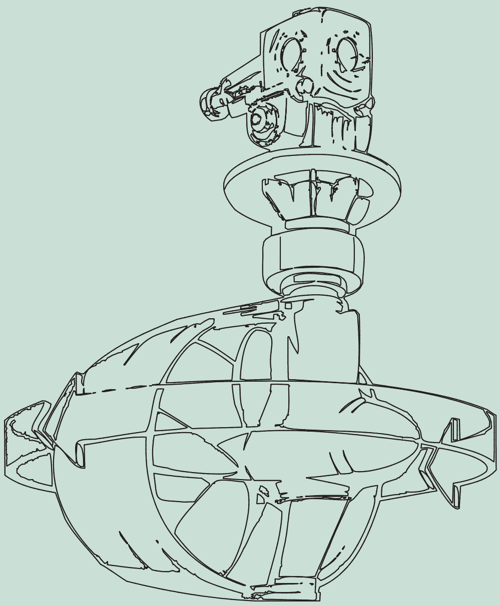


Figure 5.02. «Voith-Schneider» system

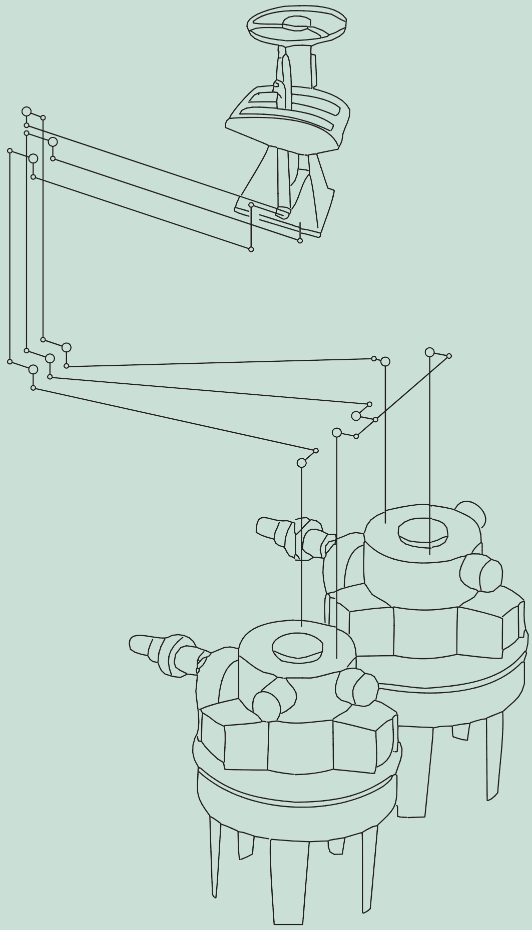
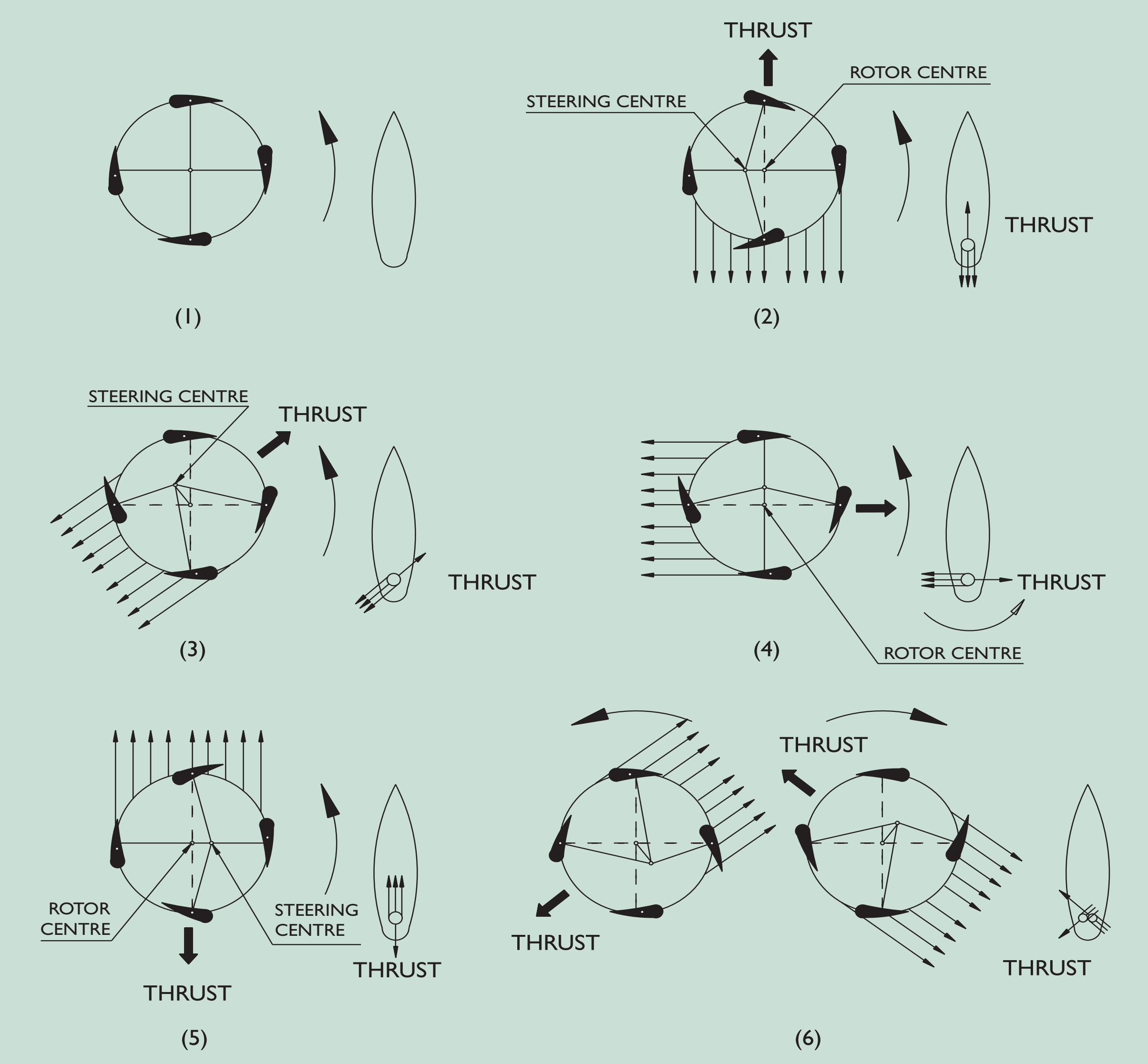


Figure 5.03. ***«Voith-Schneider» system operation***



The Voith-Schneider system produces less thrust for forward navigation than a fixed pitch propeller for the same horsepower installed. However, this loss of efficiency is offset by the high degree of manoeuvrability obtained, which is very necessary for operations in restricted waters.

Figure 5-04 gives a comparison of the propulsion systems described. The thrust vector diagram at zero speed is represented and the efficiency of the special propellers working in all directions can be seen. Figure 5.05 shows the bow thrust force produced by the different propulsion systems as a function of the tug boat's speed. The loss of tug boat efficiency occurring when speed is increased is clearly shown.

5.3.1.2. Tug boats may be classifieed as follows according to the number and position of the propellers:

Single-screw tug boat. It is the classic and conventional tug boat with a single stern propeller which may be ducted in a nozzle to increase the pull; blades may be fixed or controllable pitch (see figure 5.06). Its features are as follows:

- It is suitable as a bow tug boat and it is manoeuvrable at all speeds.

Figure 5.04. **Thrust diagrams for various propulsion systems**

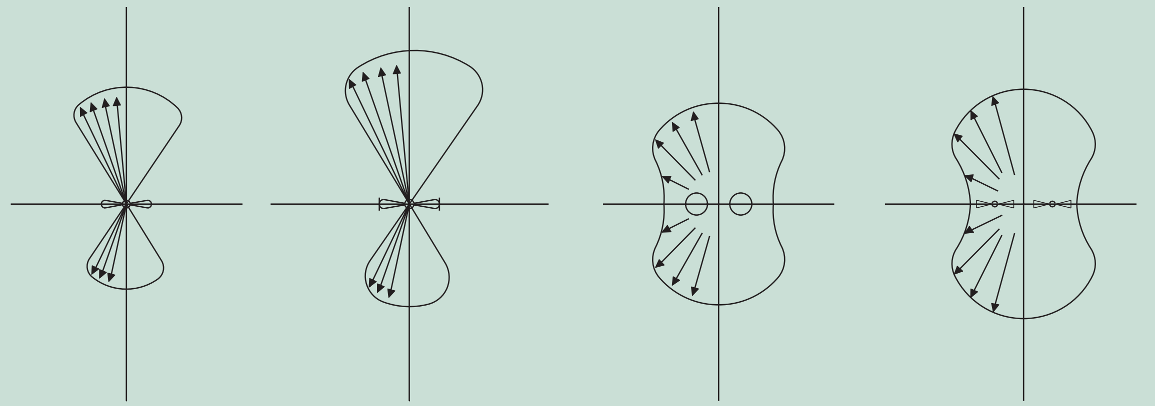
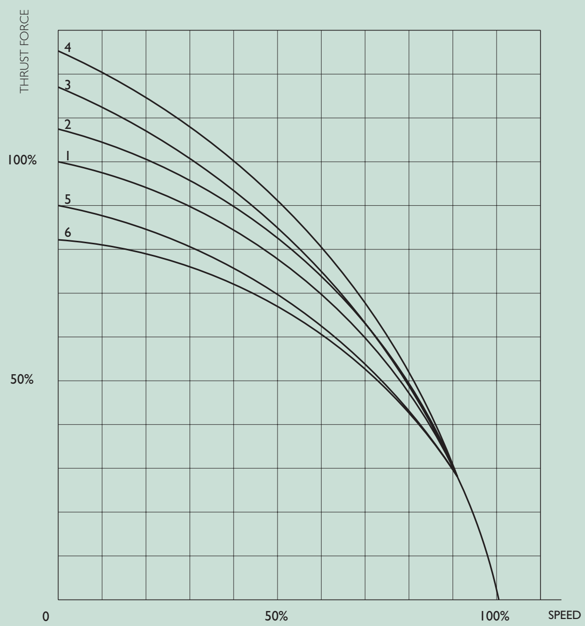


Figure 5.05. **Bow thrust forces as a function of speed (for a 2,000 HP tug boat)**



1. Fixed pitch propellers.
2. Controllable pinch propellers.
3. Fixed pitch ducted propellers.
4. Controllable pinch ducted propellers.
5. Schottel system.
6. Voith-Schneider system.

- It is unsuitable as a stern tug boat because it has no manoeuvrability
- It has no manoeuvrability going astern.

Twin-screw tug boat. It has twin propelleres fitted at the stern and driven by horizontal shafts, whose blades may be fixed or controllable pitch, fitted inside nozzles or without them. Two nozzle-rudders which provide the tug boat with great manoeuvrability can be fitted to increase the latter.

Tractor type tug boat. It has the propulsion element at the bow, either the Schottel or Voith-Schneider type (See figures 5.07 and 5.08). Due to its particular manoeuvrability, it has the towing hook at the stern which prevents the possibility of the tug boat capsizing when pulling beam-on. Its characteristics are:

Figure 5.06. **Typical tug boat with ducted propeller**

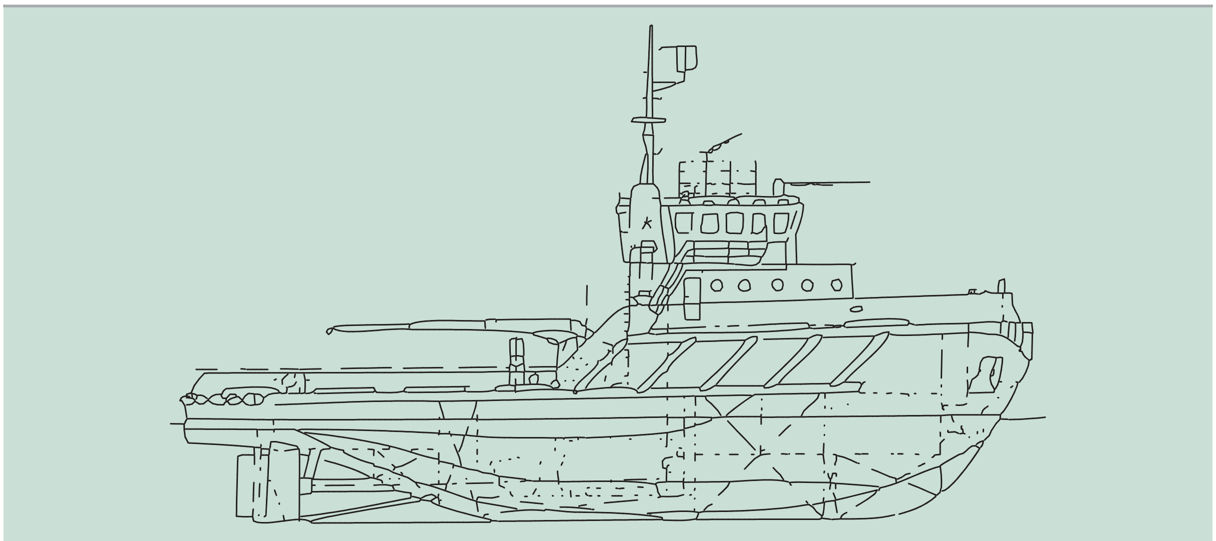


Figure 5.07. **Tractor type tug boat with Schottel propeller**

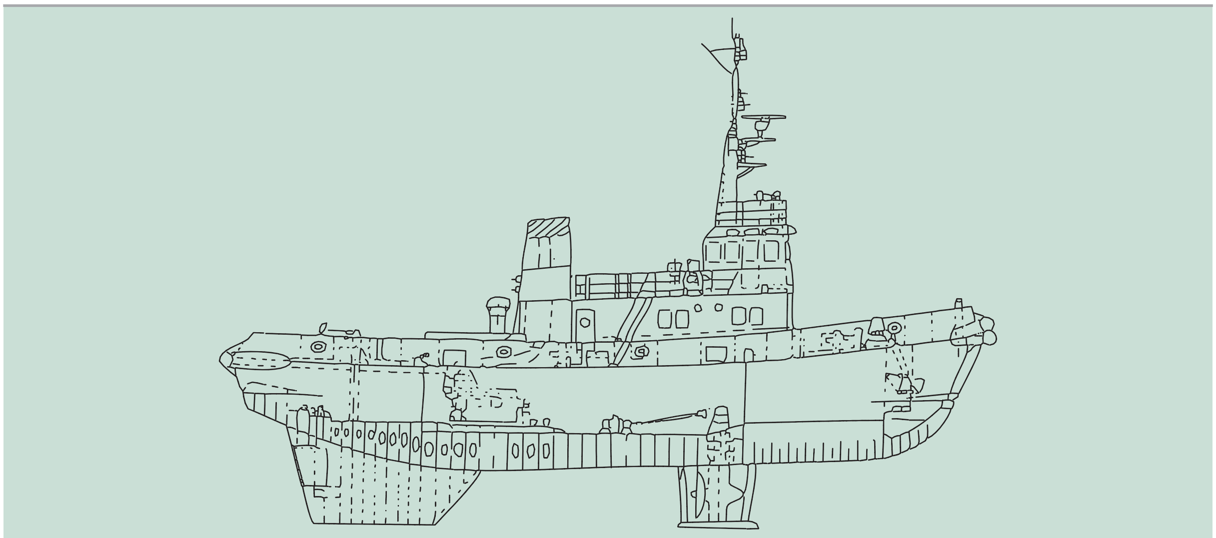
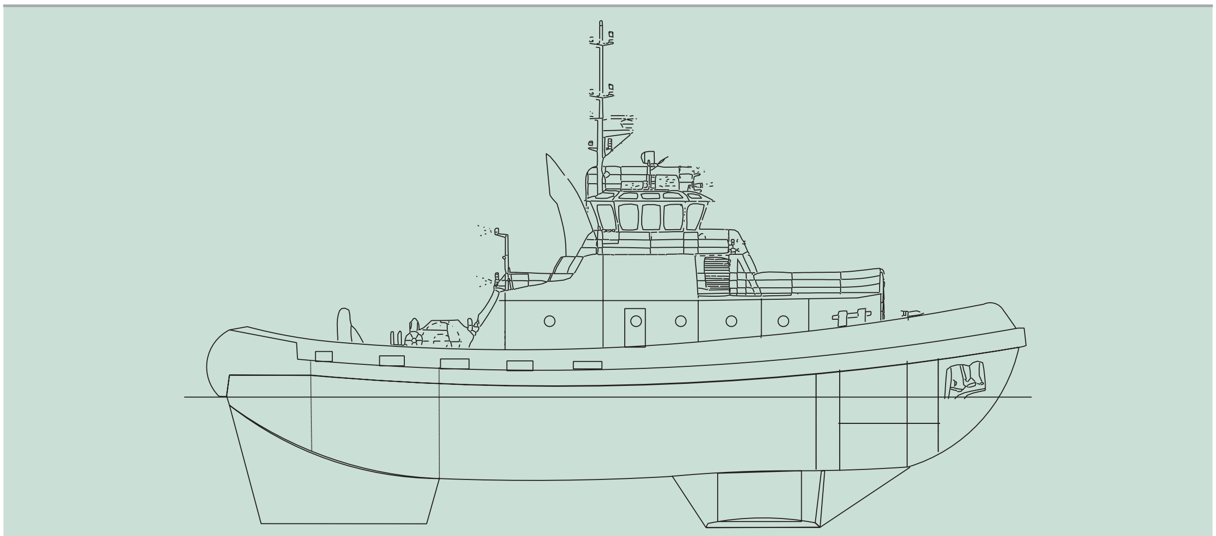


Figure 5.08. **Tractor type tug boat with Voith-Schneider propeller**



- Is suitable as a bow and stern tug boat
- Is suitable for pushing and towing operations.
- Is highly manoeuvrable, even moving sideways.
- Has a large pulling force in all directions.

«Z-peller» type tug boat. This is a 360° rotation Schottel type twin-screw stern driven tug boat which, because of its high manoeuvrability and pull can act as a tractor type tug boat or for pushing and towing.

Fitting two fore and aft towing winches near the main towing bitt increases its capability for acting in any direction. Its features are:

- It is suitable as a bow tug boat using the winch in the main bitt like a conventional tugboat.
- It is suitable as a stern tug boat, by hooking up the tow rope at the front winch and operating as a tractor type tug boat.
- It has high speed in free forward and stern running.
- It is highly manoeuvrable both with or without a tow.
- It is suitable for pull and push operations.

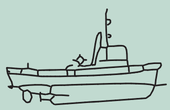
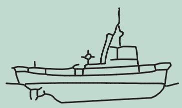
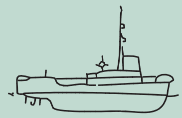
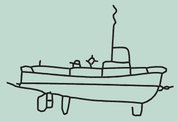
5.3.2. Steering system

As far as steering systems are concerned (regardless of those already described when analysing the Schottel and Voith-Schneider propulsion systems, etc.), most tug boats are fitted with balanced and semibalanced rudders, i.e., with the main piece's leading edge extended towards the bow with the purpose of using the flow more efficiently and making the steering gear work with less load. Most tug boat rudders are oversized compared to conventional vessels to favour manoeuvrability which generally leads to fitting stern posts with a heel for supporting the rudder and, should such be the case, the propeller.

The following are some special rudder systems developed for tug boats:

- *Towmaster:* This steering system locates several rudders behind each nozzle which can turn up to 60° on each side instead of the usual 35 or 40°. This allows an excellent manoeuvrability in going ahead but calls for greater stern draught as a counterpart.
- *Kort rudder:* This system consists of a nozzle inside which the propeller is located. The nozzle is coupled to the rudder's main piece and is turned by the steering gear. The advantages of this system over the conventional are an improvement in the efficiency going aheade and higher manoeuvrability going astern. The disadvantage is that this rudder's response is slower than that of other conventional rudders.
- *Lateral rudders:* These auxiliary rudders are fitted forward and on either side of the propeller and provide greater steerability in manoeuvres astern. They are operated by separate controls and are kept steady when running ahead. They are normally fitted in conjunction with Kort nozzles.
- *Two propellers and a single rudder:* This steering system is not very efficient in manoeuvres because the flow from the propellers ia not directly falling on the rudder as the latter is central to them; however, it is efficient in hook towing operations.
- *Double rudder and one propeller:* This type of installation is used in controllable pitch propeller tug boats with the aim of improving the poor steering features they show when a single rudder is fitted behind and the propeller runs at zero pitch.

Table 5.1. ***Compared twin-screw tug boat characteristics***

Type of propulsion	Controllable pitch propeller and double hanging rudder	Variable pitch propeller and Kort rudder	Voith-Schneider propulsion	Schottel propulsion
General configuration				
Relative rudder size compared to Length	Large	Large	Medium	Medium
Approximate engine revs (rpm)	400	400	500-600	750
Time required for emergency stop in seconds	39	20	18	10
Time required to change from full ahead to full astern in seconds	10	10	7	7.5
Arc on which the steering force can be exerted, in degrees	70	70	360	360
Time required to run the whole steering arc defined above in seconds	15-30	15-30	15	15
Time required for a 360° turn in seconds	65-70	45-50	35-45	20-25
Turning radius compared to the Tug boat's length (*L*)	3-5L	1.5-2.0L	1.0-1.3L	1.0-1.3L

Propeller-steering. In this case, the propeller acts as the rudder performing the functions of propulsion and steering. This type corresponds to the propeller-rudder (Schottel) and cycloidal (Voith-Schneider) systems described before when analysing propellers.

5.3.3. The combination of the different compatible propulsion and steering systems described in the foregoing sections, to which can be added thrusters, leads to highly varied types of tug boats. Table 5.1. includes data of some of the most usual types of tug boats with the purpose of providing comparative information of their manoeuvrability characteristics.

5.4. FUNDAMENTAL TUG BOAT CHARACTERISTICS

The main characteristics a tug boat should have are manoeuvrability, stability and power.

5.4.1. Manoeuvrability

A tug boat's capability and facility for manoeuvring are fundamental for performing its most characteristic functions because in manoeuvring with large vessels in small spaces it will have to be able to move in all directions. A tug boat's manoeuvrability depends on the shape of the hull, which is why they are usually specially built in a hydroconic shape at the stern or flat bottomed so that suction currents reach the propellers with no turbulence.

The propulsion and steering systems are determining factors of a tug boat manoeuvrability, particularly the combined Schottel or Voith-Schneider propulsion-steering systems which, as mentioned before, provide the tug boat with mobility in all directions.

Another factor influencing manoeuvrability is the position of the towing hook or winch which should be very close to the centre of lateral resistance or somewhat aft of it.

A further item which will influence manoeuvrability is the tug boat's capability of changing from a full ahead situation to a complete stop. The stopping time should not exceed 25 seconds.

5.4.2. Stability

The static stability curve for a tug boat must be positive up to 60-70° with a metecentric height of about 60 cm. The accommodation and engine room entry doors must be watertight in view of the possibility of reaching large heeling angles when the tow rope is pulling in a beam-on direction. Methods whereby static tug boat stability can be improved are based on increasing the beam (present day tug boats have length/beam ratios less than 3.0), on reducing the hull's lateral resistance, on reducing the height of the hook or pulling point and of the height of the pushing point and on using mooring lines or tow ropes with good impact load absorption characteristics.

5.4.3. Power

The power of a tug boat should be that necessary to tackle its mision safely. A tug boat's horsepower for transport operations (towing or pushing vessels, pontoons, rigs, etc.) should be at least the necessary to pull or push a tow of a certain displacement at a certain minimum speed which will enable it to steer under the worst possible weather conditions to be expected during the operation. This horsepower necessary for reaching a certain speed will depend on the propulsion engine's efficiency, the efficiency of the shafting line, the efficiency of the propeller and the efficiency of the tug boat's and towed vessel's hulls.

The horsepower required for a tug boat will be the sum of the power necessary to move the towed vessel and the tug boat. It may be approximately assumed that the horsepower a tug boat requires to reach a certain speed is 9 to 10% of the total horsepower needed to perform the tow. Then, knowing how much horsepower is required to move the towed vessel, the approximate horsepower the tug boat will need to perform a certain tow can then be calculated.

The bollard pull must be highlighted within the concept of tug boat horsepower. This is the characteristic that better determines the horsepower it needs to undertake the remaining functions, especially when manoeuvring with vessels in harbours and restricted areas.

5.4.4. Bollard pull

This is the amount of horizontal force the tug boat can apply working ahead in the case of zero speed. It would therefore be the same as the pull the tug boat would produce in a mooring line holding it to a bollard fixed on a quay.

The bollard pull depends on the propeller's turning area, its pitch, the brake horsepower and shaft horsepower, besides the displacement, hull form and type of propeller.

The bollard pull supplied by a tug boat can be simply determined with the following equation:

$$T_{PF} = K_{PF} \cdot \frac{W_R}{1000}$$

where:

T_{PF} = Bollard pull (tonnes).
W_{PF} = Tug boat's brake power in HP.
K_{PF} = Coefficient depending on the tug boat's characteristics. The following figures may be used as a function of the propulsion system for tug boats in the 500-2000 HP and 2000-4000 HP ranges, which are normal in harbour manoeuvres:

	500-2000 HP	2000-4000 (HP)
Fixed pitch propellers	10.0-11.0	9.0-10.0
Ducted fixed pitch propellers	11.5-13.0	10.5-12.0
Variable pitch propellers	10.5-11.5	9.5-10.5
Ducted variable pitch propellers	12.5-13.5	11.5-12.5
Schottel system propellers	9.0-10.0	8.0-9.0
Voith-Schneider system propellers	9.0-9.5	8.5-9.0

Knowing the bollard pull, the pull or push ahead supplied at other speeds can be determined by using the curves in figure 5.5. It is reminded that pushes with the tug boat working in other directions other than ahead may show very significant reductions depending on the type of tug boat. The criteria given in section 5.7. will be applied to determine the horsepower of tug boats necessary for carrying out certain vessel navigation aid manoeuvres.

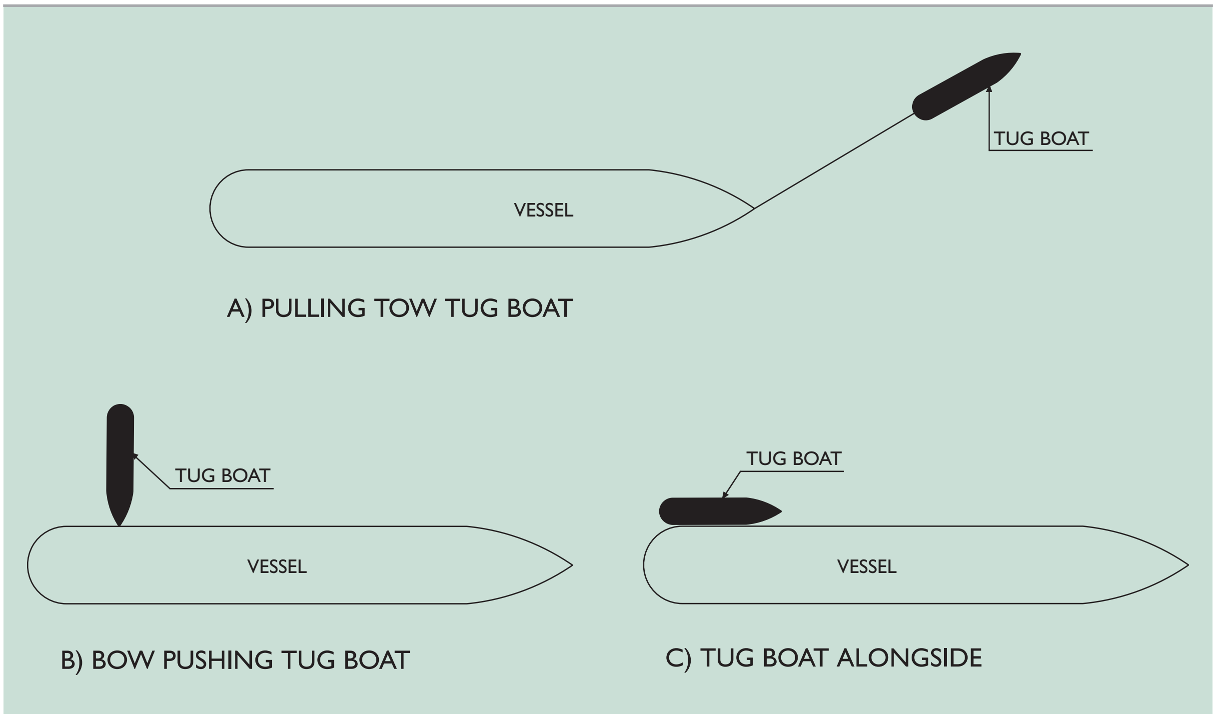
5.5. TUG BOAT OPERATION MODES

Tug boats generally operate in one of the following three modes (see fig. 5.09).

a) PULLING TOW TUG BOAT (ARROW WORKING)

In this mode, the tug boat works separated from the vessel it is aiding. It tows it from the end of a tow rope which may be secured at different points on the vessel, and thus performs different functions (towing, holding, etc.). This procedure avoids direct contact between the vessels and also ensures that the whole of the tug boat horsepower is exerted in the tow rope direction. The disadvantage is that more room is needed to manoeuvre due to the length of the tow rope, so the system cannot be used where there are space limitations. The effect of pull towing is similar to a mooring line with its anchor point moving and a pull varying in magnitude.

Figure 5.09. *Usual tug boat operation modes*



b) BOW PUSHING TUG BOAT (RAM WORKING)

In this mode, the tug boat leans its bow on the side of the vessel it is aiding and pushes it in a direction noticeably perpendicular to the centre line. It is normal in this procedure for the tug boat to be secured to the vessel by 1, 2 or 3 mooring lines which prevents relative sliding between both vessels during the manoeuvring besides exerting a pull on the vessel in the case this is needed during the manoeuvring, providing greater flexibility to the operation. The procedure requires less manoeuvring space and enables the direction of push to be changed quickly although the efficiency of the tug boat working by pulling is less than with the previous method due to the worse position the mooring lines may adopt.

The tug boat may be used at the stern of certain craft (pontoons, barges, etc.) as a variant on this system, transmitting the push in a longitudinal direction and thus providing the power necessary for the longitudinal motion of which these craft do not generally avail.

The effect of a bow pushing tug boat is like that of a mooring line working in both directions, with its point of application moving and with a pull of a varying magnitude, although possible friction loads in the case of working by pushing must be taken into account.

c) TUG BOAT ALONGSIDE

In this mode, the tug boat positions itself alongside the vessel, noticeably parallel to it and is moored to the latter by several lines which ensure the transmission of forces. This procedure is generally used to manoeuvre vessels which lack sufficient propulsion in small areas and in very calm waters.

The tug boat generally positions itself on the quarter of the vessel it is aiding so that the rudders of both boats are at the same position to favour the combined unit's evolution conditions. The tug boat alongside therefore produces the same effect as though the vessel being towed had two propellers, one very far from the centreline. In cases of vessels very sensitive to wind action and other lateral loads, it is normal to have two tug boats alongside, each located on one side with which greater control of manoeuvrability is achieved.

Depending on the working system chosen, the relative position of the tug boat and vessel is modified, affecting the hydraulic characteristics of the water flow around both vessels and in the surroundings of their propellers, causing secondary effects, an analysis of which is beyond the scope of this Recommendation.

5.6. TUG BOAT ACTION

The action of each tug boat operating on a vessel may be simplified into a resulting horizontal force F_{Ri} varying in intensity which may be applied with a large eccentricity to the vessel's centre of gravity to achieve the largest evolution effects (see fig. 5-10). Each of these forces can be broken down into the following partial effects:

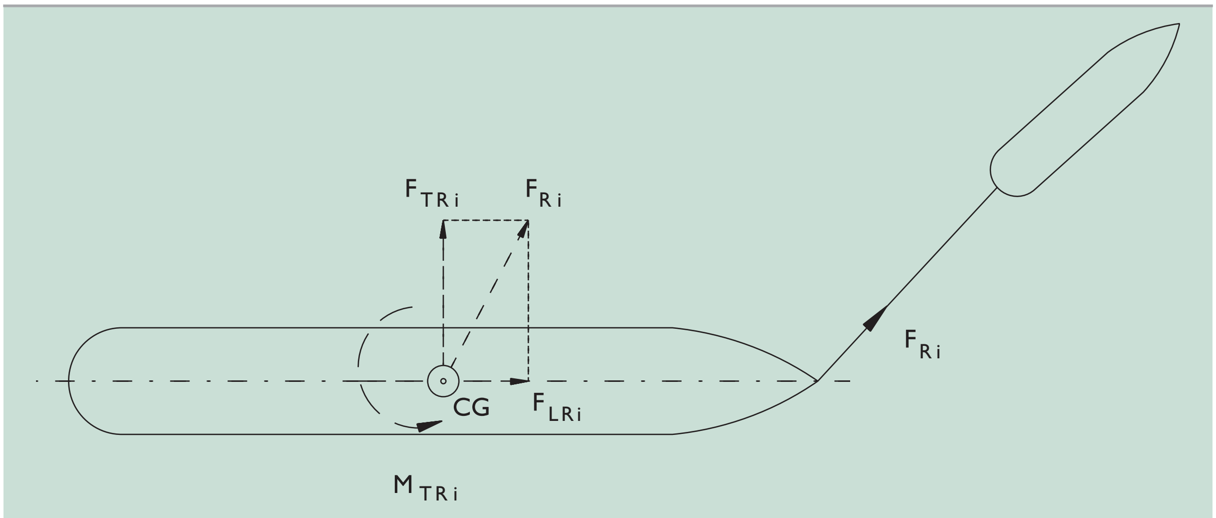
- A component F_{LRi} in the vessel's longitudinal direction, which produces the vessel's forward motion or braking depending on the direction in which it is applied.
- A component F_{TRi} in the vessel's transverse direction, which produces drift motions.
- A resulting Moment M_{TRi} due to the eccentricity of the force to the vessel's centre of gravity which produces yaw motions.

Depending on the manoeuvre it is intended to perform, tug boat actions will be directed towards achieving the best effects for each case (greater longitudinal component in the case of a tow, greater transverse component in the case of compensating for a drift, greater turning moment in the case of turning about, etc.).

Should several tug boats intervene in the manoeuvre, each one's action will be established in a coordinated manner so that the wanted favourable effects are strengthened and the unfavourable are lessened or offset.

In addition to these main forces, the component in the vessel's vertical direction and the moments on the vessel's longitudinal and transverse axes may be considered. Their effect might have to be taken into account to determine the vessel's additional draughts due to tug boat actions which are not generally considered (except in the tug boat or in small boats) due to their low magnitude.

Figure 5.10. ***Tug boat action***



5.7. DETERMINING THE REQUIREMENTS FOR TUG BOATS

5.7.1. Determining requirements for tug boats to carry out a proper manoeuvre depends on a large number of factors, amongst which are:

- The characteristics of the area where the manoeuvre is to be undertaken.
- Environmental conditions.
- The type of vessel and its manoeuvrability conditions
- The type of manoeuvre to be performed and the way the tug boats act under safe conditions.
- The fleet of tug boats available.
- The experience of the ship handlers participating in the operation.
- The providing of services supplementary to the manoeuvring.
- The economic conditions governing the tug boats' participation.

Should it be required to determine the fleet of tug boats necessary for a port or a complex facility integrating different Approach Channels, Basins or Manoeuvring Areas, studies of demand, simultaneity of operations, etc. would have to be conducted, the analysis of which is beyond the scope of this ROM.

5.7.2. Leaving aside the pure towing operations already discussed in section 5.4.3., the assistance of tug boats in the arrival or departure of a vessel to or from a port facility is normally done in three phases:

- An initial phase in which a vessel keeps to an appreciable speed at which it can maintain adequate control of navigation with its own resources (propellers, rudders, etc.). Tug boat assistance in this phase may be necessary, with requirements which will not generally demand excessive power or bollard pull but will require specific conditions of navigability and efficiency for assisting a moving vessel.

- An intermediate phase in which the vessel reduces its speed to approach a manoeuvring area, basin, quay, etc., in which the vessel is undertaking part of its stopping process. The vessel reduces its speed in this phase and, as a consequence, the efficiency of its own resources diminishes. As a result, the influence of outside forces (wind, wave, current, etc.) is unbalanced and tug boat assistance has to be resorted to more frequently and in more prolonged actions.

- A final phase when the last approach, turning and berthing manoeuvres or the contrary process of commencement of departure are undertaken. The vessel during this phase has practically zero speed such that the possibility of using its own resources in controlling external actions is practically null and therefore it needs more tug boat assistance.

The demand for tug boats, at least for vessels sensitive to wind, wave and current action, is usually determined by this last phase in which the greatest bollard pull requirements are quantified. During this last phase with the vessel moving at a low speed, is when its thrusters act most efficiently, which is why they must be taken into account to the effects of quantifying bollard pull requirements to be provided by tug boats.

5.7.3. The general procedure for dimensioning tug boat requirements is based on the forces provided by the latter (plus the vessel's thrusters, if it has them) being able to balance the outside and inertia or residual forces of the vessel, whilst keeping a suitable safety margin for the vessel to remain under control at all times. This general criterion may have an alternative hypothesis in which it is accepted that the tug boat forces are not able to balance all the outside and inertia or residual forces of the vessel with unbalanced loads remaining which will cause the vessel to move (advances or reverses, drifting and yawing) for which there must be reserves of space in sufficient amount for the worst conditions which might arise. In any case, it is recommended not to use this procedure when the vessel's may move towards areas with insufficient depth, quays or other fixed facilities or vessels either stopped or in motion, since serious accidents could follow in these cases.

Usual scenarios belong to one or both of the two following cases:

a) KEEPING A VESSEL SUBJECT TO ENVIRONMENTAL LOADS IN POSITION

The outside forces provided by tug boats (plus manoeuvring thrusters, if there are any) must balance the resultant (forces and moments) of the loads on the vessel from the action of wind, waves and currents which have been established as limit operating conditions for the manoeuvring, following the criteria as established in Chapter IV. A 1.25 safety coefficient will be applied to the loads obtained. To move from these outside forces which must be provided by the tug boats to specific requirements in terms of bollard pull, corrections which quantify the loss of tug boat efficiency as a function of speed and angle of push or pull in relation to the direction of forward running of each tug boat being considered will be taken into account. It must be pointed out that should the vessel's configuration and the external action forces cause major unbalanced moments, the external forces to be provided by the tug boats will not be the same at the bow as at the stern and this advise locating the tug boats available in the best way to balance these forces, with the greatest eccentricity possible to the vessel's centre of gravity in order to achieve the greatest efficiency in absorbing such forces. The advisability of having tug boats in pulling tow working, at the bow or even alongside (should there be many unbalanced longitudinal forces) will generally depend on the space available and on what proves the best for the following manoeuvres to be performed afterwards, whether turning about, straight line moving to a quay which accepts tug boat navigation behind the berthing line or not, etc.

b) TURNING A STOPPED VESSEL NOT SUBJECTED TO ENVIRONMENTAL LOADS

The external forces provided by tug boats (plus thrusters if there are any) must balance the forces and moments due to the current's speed relative to the vessel which is generated by the actual turning. The current force will be determined with the criteria as established in Chapter VI, assuming that the form coefficients are kept for a linear distribution of the current's speed relative to the vessel and that turning about is achieved in a maximum of 20 minutes for a 180° turn. A 1.25 safety factor will be applied on the loads obtained. The balance equations will be determined by assuming that the turn about occurs at a uniform speed therefore ignoring the acceleration and deceleration phases of the movement. The resulting mathematical formula will depend on the number of tug boats used and the way in which they are arranged. To move from these external forces which must be provided by the tug boats to specific requirements in terms of bollard pull, corrections which quantify the loss of tug boat efficiency as a function of speed and angle of push or pull in relation to the direction of forward running of each tug boat being analysed will be taken into account.

c) LATERAL MOVEMENT OF A VESSEL NOT SUBJECT TO ENVIRONMENTAL LOADS

In this case related to the most usual final approach phase to a quay, it will be assumed that the vessel's kinetic energy due to the initial transverse speed (including the added mass of water) is wholly absorbed by the work of the external forces provided by the tug boats and manoeuvring thrusters, if there were any) acting uniformly on the space available for the vessel's stopping which, in any event, will not be taken with a value higher than one beam of the vessel manoeuvring. A 1.25 safety factor will be applied to the loads thus obtained. To move from these external forces which must be provided by the tug boats to specific requirements in terms of bollard pull, it will be taken into account corrections which quantify the loss of tug boat efficiency as a function of speed and angle of push or pull in relation to the direction of forward running of each tug boat being analysed.

5.7.4. As can be seen from the foregoing procedure, calculating tug boat requirements is not a univocal process leading always to a unique solution. Not even knowing the overall requirements expressed in terms of bollard pull can the number and horsepower of tug boats to be used in each case be invariably determined. However, the procedure is objective and may be formed into Operating Rules in each case which assign tug boats as a function of the type of vessel, the type of manoeuvring to be performed, the tug boats available and the limit operating environmental conditions established for each case or for each interval of vessels and environmental conditions should greater flexibility be wanted in this respect.

Should the vessel have thrusters, their effect on offsetting the resultant of the external forces on the vessel may be considered and tug boat requirements reduced.

5.8. TOWING EQUIPMENT

Each type of tug boat will be fitted with the equipment necessary to carry out its work normally. Some items are fixed on deck such as towing winch, towing hook, «H» bitts and normal bitts. Others will compose the towing material such as tow rope, crowfeet, triangle, life line, extension handling rope and warping guides. Therefore, each tug boat according to its towing power and bollard pull should have these items with the strength necessary to allow towing to be undertaken in safety. The most important elements mentioned before area briefly described hereafter, as far as operations which are the subject of this ROM are concerned.

Towing winch. It is a hydraulic machine fitted with one or two drums where the towing line is reeved. The system may be automatic tensioning or constant length or non automatic. The constant tension winch keeps the cable at the programmed tension at all times, heaving out when entering into excessive force and heaving in when remaining at the side. Thus, once the length of towing line or maximum tension is set, these values will be automatically kept to. The non automatic towing winch is hand operated and calls for the distance to be regulated by hand and care to be taken that it does not work to excess.

The towing winch must be installed as low as possible so as not to reduce stability and, if possible, coinciding with the centre of lateral resistance to facilitate the tug boat's manoeuvrability.

The disadvantage of the towing winch is that it cannot change from towing forwards to backwards, especially in manoeuvres in narrow places.

Bitts. There must be sufficient bitts on deck to secure the towing lines, placed in appropriate places to be used in various types of towing operations, whether by the stern, by the bow or alongside.

Towing hook. It is a specially built hook which enables the tow rope to be unhooked automatically from the bridge. The hook's location should coincide with the centre of lateral resistance or somewhat sternwards from it, depending on the propulsion system, with the purpose of giving the tug boat maximum manoeuvrability; its height will be the minimum to prevent the tug boat losing stability.

Tow rope. Tow rope or cable or line is the cable or rope used to pull the object being towed. It may be made of metal, natural fibre and synthetic fibre such as nylon, polypropylene, dacron, etc. The tow rope is used for long towing operations, inshore and ocean going vessels, in which long length and high strength are required. The conventional tow rope may be 5 to 6 cm in diameter and over 600 m long and is wound onto the towing winch drum.

Part VI

Vessel navigation and manoeuvring

VESSEL NAVIGATION AND MANOEUVRING

Part VI

6.1. INTRODUCTION

The vessel and the forces which may act on it, whether internal or external, dependent on or independent of the helmsman, have been analysed throughout the three previous chapters. Once these forces and a vessel characteristics are known, an analysis of its motions and the areas occupied is a problem which can be addressed by general physics procedures. However, even though the general equations of motion may be written without difficulty, solving such equations and determining these paths and swept areas are hindered by two practical aspects:

- On the one hand, many of the forces taking part in the calculation are variable as a function of multiple conditions (water depth, sea state, maritime environment, vessel's heading, etc.).
- On the other hand, a large number of forces depend on the helmsman's volition. He may make them change continuously in the way he considers most fitting to the navigation or manoeuvring he is performing.

With these assumptions, a theoretical study of a vessel's path or motions is restricted to a few standardized, singular cases which serve for measuring a vessel's steering capability. The latter should be contrasted by means of experimental curves made out for each vessel that should be available for consultation on the bridge, in accordance with International Maritime Organization provisions. Of these manoeuvres, Turning Circles and Stopping Manoeuvres (or Headway Extinction), which are analysed in this chapter, are of interest for the Navigation Channels and Harbour Basins targeted by this ROM.

A theoretical study of non standardized manoeuvres in which the helmsman's volition plays a decisive role is not of interest and a statistical analysis of the areas swept is normally used, whether by actual measurement, measurement on a physical scale model or with a simulator to find the requirements of a vessel in its motion. Manoeuvres of this type usually addressed are numberless although there is a group which are the most usual and, knowing them, contributes to form a criterion with which others not addressed could be analysed. It was decided to present these most usual manoeuvres in Annex I to this ROM, with the conviction that knowing them may contribute to understan why certain area requirements are subsequently specified in chapters VII and VIII. This knowledge will be indispensable if simulators or model tests where this type of manoeuvre or other similar ones should be tested are used.

6.2. TURNING CIRCLES

6.2.1. Vessel motion definition and basic study

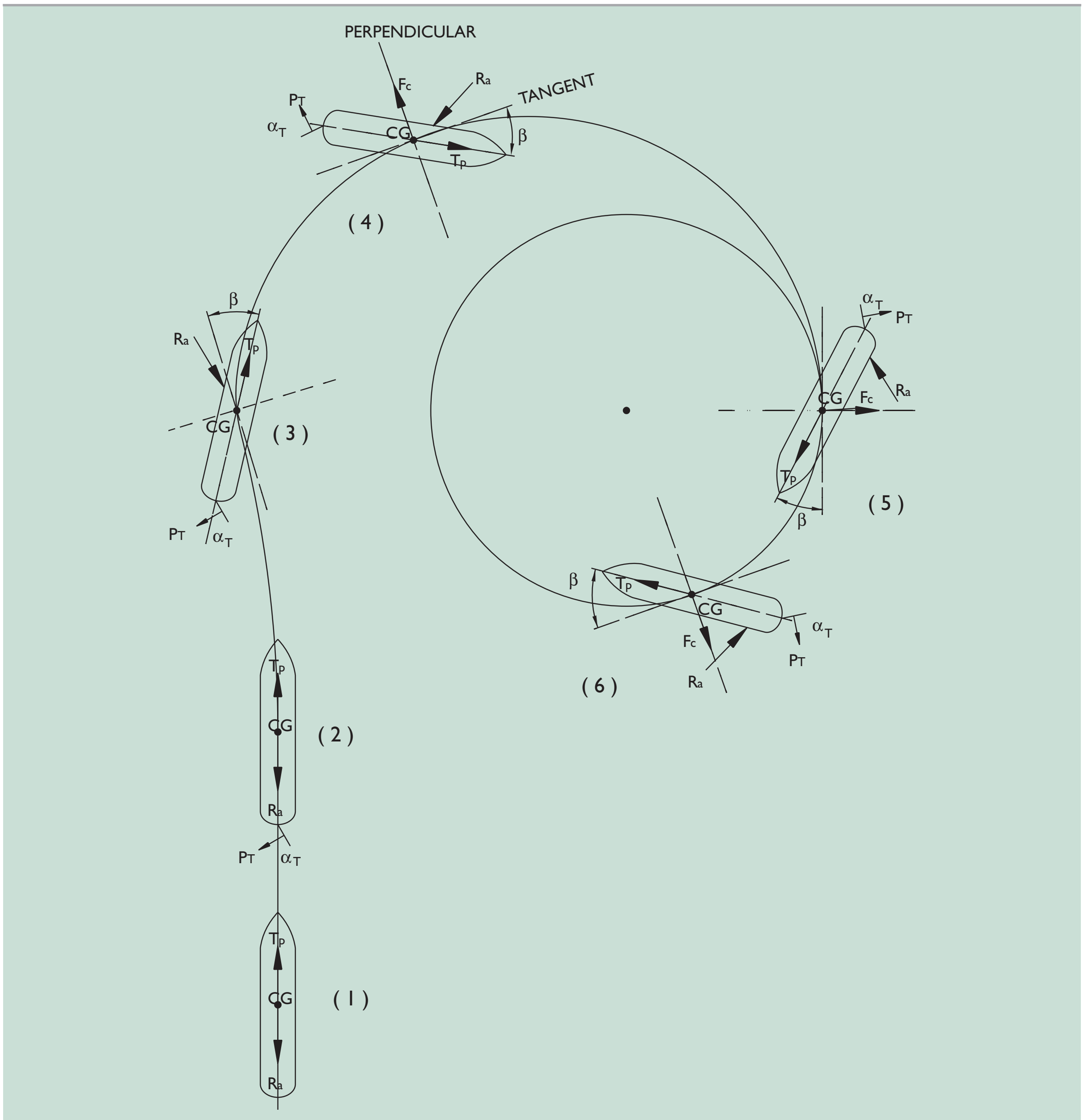
The path described by a vessel's centre of gravity when turned whilst keeping a constant engine speed and rudder angle is called the turning circle. Graphic representations of such circles for different speeds and rudder angles are called turning diagrams and provide an excellent overview of the vessel's behaviour, allowing the ship's handler to forecast the path the vessel will follow under the specific conditions affecting it.

Three phases must be considered to analyse this vessel movement. They occur consecutively as from commencement of the operation, and are respectively called manoeuvring, varying and steady. The manoeuvring phase extends from the moment when the rudder is deflected until the blade reaches the angle desired. The varying phase is that when the rudder-deflection angle remains constant but dynamic equilibrium among all the forces acting on the vessel has not been reached and, therefore, the vessel's motion can vary. Finally, the steady phase is that occurring as from the moment when said equilibrium is reached and lasts whilst the engine and rudder conditions under which the evolution is undertaken are not altered.

Forces occurring on the vessel and their effects during the three phases are schematically analysed in figure 6.01. Before commencing the manoeuvring phase, the only forces acting are the propeller thrust «T_p» and resistance to advance «R_a». If the motion is straight-line and steady, both forces are located in the centreline plane and are equal and opposite in direction (position 1 in figure 6.01).

As soon as the manoeuvring phase commences and the rudder begins to deflect (position 2), force «P_T» appears perpendicular to its blade and causes the evolution moment on the vessel making it veer to the pertinent side with a drift angle «b» to the path although, due to inertia, the vessel will continue keeping its centreline plane in the initial direction in the first few moments. Apart from the foregoing effect, the breakdown of force «P_T» into a longitudinal direction and transverse to the vessel produces a force opposing the propeller which diminishes the vessel's speed and a transverse component which makes the ship cast to the opposite side to that to which the rudder has been deflected.

Figure 6.01. ***Forces acting on a turning vessel***



The manoeuvring phase continues as the rudder-deflection angle increases (positions 3 and 4) until reaching the angle desired, which is the position shown as «4» in figure 6.01. The forces acting during this phase are the propeller thrust «T_p», resistance to advance «R_a», the force on the rudder blade «P_T» and centrifugal force «F_c»

which will act perpendicular to the path. It must be pointed out that, of these forces, Resistance to advance no longer remains in the centreline plane since, due to drift angle «b» with which the vessel is moving, resistance to advance is not symmetrical on both sides of the hull and the point of action of «R_a» is progressively displaced sternwards in view of the fact that the parts of the underwater hull which will offer higher resistance will be those farthest from the instant centre of rotation where velocity is highest. Establishing the equilibrium conditions of this system of forces will enable the motion equations to be worked out. Position «3» in figure 6.01 represents the moment when the components of «T_p», «R_a» and «P_T» perpendicular to the path balance out and, therefore, the centrifugal force «F_c» is null, which is equivalent to saying that the radius of curvature of the path is infinite and is therefore an inflection point in the path.

The varying phase extends from position «4» in which the rudder-deflection angle has reached its desired value up to position «5» when the dynamic equilibrium of all forces is reached. The system of forces in this phase is the same as described in the previous stage, with the peculiarity that the load on the rudder «P_T» and the pertinent turning moment have reached their maximum value and cannot grow any further, with which there will be a time when the moments caused by the rudder force «P_T» and the resistance to advance «R_a» will be balanced and there will be a null angular acceleration of the centreline plane or, in other words, a constant angular velocity of that centreline plane. Whilst this is happening, when balance of all longitudinal forces is reached, the longitudinal acceleration of the vessel's centre of gravity will also be null and the straight-line velocity will therefore be constant. Finally, the balance of the transverse forces obliges the centrifugal force to be constant and as well as the straight-line velocity. The result is that the radius of curvature of the path also remains constant and the path becomes a circle, with which the whole steady phase shown schematically in position (6) in figure 6.01 becomes a circular motion with a uniform speed and a fixed drift angle.

6.2.2. Drift angle and pivot point

If the different paths as described by different points of a vessel in full turning are considered (see figure 6.02), it can be seen that each of them follows a curve practically concentric with the path followed by the centre of gravity (CG).

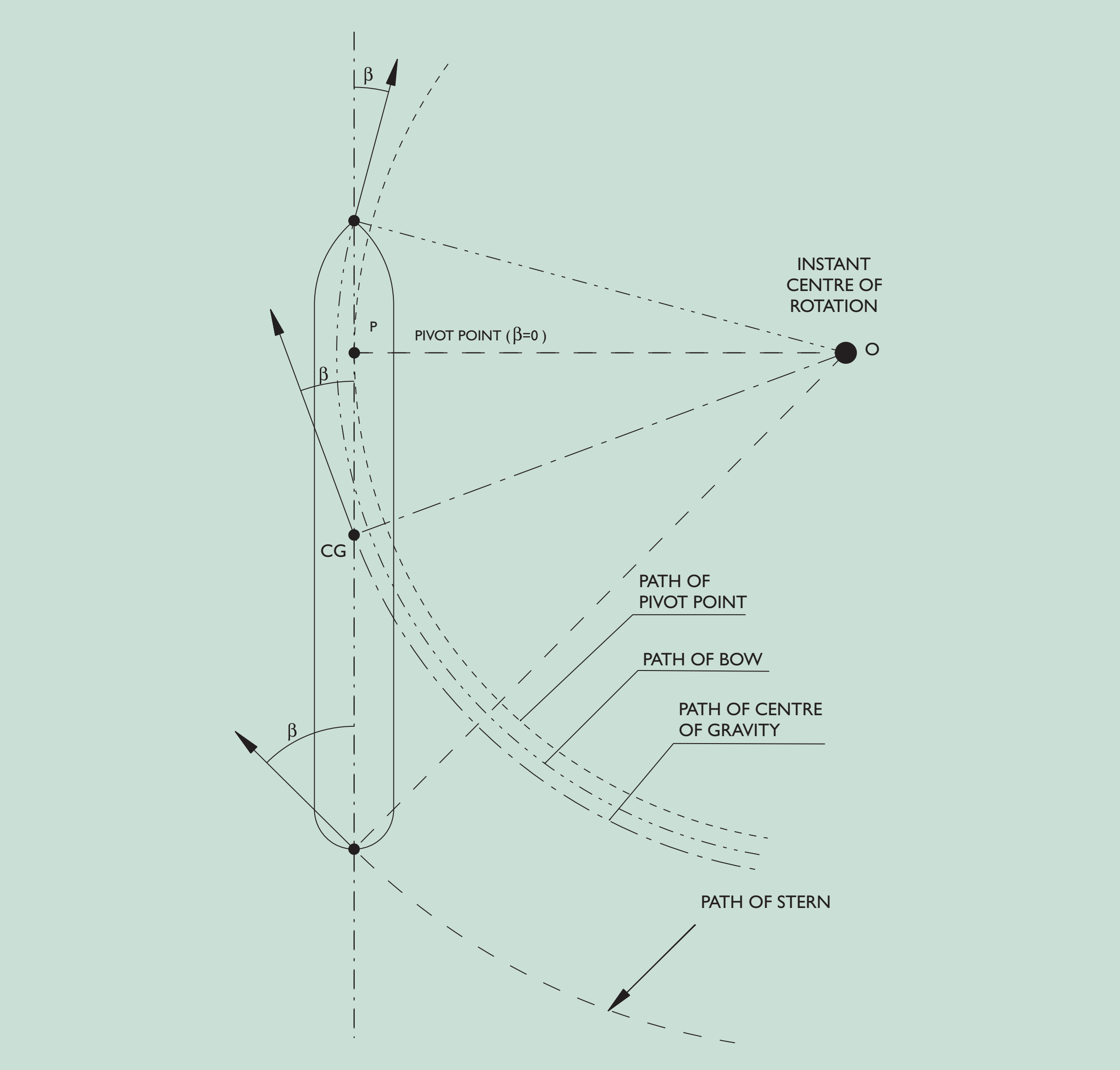
The angle formed by the direction of the keel with the geometric tangent to the path described by any point in the vessel's centreline plane is called the drift angle of that point at that moment. This angle has its maximum value at the stern and gradually diminishes as it moves bowards, until a moment when it is cancelled out (when a position P closer to the bow than the stern is reached) and then progressively grows up to the stem, but has the opposite direction in this last stretch as the tangent falls on the bow to starboard of the centreline and to port on the stern. The drift angle depends on many factors: shape of the underwater hull, rudder characteristics, the type vessel, its size and speed, wind direction and intensity, etc. In a particular vessel, and with other conditions being equal, it would vary with the rudder angle deflected during the turning.

Returning to figure 6.02, point P of the centreline where the drift angle is null is called the vessel's rotation or pivot point. According with the foregoing it is characterized because the keel line is tangent to the path in it, i.e., the longitudinal axis of the vessel is perpendicular to the radius of curvature PO of the turning path, where O is the corresponding instant centre of turn. This also means that the pivot point is that where the speed vector is directed at all times parallel to the centreline plane.

The pivot point is the apparent centre of rotation on which the vessel rotates when making it veer with the rudder, and an observer located in that position will see that the bow turns towards the inside of the path and the stern turns in the opposite direction during turning.

The pivot point does not have a fixed position but moves on the centreline bowards or sternwards, and its location is influenced by the same factors affecting the drift angle, especially because of the shape of the underwater hull. For a given vessel, it depends more on its instant speed than on the rudder angle deflected. For practical effects, it is advisable to assume an approximate position of the pivot point.

Figure 6.02. ***Turning path of a vessel***



In large vessels with conventional hull forms (bulk carriers, merchant ships, aircraft carriers, oil tankers, etc.) its mean location is one third (1/3) of the length from the bow. In faster vessels (ferries, etc.), it may be even further forward, 1/6 of the length from the stem and in very fast, lightweight boats, the pivot point may even lie in front of the bow when turning at high speed.

For vessels moving astern, the pivot point moves sternwards and is usually located in a position closer to the stern than to the bow. Moreover, trim also influences the position of the pivot point, which moves bowards or sternwards when the vessel trims respectively by the stem or by the stern. It also moves to a certain extent somewhat bowards when the vessel is in ballast and sternwards when it is much loaded.

6.2.3. Turning circle characteristics

Summarizing the foregoing section, it may be concluded that the turning circle is the path described by the vessel's centre of gravity when the ship is made to turn with a constant rudder-deflection angle.

Figure 6.03. ***Typical shape of a turning circle***

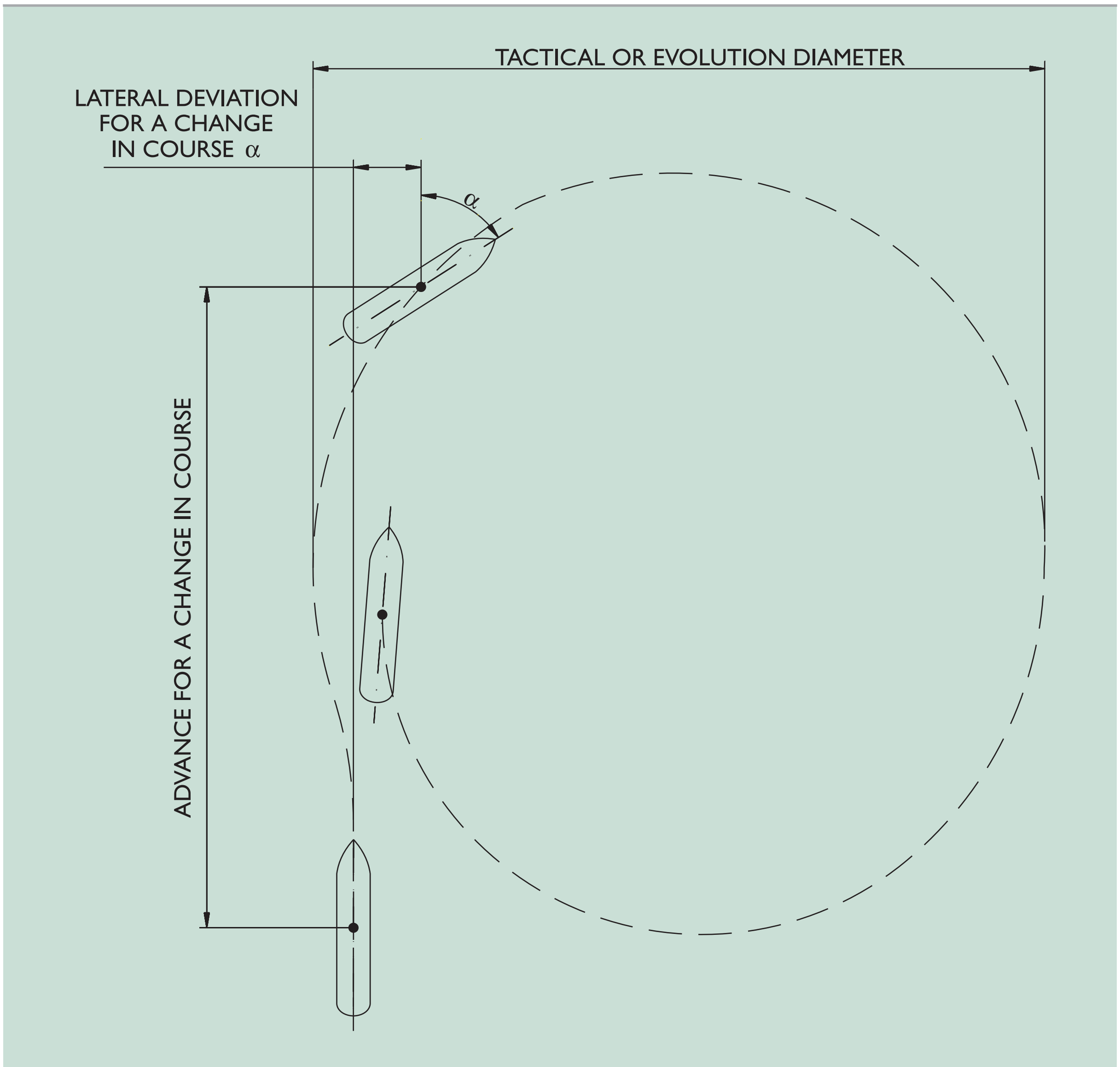


Figure 6.3. shows the typical shape of a turning circle when there is no wind, waves or currents and it can be seen there that, as it usually happens, after completing the 360° turn the vessel is at a position (3) somewhat more bowards and slightly inside that it occupied when the rudder was deflected (1).

The following terms are defined with the objective of comparing the characteristic features of different turning circles and facilitate the use of the data they provide:

- The advance of a vessel for a certain change of heading is the distance its centre of gravity moves in the direction of the original heading, measured from the position where the rudder was deflected.

- The transfer of a vessel for a certain change of heading is the distance its centre of gravity moves in a direction perpendicular to the original heading, measured from the position where the rudder was deflected.

The advance and transfer are therefore the orthogonal coordinates of the turning circle when the direction of the original heading and its perpendicular are adopted as reference axes, taking the point where the rudder was initially deflected as the origin. When reference is simply made to the advance or transfer without specifying the magnitude of the change of heading, it is taken for granted that the values indicated correspond to a 90° turn.

- The tactical or turning diameter is the greatest distance obtained by projecting the turning circle onto the perpendicular to the initial heading.

- The final or steady turning diameter is the diameter of the turning circle during the steady period, i.e., when the path becomes practically circular.

6.2.4. Variation in navigation parameters related to the turning circle

The following conclusions may be drawn from a study of the turning circles for different types of vessel:

1. Advance and transfer

The advance for a 90° turn is considerably greater than the transfer. For rudder-deflection angles of 35°, the range varies between 3 and 5 ship lengths; it diminshes when increasing the rudder angle deflected and increases with vessel speed. Transfer at 90° turn for that same rudder-deflection angle generally varies between 2 and 3 ship lengths; it diminishes when increasing the rudder angle deeflected, but is almost independent of speed.

2. Tactical and steady turning diameter

Both diameters diminish for one given velocity and water depth when the rudder angle deflected increases. These diameters vary little for the same depth of water and blade deflection for different speeds provided the latter are sufficient to guarantee good steering effectiveness from the rudder. For a given speed and rudder angle, both diameters vary with the depth of water available, both increasing when the water depth diminshes. This effect is more noticeable the smaller the rudder angle deflected is. For water depths 1.2 times the vessel's draught, the increase in these diameters may be 75% of those for a water depth 5 times the vessel's depth. If the water depth is 1.5 times the vessel's depth, this increase in the diameters may be in the order of 20 or 30%.

3. Influence of the hull form

The underwater hull form affects the dimensions of the turning circle. Two vessels similar length and draught, the one with the finer underwater hull needs more area to turn than that with fuller forms. The same happens with a relatively longer vessel, other general features being equal.

The more rectangular the submerged part of the centreline plane is, the larger the tactical diameter. The tactical diameter is usually between 4 and 6 ship lengths for fully loaded vessels with a high length/beam ratio and slender forms for water depths more than 5 times the vessel's draught and 35° rudder-deflection angles, and between 3 and 4 ship lengths for fully loaded vessels with a low length/beam ratio and full forms.

The International Maritime Organization (IMO) Regulations limit the maximum admissible tactical diameter of newly built ships with a length over 100 m in very deep waters to 5 ship lengths for 35° rudder-deflection angles.

4. Influence of draught and load condition

Differences in a vessel's draught affect its manoeuvring conditions. Generally, loaded ships have a larger turning circle than in ballast. Trim also has an appreciable effect on the turning qualities of a vessel, with the tactical diameter increasing when the vessel is trimmed by the stern and diminishing when trimmed by the stem. Therefore, the effect of trim is to move the pivot point position to the end with larger draught.

5. Turning time

For a given rudder-deflection angle, the duration of turning diminishes when speed increases. For the same speed, the time diminishes when increasing the rudder angle. Full deflection angle of the rudder and maximum speed must be used to complete a turn in the shorter time possible.

6. Linear speed

A gradual loss of speed occurs with respect to the seabed through the effect of rudder resistance and the drift angle the vessel acquires during the first 90° turn, despite the propellers continuing to rotate at the same number of revolutions per minute as before commencing the evolution because the vessel moves with a certain drift angle and doesn't take advantage of the hydrodynamic lines of its underwater hull. The amount or proportion by which linear speed is reduced greatly varies for different types of vessel and depends on the initial speed and rudder angle deflected. When turning with the rudder fully deflected, most vessels lose between 1/3 and 1/2 of their speed when they have turned about 90º and their final speed which they keep steady may be between 1/3 and 2/3 of their initial speed.

7. Angular speed

The angular turning speed, which was zero when beginning to turn, reaches its maximum value before the bow has turned 90° and then slightly falls off becoming constant in the final steady turning period. It may vary between one and three degrees per second with the rudder fully deflected in very deep water, depending on the type of vessel.

8. Drift angle

This increases with the rudder-deflection angle and depth of water available but is practically independent from speed. The drift angle at the vessel's centre of gravity for 35° rudder-deflection angles and very deep water generally varies between 5° and 10º, but may exceptionally reach values of 15° to 20°.

9. Stern swing in turning

Figure 6.02 shows how the radius of curvature of the path followed by the stern is somewhat larger than that of path followed by the centre of gravity, which by definition is the turning circle and, as a result, the stern will separate more from that curve the larger the drift angle within the arc is. When manoeuvring in restricted waters and in the vicinity of obstacles, shallow waters or other vessels, it is very important to take that motion, called stern swing into accountas well as that that end of the vessel sweeps the water more outwards of the turning circle the smaller the tactical diameter is, measured in number of ship lengths.

This fact must be borne in mind when plotting beforehand the lane route the vessel will take in restricted waters. A typical example occurs when a large amplitude turn has to be effected to enter port in order to pass between two breakwaters or take the first two buoys in the approach channel. In this case, if possible, performing that manoeuvre with a large rudder-deflection should be avoided e not to perform that manoeuvre with a large rudder angle so as to prevent the hazard caused by the stern swing.

10. Effect of a single propeller in turning

In single, right-hand pitch propeller vessels where the action of the lateral force slightly tends to take the bow to port in headway motion, it is usual to find the turning circle with the rudder deflected to that side with a diameter around 10% less than that for starboard, for similar conditions of speed and rudder-deflection angle. If the propeller has left-hand pitch, the contrary occurs, i.e., the turning circle made with rudder deflected to port has somewhat greater dimensions.

11. Turning circles of twin-screw vessels

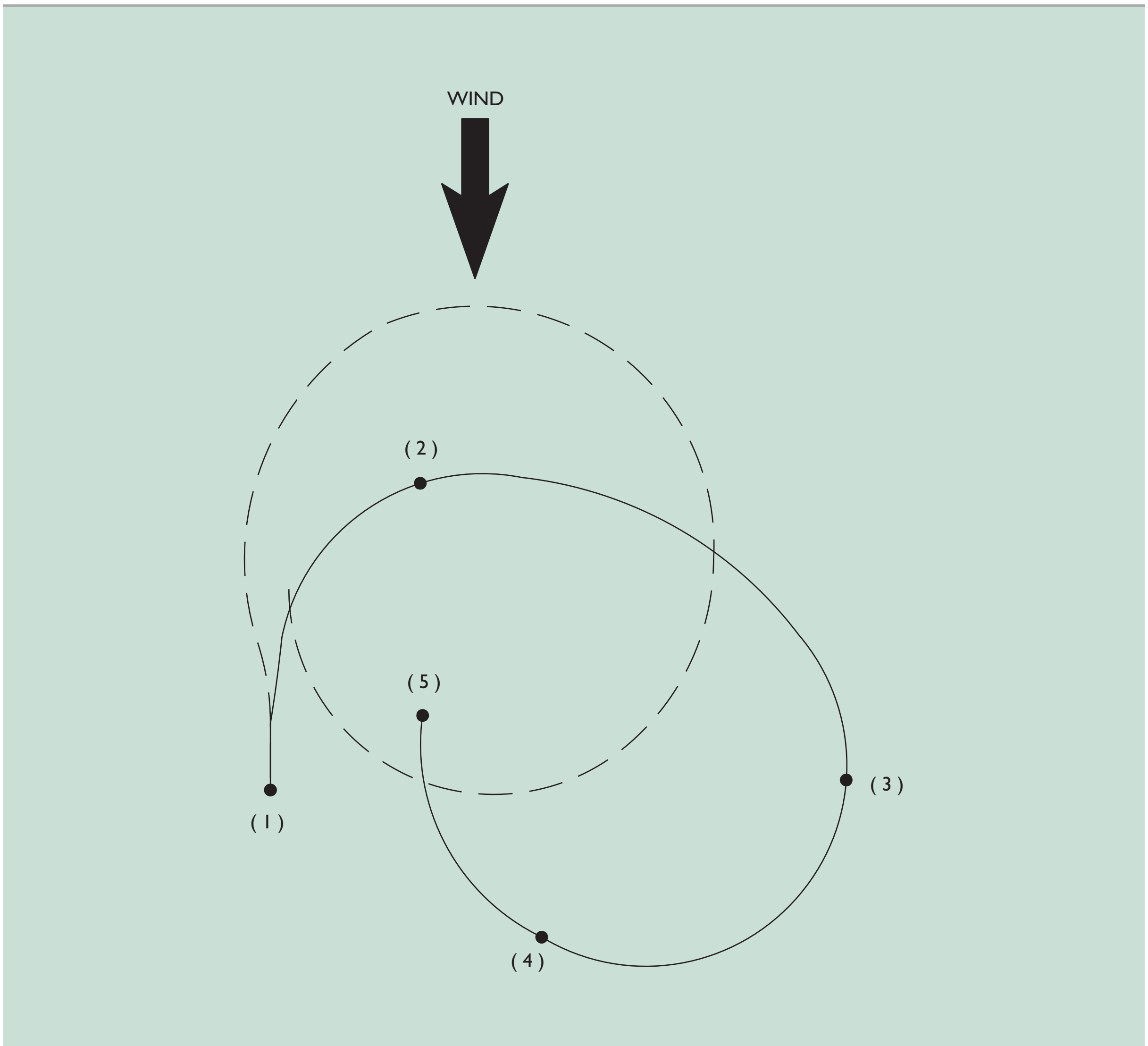
Turning circles described by twin-screw vessels under similar conditions of speed and rudder deflected to each side are symmetrical to each other and have forms similar to those already discussed above.

If the speed of the screw on the turning side is reversed during the turn, the resulting circle is quite different, but the differences in the first quadrant are not highly noticeable. The vessel's speed is drastically reduced by 70 or 80% in comparison to that it would maintain should it continue with both engines ahead, and the time employed to turn 180° increases. With respect to the turning circle's dimensions, the effect of turning under these conditions is normally to reduce the tactical diameter, Generally the advance remains unaffected.

12. Wind effects on the turning circle

The wind deforms the typical turning circle and the modification it undergoes depends on the wind force and direction with respect to the vessel's initial heading before commencing to turn. The shape of the resulting curve varies according to the type of vessel being considered and the intensity and direction of the wind action, because of the fact that the leeway and transfer are not uniform during the whole turning and, therefore, the vessel's angular turning speed accelerates or slows down according to the wind's angle of incidence with respect to the centreline plane. Assuming that the initial heading has a bow wind (see fig. 6.04), the following phases occur:

Figure 6.04. ***Effect of a bow wind on the turning circle***



- When fully deflecting the rudder (1), the vessel veers quickly because it has a great facility for bearing down to the wind until reaching the balance position in making headway, in (2).

- Whilst receiving the wind beam-on to on-the-quarter, there exists a difficulty in continuing to bear down to the wind; the angular speed diminishes and this causes an elongation of the circle in the direction perpendicular to the wind, between (2) and (3).

- From (3) to (4), the tendency to luff facilitates the veering and increases the angular speed of rotation.

- From (4) to (5), there are difficulties in continuing to luff from the moment the vessel reaches the equilibrium position making headway, particularly in small, low powered boats.

If the vessel continues the motion maintaining the rudder-deflection angle, the process is repeated in the subsequent circles and a corkscrew path is originated displaced in the average direction of drift caused by the wind action.

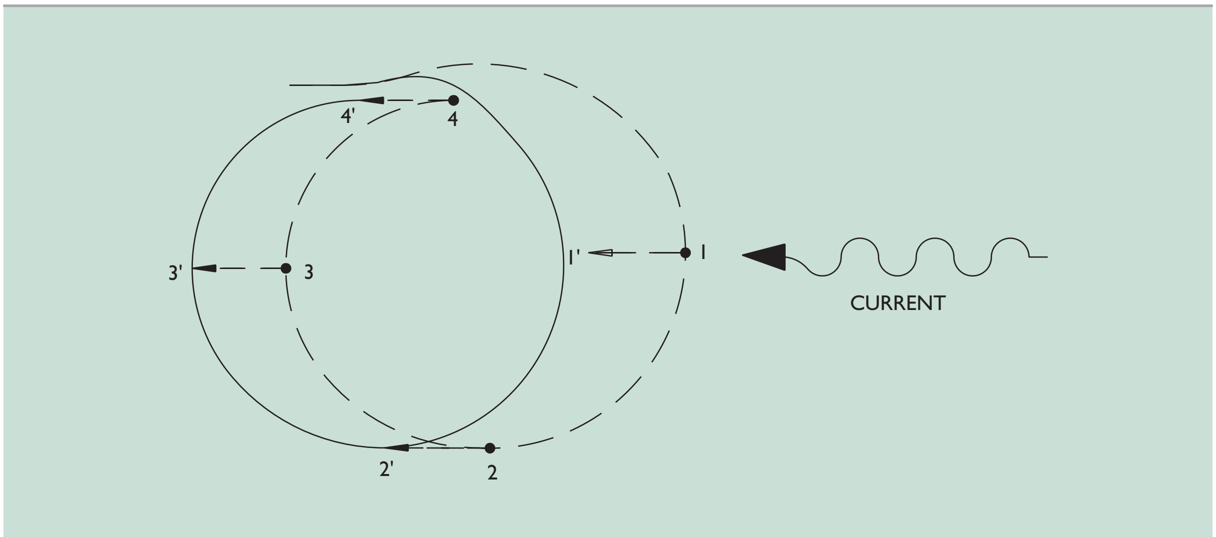
13. Effects of the current on the turning circle

When a vessel is turning on mass of water moving at a steady speed, its turning circle keeps the typical shape on the water surface, but is deformed with respect to the seabed, elongating in the direction of the current flow (see figure 6.05).

The current may sometimes take the ship to a position quite far from the place it began to turn. The figure shows how points 1, 2, 3 and 4 shift in the direction in which the current is pushing until they occupy positions 1', 2', 3' and 4'. The shift they undergo is proportional to the current's velocity and the time interval in which the current acted in each case.

If the vessel continues the motion maintaining the rudder-deflection angle, the process is repeated in the subsequent circles and a corkscrew path is originated displaced in the direction in which the current acts.

Figure 6.05. Effect of a current on the turning circle



6.2.5. Determining a vessel's turning circle

For any given vessel, turning diagrams for different rudder–deflection angles and normal speeds are essential in order to analyse its manouevring.

Such diagrams are generally drawn up on the basis of very precise, complete tests performed with the first vessel of a class, before being commissioned. Despite this, as there may be differences even between similar vessels, it is very usual to subject every new ship, or a ship that has undergone modifications, to a broad series of turning tests, not only to verify the data available but also to understand its behaviour under various conditions.

Should the turning circles of the vessels being analysed be not available, their approximate mean dimensions may be established using the diagrams shown in figures 6.06, 6.07 and 6.08. It is determined the advance, transfer for a 90° change in heading and the diameter of the steady turning circle for flat plate keel, fully loaded ships sailing in water depths of more than 5 times the vessel's draught, with no wind, waves or currents, as a function of the ship's block coefficient (C_b), length between perpendiculars (L_{pp}), the rudder-deflection angle (α_T) and the rudder factor F, which is calculated by the expression:

$$F_t = \frac{S_t}{L_{pp} \cdot D}$$

where:

S_t = Rudder blade area (see section 3.4.2).
L_{pp} = Vessel's length between perpendiculars
D = Vessel's draught at full load.

In using the above mentioned diagrams, rudder-dflection angles larger than 35° will never be used. Should the foregoing values need to be known for other water depths equal to or less than 5 times the vessel's draught, the values obtained in the tables will be multiplied by 1.25 for water depths 1.5 times the vessel's draught and by 1.75 for water depths 1.2 times the vessel's draught, and linearly interpolated for intermediate values.

As an indication, figure 6.09 gives the mean and maximum dimensions of the turning circle for loaded bulk carriers and oil tankers (with a high block coefficient) sailing in water depths greater than 5 times their draught, with no wind, waves or currents and at service speed, even though the variations are not significant for other speeds as was mentioned before.

Figure 6.06. Advance of the turning circle for a 90° change in headling. Fully loaded vessels in water depths ≥ 5 x the vessel´s draught

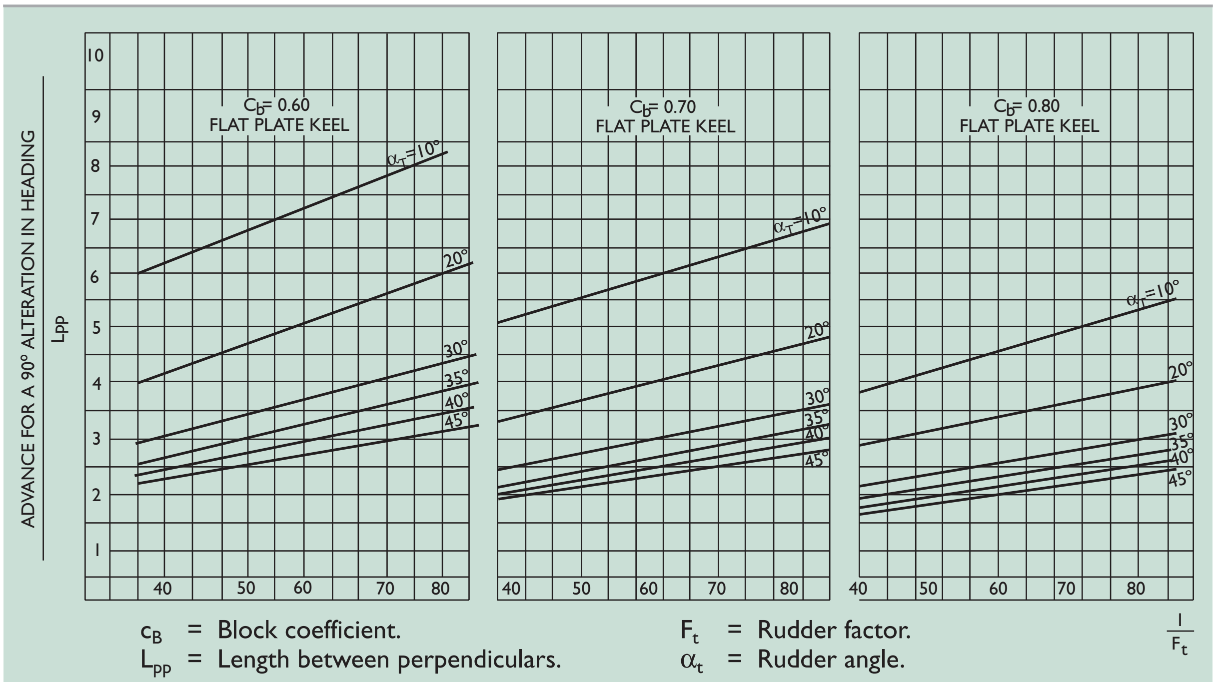
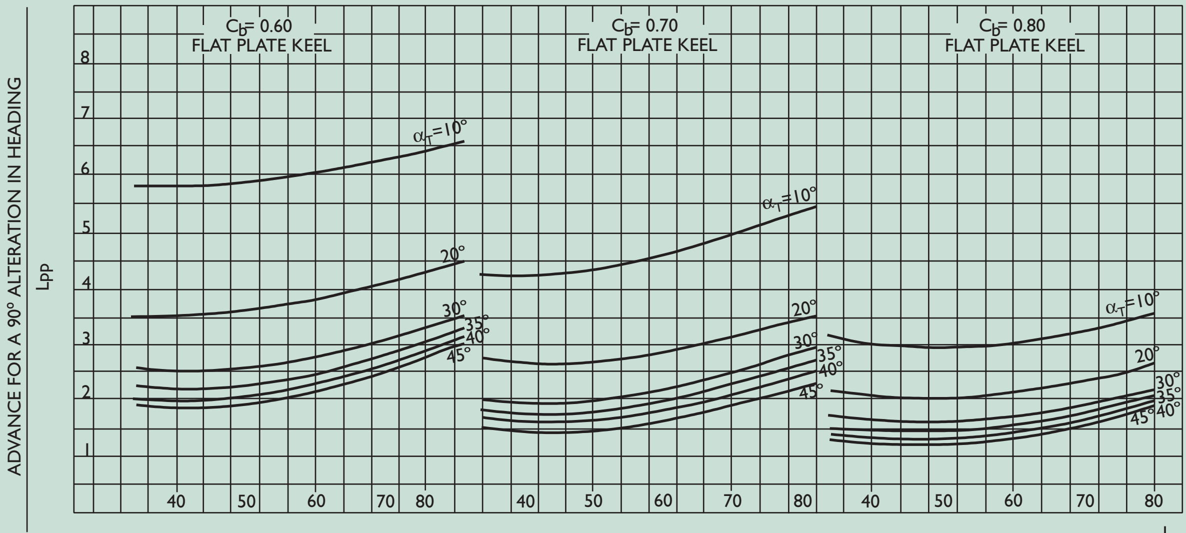
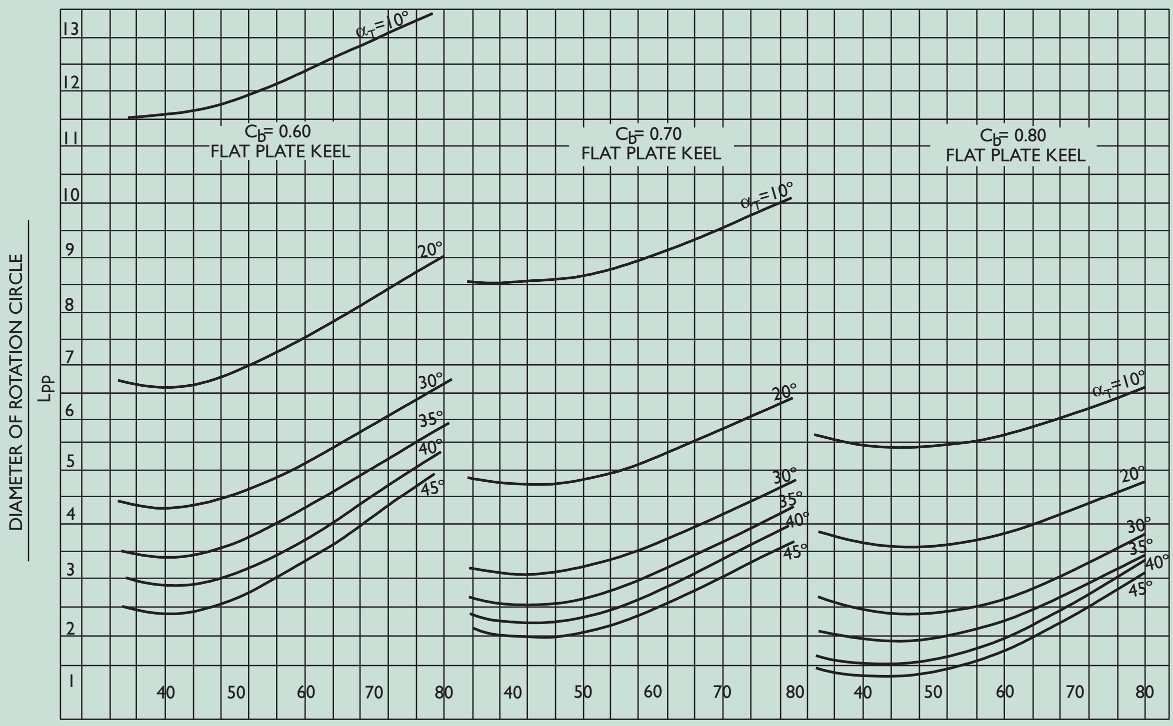


Figure 6.07. Lateral deviation (transfer) of the turning circle for a 90° change in headling. Fully loaded vessels in water depths ≥ 5 x the vessel´s draught



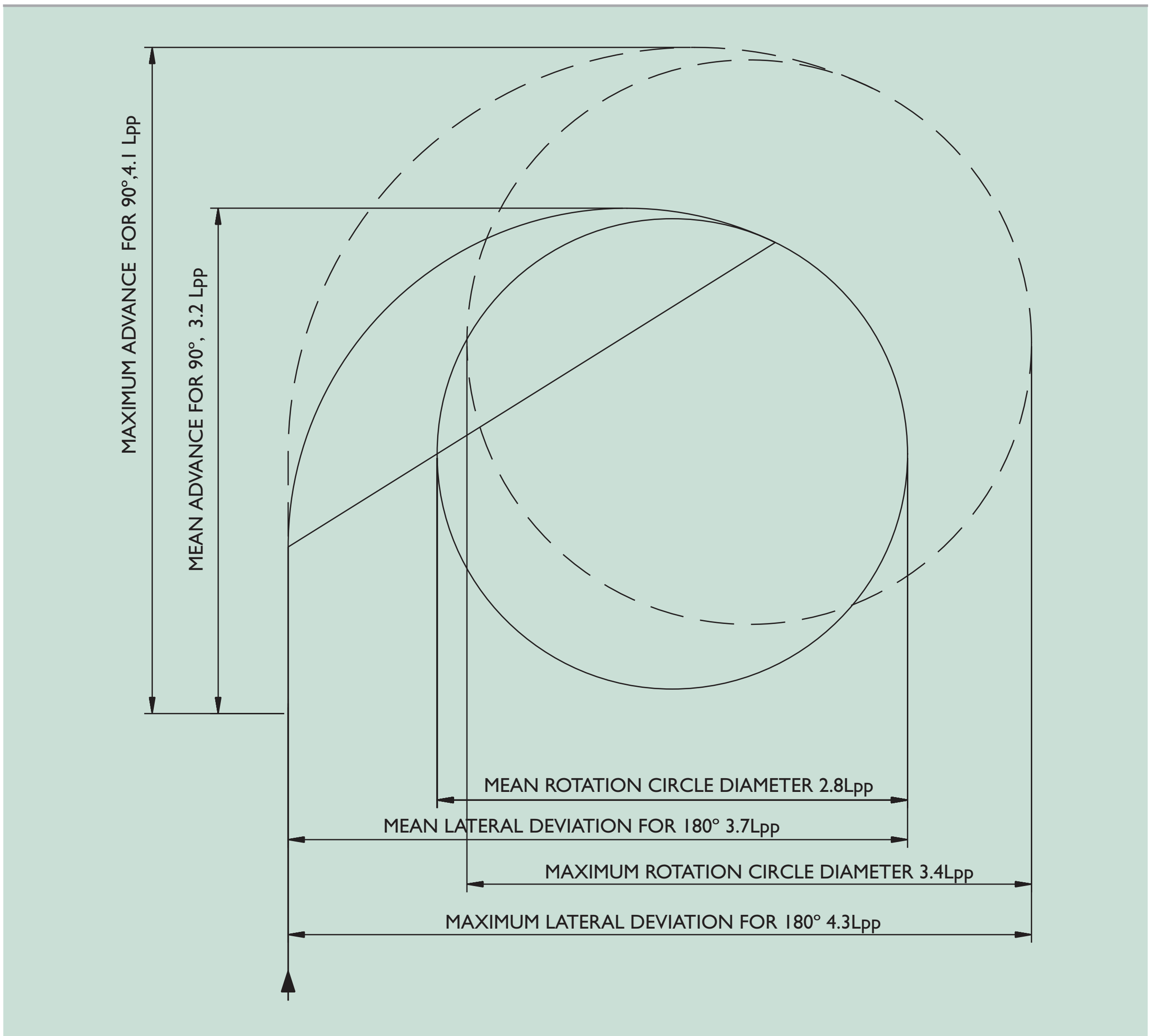
c_B = Block coefficient.
L_{pp} = Length between perpendiculars.
F_t = Rudder factor.
α_t = Rudder angle.

Figure 6.08. Turning circle diameter for fully loaded vessel. In water depths vessel´s draught



c_B = Block coefficient. F_t = Rudder factor.
L_{pp} = Length between perpendiculars. α_t = Rudder angle.

Figure 6.09. ***Typical turning circles***



The vessel´s lateral heading deviation towards starboard occurring in the initial phase is not shown in order to simplify the figure.

6.3. NATURAL AND FORCED EXTINCTION OF A VESSEL HEADWAY (SHIP STOPPING)

6.3.1. Definition and influencing factors

6.3.1.1. The natural or forced headway extinction of a vessel is the manoeuvre performed to stop the ship. If this process is carried out by stopping the engine, it would be natural extinction. If the propeller thrust direction is changed to reverse, this would be forced extinction, which is a more frequent case.

The analysis of the forces generated on the vessel and their effects are shown in Figure 6.10 for a forced headway extinction process. Before the manoeuvring phase commences and assuming a staright-line, steady motion, position (1) in the figure, the only forces acting on the vessel are the propeller thrust «T_p» and resistance to advance «R_a» which will be equal and opposite in direction. When the stopping manoeuvre is being undertaken, the propeller thrust will be null in the case of natural headway extinction or opposed to the movement in the case of forced extinction, position (2) in the figure, with which in both cases, a variable decelerated motion will be generated in which resistance to advance will also be diminishing as the vessel's speed reduces, and the forces will be balanced with the inertia force «F_i» caused by the deceleration acting on the vessel. Should the manoeuvre be carried out following a curved path, the conceptual scheme persists, even though the system of forces which would be present in the process would be more complex because of the participation of all forces associated to the curvilinear motion. Amongst other consequences they produce a braking effect with which the vessel's head reach is shortened.

Assuming a single-screw vessel stopping on a preset path, the transverse component of the force «T_{PT}» generated in the propeller increases as the manoeuvre progresses (see section 3.3.2.). This may be offset by rudder action «P_T», position (2) in the figure, and the vessel may therefore keep to the path planned. However, at the end of the stopping manoeuvre, the rudder's effectiveness is very much reduced and the transverse component of the force generated in the propeller would be unbalanced. A turning moment would also occur tending to move the vessel off its path. This, in turn, causes the Resistance to advance and the inertia Force to move from the centreline plane, position (3) in the figure, with the result that the vessel's centre of gravity turns to starboard of the initial path and the vessel's centreline plane takes up an angle «a» with respect to such path. This situation keeps varying until the manoeuvre ends. In the case of vessels with twin screws rotating in opposite directions, this effect is offset and the vessel will be able to keep to the path planned without deviating.

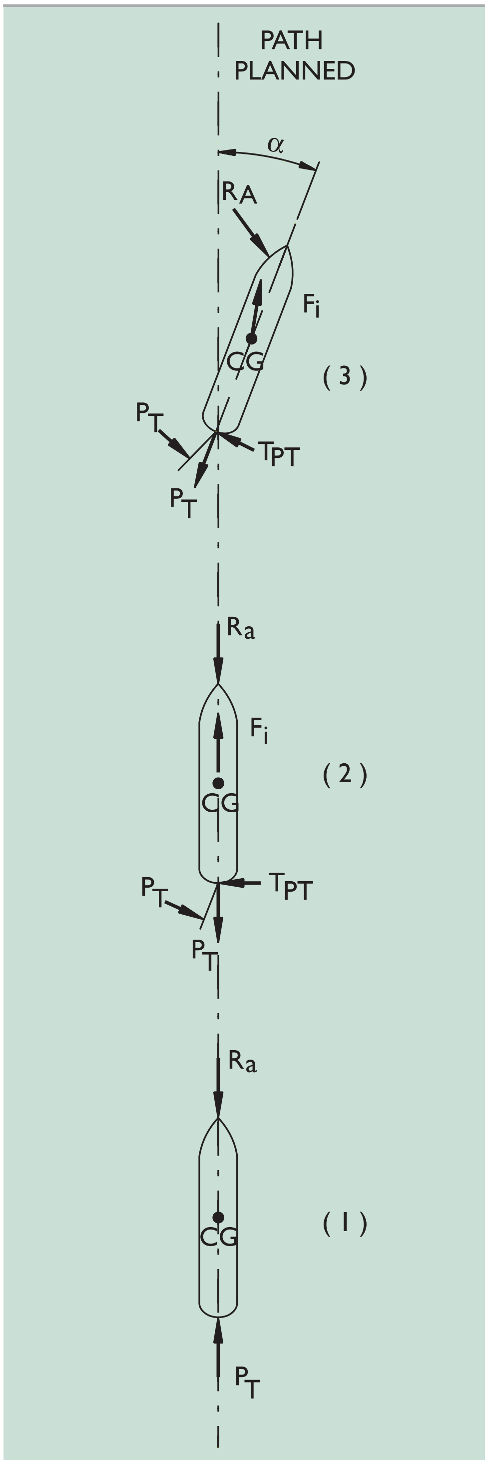
Should there be winds, waves or currents during the stopping manoeuvre, drifting or vessel motions caused by these actions which will be particularly significant in the final stage of the stopping manoeuvre, when the vessel can almost no longer be steered, must be taken into account.

6.3.1.2. The distance a vessel making headway runs (head reach) when naturally stopping after shutting down its engines until it is completely stopped basically depends on the following factors: its initial speed, its displacement, its load condition, the form and roughness of its underwater hull, water depth, the effects of wind, sea and currents and its propulsion system.

The most important factor is displacement and it can be confirmed that, with all other conditions being equal, the largest vessel keeps its headway longest. Similarly, for a given vessel and at the same initial speed, when loaded, it travels a greater distance till stopping than when it has less draught or is completely in ballast. In the latter case, it may happen that the distance covered is 1/2 or 1/3 of that when fully loaded. Between two vessels with similar displacement and dimensions, the one with finer lines keeps its headway longer than the one with fuller lines. Moreover, a vessel which has just being dry docked and has its bottom clean will run a greater distance than when its underwater hull is covered with fouling.

Shallow water causes a major braking effect by increasing resistance to advance, which is particularly shown in with large vessels when being handled in a port's restricted waters with little underkeel clearance.

Figure 6.10. **Forces acting in the forced extinction of a vessel's headway**



The distance and time which takes a certain vessel to completely stop when stopping its engines are experimentally determined for different initial speeds under calm sea conditions with no wind or current in a place free of maritime traffic and no depth limitations. The ideal thing is to calculate them on measured bases or miles, by making two measurements in opposite directions and averaging the results. The data determined correspond to natural headway extinction and are of little practical use, since vessels normally use the forced headway extinction by reversing engines.

The head reach in forced headway extinction may be experimentally determined by making measurements in manoeuvres where the propulsion is reversed under similar engine conditions as those corresponding to the actual case, and all ships should have their behaviour characteristics available in such cases. Nevertheless, the head reach may be calculated by mathematical procedures as the following section shows, developed for stopping in straight-line runs or by scale model testing or simulator studies.

Performing manoeuvres in curves or other special zig-zag manoeuvres, etc., an analysis which is beyond the scope of these Recommendations, may reduce these distances, though with more significant transfer in relation to the vessel's forward direction.

6.3.1.3. Determining the maximum transfers occurring at the vessel's worse point (the sum of those produced by the centre of gravity's transfer deviation plus those due to the yaw angle) in the final stage of the stopping manoeuvre is more complex since it depends on the vessel's inertia conditions in the manoeuvre's final phase. The following conclusions applied to stopping manoeuvres in a straight-line run may be drawn from a simulator study of multiple manoeuvres:

- The vessel falls in the last stage of the manoeuvre when its speed is less than 1.5 m/sec. Deviations in the vessel's path are not significant one ship length away from the final manoeuvring point.
- Vessel falls are very heterogeneous, depending on the type of ship and its manoeuvring capability, without exceeding one ship length, assuming there is no wind, waves or currents.
- The falling is greater the deeper the existing water depth.
- The fall increases with the time the vessel employs in stopping and, in general, is greater when the ship's initial speed is higher and when the reverse engine speed is lower.
- The action of transverse bow thrusters influences the final metres of the manoeuvre when the vessel's speed is very low.

Should the stopping manoeuvre be carried out on curved paths, the vessel's behaviour is more difficult to forecast since other forces associated to the curvilinear motion are involved. It may be generally concluded from a simulator study of manoeuvres that the aforementioned effects for manoeuvres in a straight-line run are strengthened and thus the vessel's fall begins to manifest when the velocity is less than 2.0 m/sec and at a distance of 1.5 ship lengths from the manoeuvre's final point. Fallings are more heterogeneous and may exceed one ship length and it is therefore recommended that stopping manoeuvres not be effected on curved runs unless specific studies are made in this respect.

6.3.2. Head reach assessment

Two fundamental parameters should be taken into account for determining stopping distances in straight-line sailing when the manoeuvre is carried out without the aid of tugs holding on spring: the vessel's resistance to advance «R_a» and the propeller's thrust in reverse «T_p». At high speeds, the vessel's resistance to advance predominates whilst for normal speeds in basins and fairways, the propeller's thrust in reverse is more important.

The head reach for the Navigation Channels and Harbour Basins which are the subject of this ROM in which the vessel's speed when commencing the stopping manoeuvre does not exceed 6 m/sec (≈ 12 knots) can be calculated by the simplified Chase method, with the following expression:

$$D_p = \frac{1}{2} \cdot \frac{\Delta}{g} C_m \cdot V_o^2 \left[1 - 0.32 \frac{R_{ao}}{T_p} \right] \cdot \frac{1}{T_p} + \frac{t_{ri} \cdot V_o}{2}$$

where:

D_p = Head Reach

Δ = Vessel's displacement expressed by weight.

g = Acceleration of gravity

C_m = Coefficient of hydrodynamic mass which is the quotient between the total mass of the system in motion (vessel + entrained water moving with it) and the vessel's mass. A value of C_m = 1.08 may be taken for this type of motion.

V_0 = Vessel's absolute speed when initiating the stopping manoeuvre.

R_{ao} = Vessel's resistance to advance when initiating the stopping manoeuvre.

T_p = Thrust of the propeller in reverse during the stopping manoeuvre. Should this thrust not be known, an estimate may be made assuming that the propeller's thrust in «full astern» engine mode has a value equal to 2/3 of the propeller's thrust with engines ahead at service speed, which can be evaluated with the criteria given in section 3.3.1. This propeller thrust in «full astern» engine mode will only be used for calculating head reach in emergency manoeuvres. It will be assumed that engine rate is «medium» astern for calculating the head reach in normal manoeuvring. In this case the propeller's thrust in reverse may be evaluated at 1/3 of the its thrust with engines ahead at service speed.

t_{ri} = Reaction time necessary for reversing the propeller's thrust from the moment when the stopping manoeuvre commences until value T_p is reached in reverse, for which a value of 20 sec will be taken in the absence of more specific data.

The foregoing expression is valid when the two conditions following are fulfilled:

$$T_p \geq R_{ao}$$

$$\frac{R_{ao} \cdot g \cdot t_{ri}}{\Delta \cdot C_m \cdot V_o} \leq 0.6$$

such conditions are usually fulfilled in Areas which are the subject of this ROM.

Should the stopping manoeuvre be carried out with the aid of tugs holding on spring, the Head Reach may be calculated with the same expression given above, adding the longitudinal component of the horizontal forces «F_{Ri}» resulting from the action of the tug boats acting on the vessel to the propeller's thrust «T_p». It is pointed out that in order to be able to consider this aid from tugs, they must be the suitable type to be able to take the tow rope with from the vessel underway and then their propulsion system to be reversed to be able to apply a spring pull to the vessel in an opposite direction to the tug boat's headway.

6.4. MANOEUVRING STUDIES

It is advisable to carry out the study for solving a certain manoeuvring problem from which the subsequent harbour basin requirements derive in three phases:

- Study of all factors influencing the problem.
- Propose all possible solutions and choose those feasible and acceptable.
- Study of emergency situations.

a) FIRST PHASE: STUDY OF THE RAISED MANOEUVRING PROBLEM

This phase establishes and analyses all the factors affecting the mnoeuvre or which may influence it, with the purpose of ensuring the broadest and most complete knowledge of the problem to be solved. All the important aspects related to the manoeuvre to be performed must be studied and this involves consulting the information available in sailing directions, lists of lighthouses and maritime markings, tide and current tables and charts and port drawings, local regulations, etc. The environmental conditions existing in the area and those for the admissible operating limit conditions must also be taken into account. The knowledge gathered about the vessel being handled, particularly regarding its turning data, length, draughts, steering, inertia, etc., must be applied.

b) SECOND PHASE: CHOOSING FEASIBLE AND ACCEPTABLE MANOEUVRES

Once the foregoing step has been fulfilled, different possible solutions to the manoeuvring problem raised may be conceived. These solutions must be subjected to a dual test of feasibility and acceptability. A manoeuvre is assumed feasible when it has reasonable probabilities of being successfully performed taking suitable advantage both of the vessel's elements and external ones which may provide assistance. Acceptability refers to the manoeuvre's consequences from the standpoint of safety, not only the safety of the vessel being handled, but also that of others close by which may possibly be affected by a false manoeuvre of the vessel or the facilities present at the site.

It may happen that there is more than one feasible and acceptable solution for the same manoeuvring problem. Even though the handler will foreseeably always choose the best by comparing their respective advantages and disadvantages, they must all be considered to the effects of dimensioning the harbour basin area in order to work out the area envelope, unless it is decided to eliminate some of the feasible manoeuvres in which case such limitation must be incorporated into the port's Operating regulations.

c) THIRD PHASE: STUDY OF EMERGENCY SITUATIONS

Once feasible and acceptable manoeuvres have been analysed and defined, emergency cases which may arise must be analysed, amongst which can be mentioned: manoeuvring errors, failures in the vessel's systems or the auxiliary media (mooring ropes, tug boats, etc.), changes in the actual environmental conditions when the manoeuvre begins or even those caused by agents external to the manoeuvring, such as the need to make emergency departures caused by incidents or accidents in facilities close to the ship.

It must be verified that the manoeuvres are still feasible without causing unacceptable risk situations in all these cases; however, stricter safety clearances or margins may be accepted than in normal operating cases. This consideration is particularly important when navigating in restricted waters, since the occurrence of an incident or emergency situation may provoke highly risky situations. A study of these emergency situations will normally lead to an improvement in operating procedures, reinforcing the measures contributing towards increasing safety and eliminating manoeuvres bearing unacceptable risks with them.

As mentioned before, Annex I to this ROM analyses a series of manoeuvres usually performed in navigation although it is not feasible to address all those that may occur since in practice there are no two equal manoeuvres, not even with the same vessel and Harbour Basin, since the conditions under which they must be performed suffer an infinite amount of changes.

Part VII

Cross section requirements

CROSS SECTION REQUIREMENTS

Part VII

7.1. SCOPE OF THE CHAPTER

7.1.1. The water depth and above water clearances necessary in different Navigation Channels and Harbour Basins may vary and each is established taking into account the facility's useful lifetime, the conditions of operability accepted for it, vessel traffic characteristics and distribution, construction and maintenance costs and other aspects as indicated in chapter 2. That is to say, the design of the cross section will not be performed in a determinist way as a function of a single parameter, for example, a vessel's draught, but all the aspects mentioned shall be taken into account. The water depth and above water clearance adopted shall allow vessels to navigate, manoeuvre, stay and load or unload during the whole time under the conditions of operatibility established for the facility in conditions of safety for all vessels using the said Navigation Channels and Harbour Basins.

The procedure for determining water depths and above water clearances follows the general criteria established in section 2.5, i.e.

- Calculate areas swept by vessels which depend, on the one hand, on the vessel and on factors affecting its motions and, on the other, on the water level and factors affecting its variability.
- Increase these areas by Safety Margins.
- Compare these requirements for area with those available or demandable at the site.

7.1.2. In addition to these two cases and for coherence reasons, this section includes Recommendations for the quay crowning level where specific criteria are established since in this case, we are not dealing with water areas or above water clearances to be left free for vessel navigation or floatation. This chapter therefore offers criteria for determining the following dimensions:

- Navigation Channels and Harbour Basins depths, considering vessel related factors (static draughts, load distribution, dynamic trim or squat, clearances for vessel motions because of wind, waves, currents and course alterations, clearances for vessel manoeuvrability and safety, etc.) those related to the water level (astronomical tide, meteorological tide, etc.) and those depending on the seabed (bathymetry inaccuracies, sediment deposits and dredging performance tolerances).
- Clearances for bridges and other facilities crossing over the Navigation Channels (electric lines, cables, etc.), determined so that they enable vessels to navigate or stay under safe conditions.
- Quay crowning levels, taking into account conditioning factors due to water level and those deriving from vessel operation and port running requirements.

7.2. DETERMINING NAVIGATION CHANNELS AND HARBOUR BASINS WATER DEPTHS

7.2.1. Introduction

The water depth necessary in the different Navigation Channels and Harbour Basins will be determined in each case by taking the following factors into account:

- Vessel draughts and factors related to vessels which may cause some point of their hulls to reach a lower level than that for a flat plate keel under static conditions in seawater (H_1).
- The Water level considered and the factors affecting its variability (H_2), which will determine the reference plane for positioning the vessel.
- Safety margins established to prevent the vessel touching the seabed. Evaluation of these safety margins is included in the H_1 block of Factors.

Taking the foregoing factors into account will determine the minimum water depth required at the site, or nominal depth, which will require a set of seabed related factors (H_3) to be taken into account in order to be guaranteed as space available at the site as specified in section 2.5.

The first set of factors (H_1) –see fig. 7.01– integrates all those depending on the vessel, whether under static or dynamic conditions, even though motion is caused by agents external to the vessel (winds, waves, currents, etc.). Therefore, it represents the lowest level any point of the vessel can reach in relation to the mean level of water where it is located. The clearance for the safety and control of the vessel's manoeuvrability and the dimensioning's Safety Margins are integrated into this group for reasons of coherence, even though they are spaces which, under normal conditions, will never be reached by the vessel's hull. The second set of factors (H_2) provides an analysis of the tides and other variations in the mean water level (astronomical and meteorological tides, variations in river flow rates, pumping in tide-locked basins, etc.), i.e., factors which determine the reference level of the water where the vessel is located and do not generate significant differential vertical movements between different points of the vessel's hull. The third set of factors (H_3) shows only those which depend on the seabed, including bathymetry inaccuracies, sediment deposits and dredging performance tolerances.

7.2.2. General criteria

The three sets mentioned in the foregoing section do not always need to be analysed in detail. In particular, the study of factors related to water level is omitted when additional draughts are determined from the lowest level the water could reach (LAT corrected for meteorological variations in the water level in Areas with fluvial currents, minimum operating levels of tide-locked basins, etc.). This hypothesis is equivalent to assuming that vessels can operate under any existing water level conditions. This assumption is usual in cases where there are small tidal ranges or other small variations in water level. A study of this set of factors is recommended for cases where the variation in water level is important since significant savings may be made in dredging requirements, with only small losses in operability.

The set of factors related to the vessel should normally be analysed in all cases. It must be pointed out that the values obtained largely depend on limit operating conditions as established for different vessel manoeuvres which are not really representative of the maritime environment existing in the area. Aaccording to this, avoiding high values is recommended, especially those related to waves, since, in accepting small percentages of downtime in the Area considered because of adverse weather conditions, significant saving can be made in dredging requirements.

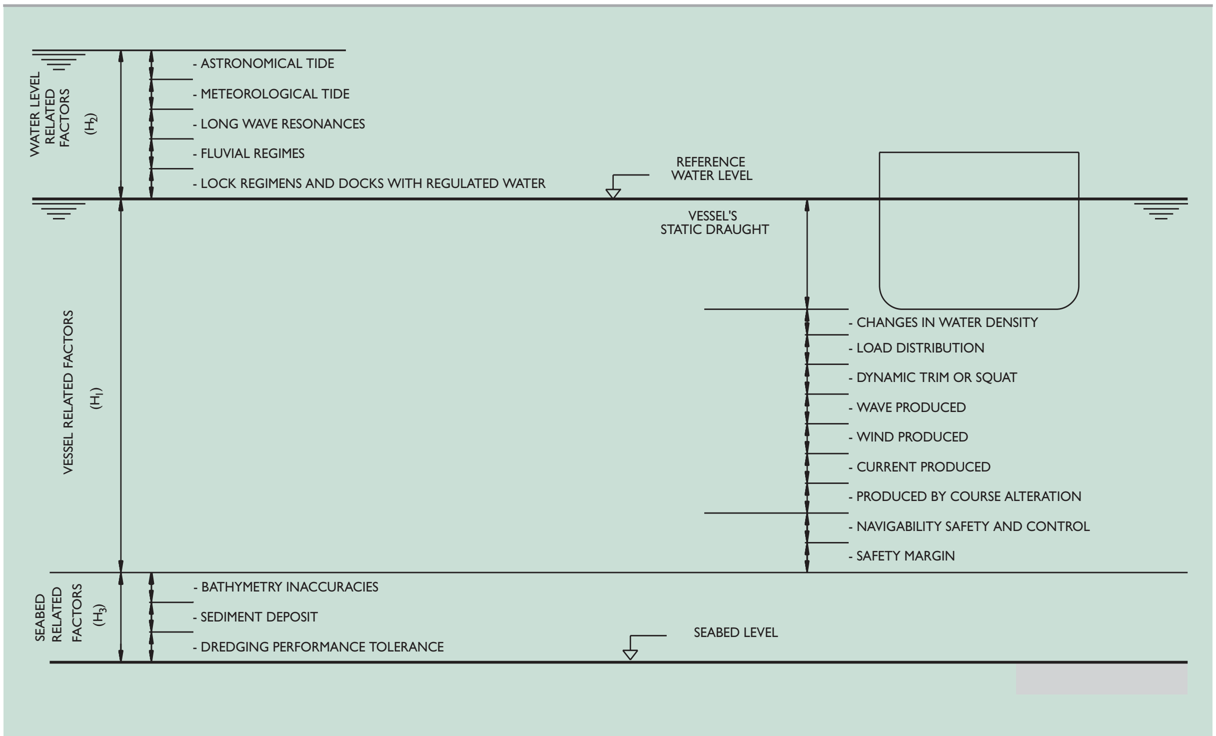
Finally, the third block of factors related to the seabed is normally considered only when carrying out dredging projects but not when evaluating a vessel's navigation through controlled depth areas in which a known seabed level where seabed related factors should already have been worked out is used, as shown schematically in fig. 7.10.

7.2.3. Vessel related factors

7.2.3.1. Static draught

The static draught of the vessel (D_e) will be determined for seawater floatation and will correspond to that with the greatest draught which can operate in the facility for each type of vessel (oil tankers, bulk carriers, etc.), according to the operating conditions established for the facility. Should the study be carried out considering the fleet as divided into categories, the most unfavourable of each category will be considered. In the absence of more specific data, it will be assumed that the vessel with the deepest draught will be that with largest displacement for each type of vessel. Since other parameters apart from the vessel's draught take part in the process for determining water depths in Navigation Channels and Harbour Basins, the most unfavourable cases for the different types of vessel that may operate in the Area must be analysed. Generally, it will not be valid to simplify the process by analysing only a single vessel with the deepest draught.

Figure 7.01. ***Factors taking part in determining water depths in navigation channels and harbour basins***



In general, the analysis will be performed assuming that vessels will sometimes operate fully loaded, except in the case of shipyards or ship repair facilities where the design condition will correspond to lightship or vessels in ballast according to the formers' operational criteria. Vessels always operating partially loaded may be considered as an exception for quays and berthings, only in the case whereby operating rules accurately define the criteria and procedures to be followed to guarantee safety.

Should vessel operations be addressed with draughts greater than the full load one (listing vessels, damaged vessels, etc.), the possibility of using the pertinent Navigation Channel and Harbour Basin must first be appraised, and the environmental conditions (tides, winds, waves, etc.) and safety and navigation aid conditions (clearances, tugs, etc.) which would enable the necessary operations to be performed will be determined.

The dimensions and characteristics of the different types of design vessel shall be provided to the designer by the authorities or owners of the facility in accordance with the use intended. When the dimensions of the vessels are not clearly known, or lacking more precise information (Lloyd's Register), the average dimensions of fully loaded vessels given in table 3.1. may be used for designing Navigation Channels and Harbour Basins and their characteristic values may be obtained therefrom with the criteria established in section 3.1. of this ROM. The characteristic dimensions thus determined may be used both to the effects of determinist and semi-probabilistic studies, regardless of more detailed statistical analyses which might be performed in each case if uncertainty about the fleet were to so advise.

When vessels are in partial load conditions, specific curves or tables should be used to obtain the draught and displacement under these conditions although they may be approximated by empirical formulas of acknowledged validity. In the case of very full form vessels (oil tankers, ore carriers, etc.), it may be assumed that the block coefficient [displacement / length between perpendiculars x beam x draught x g_W)] remains constant under any load condition. It will be assumed for other types of vessel that the block coefficient remains constant under any load condition between 60 and 100% and may decrease up to 10% of the foregoing value for load conditions under 60% of full load.

7.2.3.2. *Changes in water density*

This concept includes a change in a vessel's draught (d_S) caused by changes in the density of the water in which it is navigating (salinity, temperature, suspended solids, etc.). Considering that vessel draughts are usually determined for the most unfavourable conditions and with seawater density, the correction should only be applied when the vessel moves from salt water to fresh water, causing increases of up to 3% in the vessel's static draught. This figure is determined assuming the sea water's specific weight as 1.03 t/m³ as compared to fresh water's 1.00 t/m³ (linear interpolation may be used for intermediate conditions). These values may be considered characteristic both to the effect of determinist and semi-probabilistic studies.

7.2.3.3. *Additional draught due to cargo distribution*

This concept includes the increase in draught (d_g) with respect to the even keel situation due to trim, heeling or deformations caused by different loading conditions. The concept does not include additional draughts due to heeling caused by irregular cargo or cargo shifts, which will be analysed as established in the third paragraph of section 7.2.3.1.

This additional draught is maximum at the stem or stern where it can be quantified for fully loaded merchant vessels as a maximum of 0.0025 L_{pp} (length between perpendiculars). This value may be reduced to 0.0015 L_{pp} for large oil tankers or bulk carriers and may be 0.0020 L_{pp} for other types of vessel. Since these values are small they may also be considered characteristic both to the effects of determinist and semi-probabilistic studies.

Partial load trim may reach values 10 times higher than the foregoing, without ever causing a draught higher than the full load one with its pertinent additional draught. Should partial load conditions be considered, the maximum additional draught accepted for cargo distribution will be incorporated into the operational criteria.

7.2.3.4. *Dynamic trim or «squat»*

7.2.3.4.1. Dynamic trim or «squat» is taken to be the additional increase in a vessel's draught (d_t) in relation to the water's static level, produced by the vessel's motion at a certain speed.

A vessel navigating in calm water causes a relative speed between the vessel and the water. This difference in speeds alters the distribution of hydrodynamic pressures around the vessel, producing the following effects:

- A drop in the water level which varies along the vessel's whole length.
- A descending vertical force acting on the vessel's hull and a moment about the horizontal transversal axis which causes a displacement of the vessel in its longitudinal symmetry plane, therefore composed of two movements:
    - A parallel, vertical descending displacement (heave)
    - A rotation about the transversal horizontal axis (pitch)

The dynamic trim or «squat» is the combination of both effects (drop of the water level and the two movements) which cause the vessel's draught to change all along its length. Dynamic trim is usually taken to be the maximum value of the additional draught and may occur at the vessel's stem or stern depending on the type of vessel. In most commercial vessels it generally happens at the stem.

7.2.3.4.2. Considerning that the dynamic trim is a function of the water's relative speed to the vessel, its value mainly depends on the geometric dimensions of the area in which the vessel is navigating. The formulas enabling squat to be calculated are generally determined for navigation in shallow water with no lateral restrictions, from which generalizations applicable for navigation in submerged channels and conventional channels have been worked out (see fig. 7.02), which cover all cases of interest for the Navigation Channels and Harbour Basins analysed in this Recommendation. Navigation in channelized water is basically affected by the water's speed of return, depending on the ratio between the main cross section of the vessel's underwater body (A_b) and the channel's cross section (A_c). For submerged channels, the equivalent area configured by the prolongation of the boundary slopes to the water surface is considered as the channel's cross section (A_c).

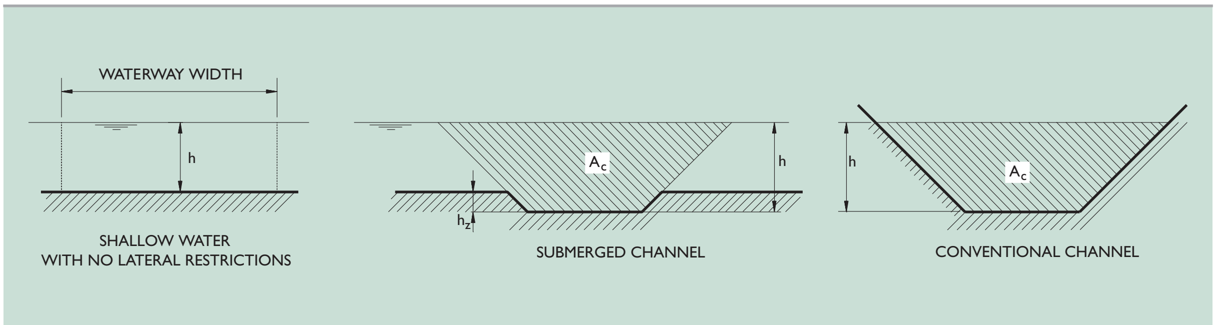
Dynamic trim or squat may be calculated by the Huus/Guliev/ICorels formula, which has the following expression:

$$d_t = 2,4 \cdot \frac{\nabla}{L_{pp}^2} \cdot \frac{F_{nh}^2}{\sqrt{1 - F_{nh}^2}} \cdot K_s$$

where:

d_t = Maximum value of dynamic trim (m).

Figure 7.02. **Typical waterway cross sections for calculating dynamic trim or «squat»**



∇ = Vessel's volume of displacement (m³).

L_{pp} = Vessel's length between perpendiculars

F_{nh} = Froude number $= \frac{V_r}{\sqrt{gh}}$ (non dimensional)

The hydrodynamic resistance to a vessel's motion depends on this Froude number. When F_{nh} approaches 1.00, resistance to motion reaches very high values, which most vessels cannot overcome with the installed horsepower. Except for special cases of fast boats, all vessels sail at speeds which do not result in F_{nh} values above 0.60/0.70 (respectively oil tankers and container ships), which figures prove to be effective vessel speed barriers. Consequently, at the same time as draught requirements are being studied, the resulting Froude numbers must be checked to be compatible with the conditions arising in each case.

V_r = Vessel's speed relative to the water, excluding local effects (m/sec.).

g = Acceleration of gravity

h = Depth of water at rest, excluding local effects (m).

K_s = Non-dimensional correction coefficient for submerged or conventional channels (see fig. 7.02) (for areas with no lateral restrictions, K_s = 1.00 will be taken). The following expressions will be used to determine it:

$$K_s = 7.45 \cdot s_l + 0.76 \quad \text{for } s_l > 0.032$$
$$K_s = 1.00 \quad \text{for } s_l \leq 0.032$$

$S_1 = \frac{A_b}{A_c} = \frac{1}{K_1}$

A_b = Area of the main cross section of the vessel's underwater body (m^2) ≈ 0.98.B.D.
B = Vessel's beam (m).
D = Vessel's draught (m).
A_c = Area of the channel's cross section located beneath the water level at rest (m^2). For submerged channels, the equivalent area configured by the prolongation of the boundary slopes to the water surface will be considered:
K_l = Correction factor, a function of and of A_b/A_c and of h_z/h (see fig. 7.03).
h_z = Depth of the trench dredged referred to the mean seabed level (m). See fig. 7.02.

7.2.3.4.3. Apart from the limitation already mentioned when analysing the Froude number, the restrictions originating in the operating rules of the Navigation Channel or Harbour Basin under consideration shall be taken into account for determining the speed V_r of the vessel relative to the water, which intervenes in the foregoing formulation. The maximum value of speed as set by the said operating rules or which may be established precisely as a consequence of the design being drafted, will be considered for determining draughts in the design phase. Should these rules consider different velocities according to vessel types and dimensions, the most unfavourable cases must be analysed. In the absence of specific criteria in this respect, maximum values of the absolute vessel speed «V» within the following margins are recommended, without Froude numbers exceeding 0.70 resulting in any case:

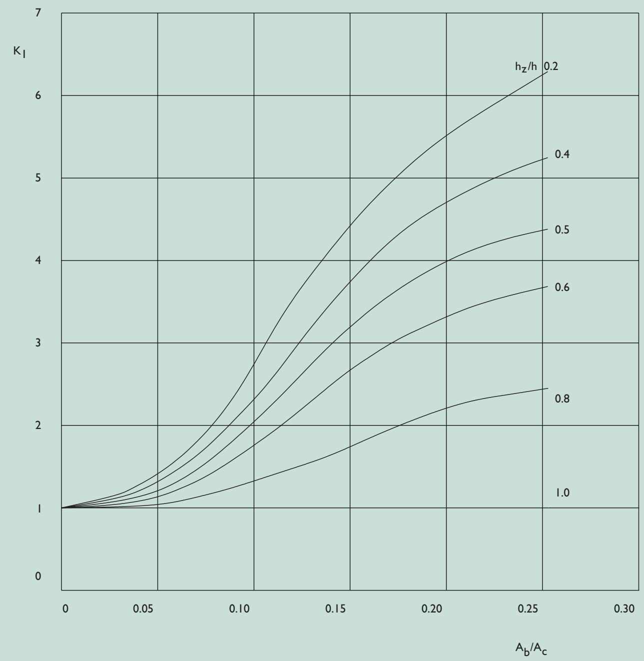
	Absolute vessel speed «V»	
	m/s	**≈ knots**
◆ Outer areas		
• Navigation through approach lanes		
Long (≥ 50 L_{pp})	4-7.5	8-15
Short(< 50 L_{pp})	4-6	8-12
• Anchorage approach navigation	1-1.5	2-3
• Approach channel navigation	3-5	6-10
• Manoeuvring Area approach navigation	2-3	4-6
• Berth (jetty) Area approach navigation	1-1.5	2-3
◆ Passing harbour entrances	2-4	4-8
◆ Inner areas		
• Anchorage approach navigation	1-1.5	2-3
• Channel navigation	3-5	6-10
• Manoeuvring Area approach navigation	2-3	4-6
• Basin, piers and berthings approach navigation	1-1,5	2-3

All these recommended speeds relate to navigation as defined in each of the headings and, therefore, all the hypotheses which may arise in each case will have to be considered in order to carry out a correct study (e.g., vessels navigating through a channel may be not only vessels in transit towards inner areas but also towards berthings located in the same channel).

It must be pointed out that these recommended speeds are absolute «V» whilst speed «V_r» appearing in the formulation is the vessel's speed relative to the water such that the water's velocity will have to be taken into account in the case whereby fluvial currents, tidal currents, etc. are present.

The squat effect may be assumed as negligible for navigation in the final phase of the approach and berthing manoeuvres or beginning of departure manoeuvres where speed is less than 1 m/sec and tug boat assistance is normally used.

Figure 7.03. **Correction factor for dynamic trim or «squat» calculation**



7.2.3.4.4. The foregoing dynamic trim calculation formula does not take into account all the circumstances which may arise, as there are currently no global studies available covering all aspects so its use is recommended both for determinist and semi-probabilistic studies. The most usual circumstances to arise which are not covered by the formulation are as follows:

- *Vessel overtaking and passing.* The flow of water around the vessel is affected by modifying the dynamic trim, the value of which may be increased up to 50-100%. If vessel overtaking or passing happens only occasionally, the speed of the vessels is normally reduced in order not to increase draught requirements. If these manoeuvres were a normal occurrence, an increase in dynamic trim should be considered.

- *Off centre navigation.* A vessel's motion outside a channel's axis and the proximity of a slope changes the hydraulic regime around the vessel, increasing the dynamic trim. The effect is negligible if the distance from the slopes is greater than 2 or 3 vessel beams (depending on the Froude number: the higher the Froude number, the greater the separation required). In a similar way, if being off centre is occasional, the vessel's speed is normally reduced, whilst studies need to be made in greater detail if manoeuvres are the norm.

- *Geometric configuration of the seabed.* The calculation procedure as described above presupposes that the water depth available and the vessel's speed remain constant. If the water depth gradually decreases, as normally happens when approaching port, the water resistance increases, the vessel's speed diminishes and the dynamic trim phenomenon is reduced. However, if the water depth reduces rapidly and vessels enter at high speeds in this area, the dynamic trim significantly increases and violent vibrations occur. A reduction in the vessel's speed is recommended in these cases so that the Froude number does not exceed 0.50.

- *Muddy seabeds.* A layer of fluidified mud on the seabed generally causes a reduction in the dynamic trim due to variations in the hydraulic regime of the flow round the vessel and to the variation in floatability conditions. Exceptionally high dynamic trim values may arise if the vessel is moving over not very dense mud bottom and if the navigation speed exceeds 4 m/sec (≈ 8 knots).

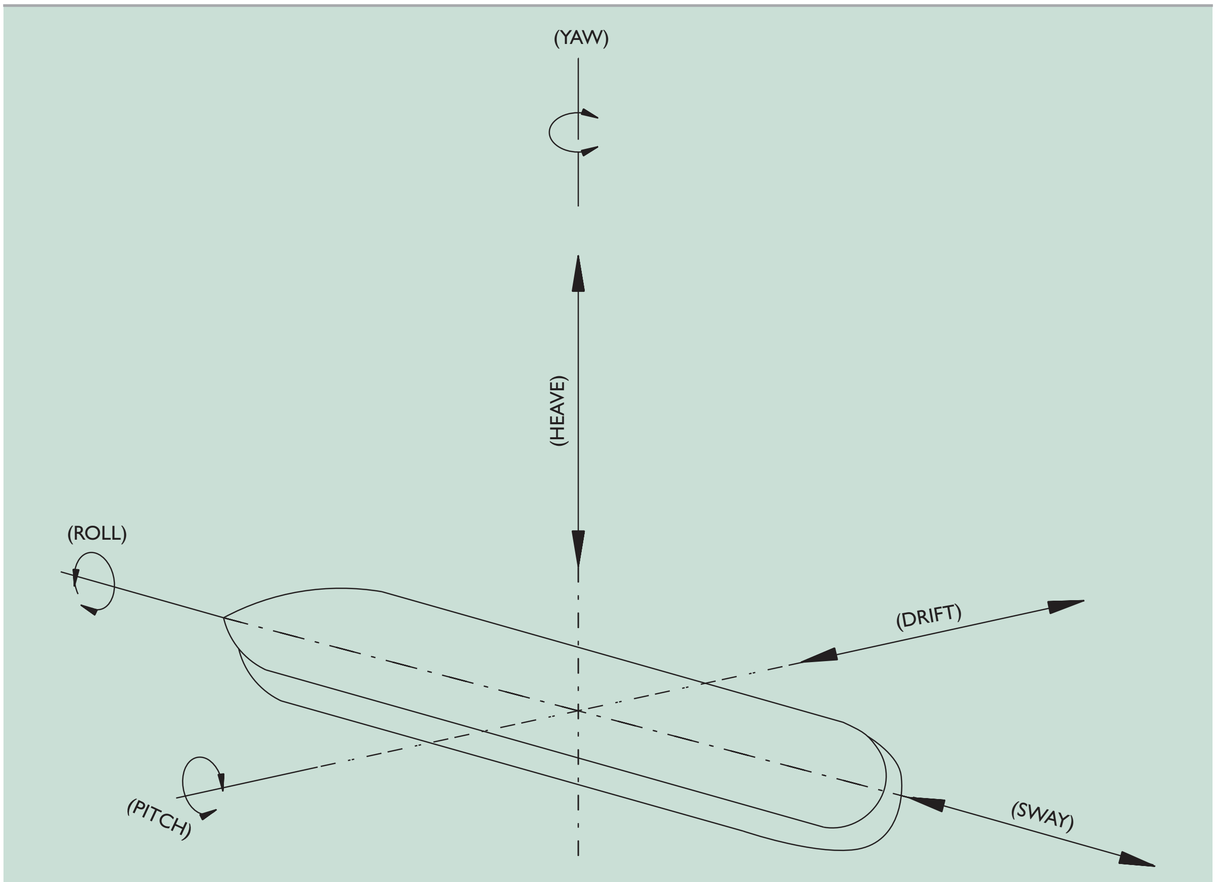
- *Navigation on a bend or with a drift angle*. No current research is reported that enables the importance of these cases be quantified. To practical effects, calculation for navigation in straight stretches with no drift angle shall be kept to and should dynamic trim be more unfavourable, the vessel's speed will be reduced.

7.2.3.5. Motions caused by waves

7.2.3.5.1. The effects of wave action on vessels were analysed generally in section 4.3. This section specifically examines a vessel's vertical motions - heave, pitch and roll (see fig. 7.04) caused by wave action which may cause a considerable increase (d_W) in the vessel's draught requirements. The magnitude of these vertical motions depends on wave parameters (height, period and direction), on vessel characteristics (type, draught, load conditions and navigation speed) and the site's water depth. The greatest motions occur when the wave period coincides with the vessel's natural oscillation period, which is a circumstance where resonance phenomena appear. Considering that the natural periods for heave, pitch and roll motions are usually over 8 seconds for the larger displacement vessels, it is the long swell waves which most affect the motion of this type of vessel. The critical wave periods for small boats are lesser, between 2-3 secs for boats up to 6 m long, 3-5 secs for 12 m long and 5-7 secs for 20 m long.

The basic procedure for addressing a study of a vessel's wave induced motions is to determine the response amplitude or transfer function operator, which determines the ratio between the vessel's motion and incident wave height for each wave frequency and direction. The frequency to be used is the wave frequency relative to the vessel's speed and wave direction.

Figure 7.04. **Vessel motions**



This analysis system is complex and does not accept a simplified generalization of its conclusions, particularly when resonance phenomenon is induced. Nevertheless, taking into account that these conditions will normally be excluded from the usual operating conditions for vessel navigation and staying under safe conditions, it is possible to establish simplified criteria due to the large pitch and roll angles which may occur, as shown in Table 7.1. (not applicable to ships with L_{pp} < 60 m) to assess draught increases required to meet wave induced motions. This table takes the following factors into account:

- The study method, whether determinist or semi-probabilistic, establishing the maximum values of the vessel's vertical motion to be expected, as applicable in both cases.
- The vessels' displacement as a function of the load percentage.
- The vessel's speed, even considering vessels at rest. The restrictions imposed by mooring lines and anchors for moored or anchored vessels will generally tend to reduce motions, and, therefore, the values obtained in these cases will normally be on the safety side.
- The ratio between the water depth available at the site (under an at rest condition) and the vessel's draught.
- The wave action direction relative to the vessel.
- Wave characteristics. The procedure recommended assumes in a first approximation that the vessel's vertical motion spectrum is proportional to the wave spectrum.

7.2.3.5.2. For the case of vessels with L_{pp} < 60 m, such a simple correlation as shown in the aforementioned table cannot be established and the following criteria may be formulated (see Fig. 7.04).

Table 7.1. ***Vessel´s vertical motions due to wave action***

	Wave height (m)							
	0.5	1.00	1.50	2.00	2.50	3.00	3.50	4.00
Vessel's length overall (L_{pp} in m)	**Vertical displacement (m)**							
75	0.10	0.17	0.34	0.58	0.76	1.02	1.30	1.58
100	0.05	0.14	0.28	0.46	0.65	0.87	1.12	1.36
150	0.00	0.09	0.20	0.34	0.51	0.69	0.87	1.08
200	0.00	0.05	0.15	0.26	0.40	0.57	0.72	0.92
250	0.00	0.03	0.10	0.21	0.33	0.48	0.63	0.80
300	0.00	0.00	0.07	0.16	0.25	0.39	0.56	0.68
400	0.00	0.00	0.04	0.11	0.18	0.31	0.51	0.58

1. The wave height to which this table refers is the significant wave height H_s of the sea state. The vessel's vertical motion obtained is also the «significant» one. The maximum vertical motion may be determined by assuming that the correlation factor with the wave height is constant and that, therefore, the vessel's motion spectrum is proportional to the wave spectrum. It will be considered in this assumption, and for determinist studies, that the vessel's maximum vertical motion is the resultant of increasing the Table's values by the following factors:

   - Vessel in motion: 2.00 - E_{max}
   - Vessel anchored or moored: 2.35 - E_{max}

   where E_{max} is the maximum admissible Risk as defined in Table 2.2. according to the characteristics of the area and manoeuvre being analyzed.

(Continued)

Table 7.1. Vessel´s vertical motions due to wave action

Should semi-probabilistic studies be carried out, it will be assumed that the greatest value of the vessel's vertical motion in performing an isolated manoeuvre with a probability of being exceeded equal to «m» may be obtained by integrating the function of density which represents the probability of the maximum vertical motions associated to a group of «N_w» waves occurring. Consequently, having done this integration, it will be assumed that the vessel's maximum vertical motion is the resultant of increasing the Table values by the following factor:

$$f(\mu \cdot N_w) = 0.707 \left[L_n \frac{N_w}{\frac{1}{1-\mu}} \right]^{1/2}$$

where «L_n» is the natural logarithm. The number of waves to be expected as a function of the time the vessel remains in the area under study will be taken for «N_w», with a maximum value of 10,000.

2. The Table's values are determined for loaded vessels (displacements ≥ 90% of the maximum), vessels at rest or vessels with reduced speeds (Froude number $F_{nh} \leq 0.05$), located in areas with a water depth ≥ 1.50 x vessel's draught and with waves acting longitudinally to the vessel's axis (± 15%).

3. The Table's coefficients will be multiplied by the following factors for partially loaded vessels:
   - Displacement ≥ 90% of maximum: 1.00
   - Displacement = 70% of maximum: 1.10
   - Displacement ≤ 50% of maximum: 1.20
   - Displacement between 90% and 70%: linear interpolation between 1.00 and 1.10
   - Displacement between 70% and 50%: linear interpolation between 1.10 and 1.20

4. The correction as a function of speed will be determined by multiplying the Table's values by the following factors:
   - Froude number ≤ 0.05: 1.00
   - Froude number = 0.15: 1.25
   - Froude number ≥ 0.25: 1.35 (*)
   - Froude number between 0.05 and 0.15: linear interpolation between 1.00 and 1.25
   - Froude number between 0.15 and 0.25: linear interpolation between 1.25 and 1.35 (*)

5. The influence of depth will be calculated by multiplying the Table's values by the following factors:
   - Water depth/vessel's draught ratio ≥ 1.50:1.00
   - Water depth/vessel's draught ratio ≤ 1.05:1.10
   - Ratio between 1.50 and 1.05: linear interpolation between 1.00 and 1.10

6. The influence of the wave action's direction will be determined by multiplying the Table's values by the following factors:
   - Angle between the vessel's longitudinal axis and wave direction ≤ 15°: 1.00
   - Angle between the vessel's longitudinal axis and wave direction = 35: 1.40
   - Angle between the vessel's longitudinal axis and wave direction = 90: 1.70
   - Angles between 15 and 35°: Linear interpolation between 1.00 and 1.40
   - Angles between 35 and 90°: Linear interpolation between 1.40 and 1.70

7. For intermediate length overall values of the vessel, linerar interpolation will be made between intervals. For small length overall vessels, see the specific criteria in the Recommendation's text..

8. Should several correction factors apply, the product of the different individual factors determined as per the preceding criteria will be used as a multiplier of the Table's values.

(*) The 1.35 factor may be less than 1.00 for low period waves acting on long length overall vessels. In other cases, lower values may be used based on specific detail studies.

- When heaving, small boats follow the vertical motions of the waves if the wave length is greater than 2.5 times the boat's waterplane measured along the wave direction (L_{pp} for longitudinal waves or beam (*B)* for 90° cross waves). Heave tends towards zero for wave lengths less than 0.5 times the foregoing dimension.

- A vessel's roll for 90° cross waves is mainly related to the wave period. Should there be wave period resonance with the vessel's, the maximum roll angle may reach a value 3 times the water surface slope.

- A vessel's pitching does not display significant resonances with longitudinal waves so the vessel's pitching angle approximately follows the slope of the water in its vicinity.

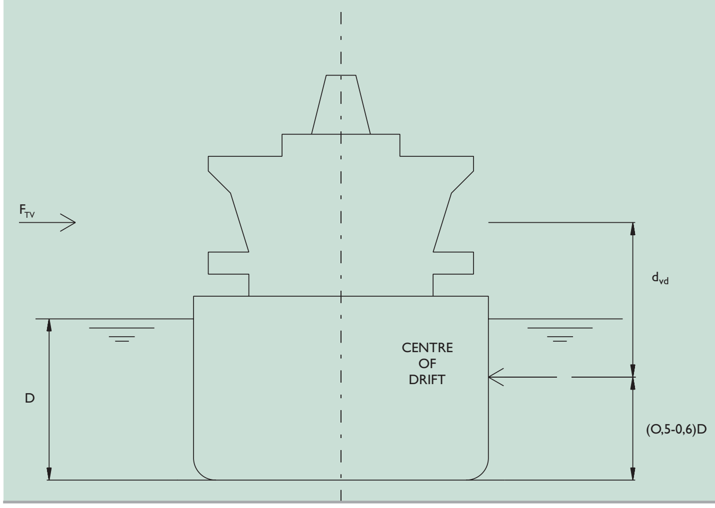
- In the absence of specific studies, it may be assumed that the vertical motion of small boats due to wave action is 50% of the wave height, determined in the same suppositions as defined in Table 7.1.'s Note 2. The factors given in the Notes to that Table will be applied for taking other effects into account.

In order to determine the vessel's motions caused by wave action, the maximum value compatible with the navigation manoeuvre of the vessel will be taken in all cases as the significant wave height, in accordance with the operating limits as established for the design (see Table 8.1.). It must be pointed out that the conditioning factor for determining the depth in the case of quays, anchorages, moorings and other areas where loading and unloading operations may be carried out will be that for the vessel's stay in the area considered and not that which limits loading and unloading operations which will always be equal to or less than the stay's.

7.2.3.6. Heeling caused by wind

Wind action on a vessel produces heeling motions which require additional draughts (d_v), the amount of which depends on the vessel's dynamic characteristics and wind action being considered. This effect is practically negligible for longitudinal wind action but has a greater effect in the case of lateral winds although its repercussion on draughts is also minimal except in the case of flat hulled boats or some small sailing boats. Its effect on vessels underway may be approximately quantified by assuming that the resultant of the lateral winds on the vessel is displaced from its centre of drift where the resultant of drifting loads is located (see fig. 7.05), and this causes a rotation around the vessel's longitudinal axis (roll) until reaching a value in which the stabilizing righting couple balances the moment of the wind's external loads. The effect is similar for moored vessels although the wind produced external loads will be balanced by the mooring line pulls or fender reactions with which a different arm of the couple will have to be considered.

Figure 7.05. **Forces generating heel through wind action**



F_{TV} = Cross component of the wind force on the vessel.
D = Vessel´s draugh.
d_{vd} = Vertical distance between the F_{TV} line of action and the centre of drift.

This rotation may be quantified by the following formula:

$$tg\theta_{TV} = \frac{F_{TV} \cdot d_{vd}}{\gamma_w \cdot (I - \nabla d_{bg})}$$

where:

Θ_{TV} = Vessel's rolling angle caused by cross wind action.

F_{TV} = Component of the resultant wind action force on the vessel in its transverse direction.

d_{vd} = Vertical distance between the F_{TV} line of action for the case of vessels underway and the centre of drift. The centre of drift may be assumed to be at a distance of 0.5 to 0.6 times the vessel's draught measured from the lower level of the keel. It will be determined for moored vessels between the F_{TV} line of action and that of the mooring or fender forces balancing F_{TV} measured in the centreline plane.

γ_w = Specific weight of water

I = The area moment of inertia of the the waterplane of constant displacemenet about its longitudinal axis. This waterplane area may be assimilated to an ellipse whose long axis is the length between perpendiculars (L_{pp}) and its short axis the vessel's beam (B), with which the Moment of Inertia would be

$$I = \frac{\pi \cdot L_{pp} \cdot B^3}{64}$$

∇ = Vessel's displacement expressed in units of volume.

d_{bg} = Vertical distance between the mass centre of gravity and the centre of buoyancy (centroid of the submerged volume) of the vessel being analysed.
This distance «d_{bg}» is an uncertain value since the position of the mass centre of gravity may vary considerably with the type of vessel, the type of load and load condition (full, half, ballast, etc.). Despite the foregoing, if the location of that centre of gravity were known, the following formula could be used:

$$d_{bg} = KG - D\left(0.84 - \frac{0.33 \cdot C_b}{0.18 + 0.87\ \ C_b}\right)$$

where:

KG = Height of the mass centre of gravity above keel

D = Vessel's mean draught under the load conditions considered

C_b = Block coefficient at the foregoing draught D

The additional draught due to this roll will be determined for flat bottomed vessels by the expression:

$$d_v = \frac{Bsen\theta_{TV}}{2}$$

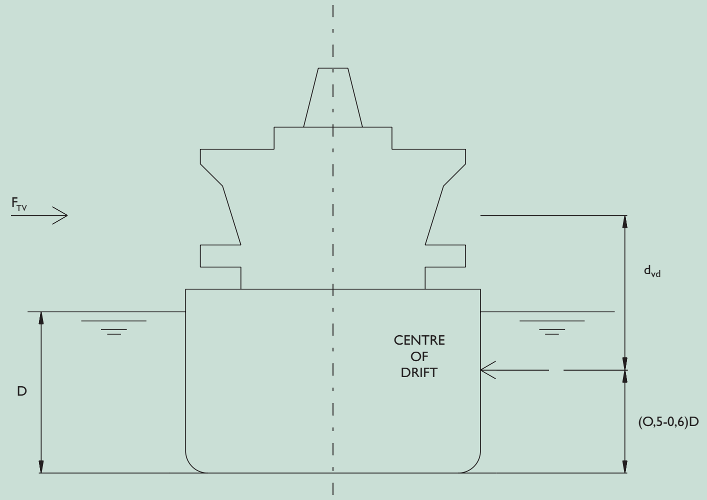
and this value may be adopted as characteristic both in determinist and semi-probabilistic studies, its value being small.

The value of F_{TV} will be assessed with the criteria as set down in Chapter IV, applying them to the relative wind speeds which correspond with those established as operating limits in the case being considered.

7.2.3.7. *Heeling caused by current*

The motion of a vessel underway subject to the current's action once the permanent equilibrium regime has been reached does not cause heeling nor additional draughts since the line of action of the resultant of the current loads on the vessel coincides with that of the drifting loads and there is no other unbalanced couple generating rolling. However, when the permanent equilibrium situation is altered due to variable action currents, what frequently happens in the case of cross currents through changes in the alignment of the waterway or through physical obstacles is that an unbalancing couple may occur because the current forces on the vessel are not in equilibrium with the drift forces applied at the centre of drift but with the forces of inertia applied at the

Figure 7.06. ***Forces generating heel through current action***



F_{TC} = Cross component of the current force on the vessel.
D = Vessel´s draugh.
d_{cg} = Vertical distance between the F_{TC} line of action and the centre of gravity.

Note: This effect only occurs when the permanent equilibrium situation is altered due to variable action currents.

centre of gravity (see fig. 7.06). This effect, which is practically negligible for currents acting longitudinally and practically negligible in the case of cross currents, can be calculated by determining the vessel's roll rotation necessary for the righting couple to balance the moment of the current's external loads. This rotation for vessels underway can be quantified by means of the following formula:

$$tg\theta_{TC} = \frac{F_{TC} \cdot d_{cg}}{\gamma_w \cdot (I - \nabla d_{bg})}$$

where:

Θ_{TC} = Vessel's rolling angle caused by the cross current.

F_{TC} = Component of the resultant current action force on the vessel in the transverse direction.

d_{cg} = Vertical distance between the F_{TC} line of action and the vessel's centre of gravity.

γ_w = Specific weight of water.

I = The area moment of inertia of the the waterplane of constant displacemenet about its longitudinal axis. This waterplane area may be assimilated to an ellipse whose long axis is the length between perpendiculars (L_{pp}) and its short axis the vessel's beam (B), with which the Moment of Inertia would be:

$$I = \frac{\pi \cdot L_{pp} \cdot B^3}{64}$$

∇ = Vessel's displacement expressed in units of volume.

d_{bg} = Vertical distance between the mass centre of gravity and the centre of buoyancy (centroid of the submerged volume) of the vessel being analysed.

This distance «d_{bg}» is an uncertain value since the position of the mass centre of gravity may considerably vary with the type of vessel, the type of load and load condition (full, half, ballast, etc.). Despite the foregoing, if the location of that centre of gravity could be known, the following formula could be used:

$$d_{bg} = KG - D\left(0.84 - \frac{0.33 \cdot C_b}{0.18 + 0.87\ C_b}\right)$$

where:

KG = Height of mass centre of gravity above keel.

D = Vessel's mean draught under the load conditions considered.

C_b = Block coefficient at the foregoing draught D.

The resultant of the current's action for moored vessels will be balanced by the mooring line pulls or fender reactions, with which the calculation formula will be the same, taking the vertical distance between the F_{TC} line of action and that of the mooring line or fender forces balancing it measured in the centreline plane.

The additional draught due to these rolling motions (d_C) will be determined for flat bottomed vessels by the expression:

$$d_c = \frac{B sen \theta_{TC}}{2}$$

and this value may be adopted as characteristic both in determinist and semi-probabilistic studies, its value being small.

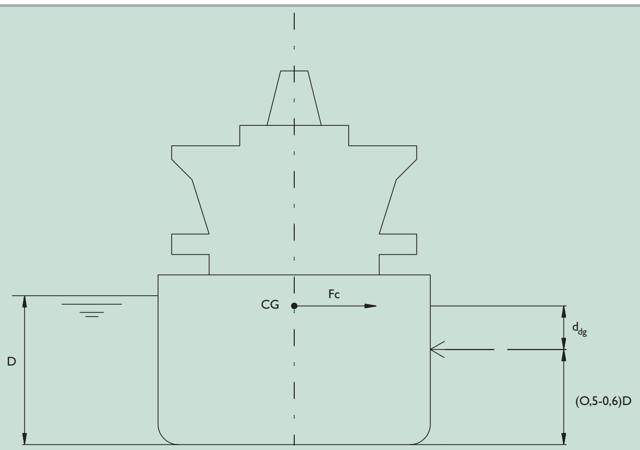
The value of F_{TC} will be assessed with the criteria as set down in Chapter IV, applying them to the relative current speeds which correspond with those established as operating limits in the case being considered.

7.2.3.8. Heeling due to course alterations

Heeling effects due to rudder action manifest through two opposite motions. At the first moment when full rudder is deflected and before the vessel commences to turn, it will heel towards that side because the rudder blade pressure centre is always located below the vessel's centre of gravity. This initial heeling angle will normally be small. As the vessel begins and continues turning, a centrifugal force will develop, applied to the vessel's centre of gravity and far higher than that acting on the rudder blade and in the opposite direction so that its action not only cancels out the initial heeling but causes further heeling towards the other side, i.e., towards the opposite side to the turn and greater in amplitude than the foregoing (see Fig. 7.07).

Heeling caused by a change in course will be determined in this second, more unfavourable case, accepting that the centrifugal forces applied at the centre of gravity balance out with the drifting forces applied at the centre of drift, therefore ignoring the effect of the rudder blade load or transverse component of the propeller action. This force couple causes a rotation round the vessel's longitudinal axis (rolling) until reaching a value in which the stabilizing righting couple will balance out the centrifugal force moment. The amount of this rolling and the additional draught it requires are insignificant for most motions occurring in ports (except for small boats), in view of the low speed at which vessels move and even the action of other forces (mooring pulls, tug

Figure 7.07. Forces generating heel through change of course



F_{TC} = Centrifugal force.
D = Vessel´s draugh.
d_{cg} = Vertical distance between the centre of drift and the centre of gravity.

Note: The cross force applied on the rudder blade is not considered.

boat actions, etc.), which generally reduce the unbalanced couple. However, rolling is heavy in outer navigation where it may reach 10/15°. This effect should therefore be taken into account in port approaches, navigation channels and, in general, wherever the vessel's speed may be significant.

This rolling rotation may be quantified by the following formula:

$$tg\theta_{CR} = \frac{F_C \cdot d_{dg}}{\gamma_w \cdot (I - \nabla d_{bg})}$$

where:

Θ_{CR} = Vessel's rolling angle caused by centrifugal force

F_c = Centrifugal force = $\frac{M \cdot V_L^2}{R}$

M = Vessel's mass including the mass of water moving with it (see section 3.9).

V_L = Component of vessel's absolute speed in the longitudinal direction of the path.

R = Radius of curvature of the vessel path

d_{dg} = Vertical distance between centre of drift and the centre of gravity

γ_w = Specific weight of water

∇ = Vessel's displacement expressed in units of volume.

d_{bg} = Vertical distance between the mass centre of gravity and the centre of buoyancy (centroid of the submerged volume) of the vessel being analysed.
This distance «d_{bg}» is an uncertain value since the position of the weight centre of gravity may considerably vary with the type of vessel, the type of load and load condition (full, half, ballast, etc.). Despite the foregoing, if the location of that centre of gravity were known, the following formula could be used:

$$d_{bg} = KG - D\left(0.84 - \frac{0.33 \cdot C_b}{0.18 + 0.87\ \ C_b}\right)$$

where:

KG = Height of mass centre of gravity above keel

D = Vessel's mean draught under the load conditions considered

C_b = Block coefficient at the foregoing draught D

I = The area moment of inertia of the the waterplane of constant displacemenet about its longitudinal axis. This waterplane area may be assimilated to an ellipse whose long axis is the length between perpendiculars (L_{pp}) and its short axis the vessel's beam (B), with which the Moment of Inertia would be:

$$I = \frac{\pi \cdot L_{pp} \cdot B^3}{64}$$

The additional draught due to this rolling will be determined for flat bottomed vessels by the expression (d_r):

$$d_c = \frac{Bsen\theta_{CR}}{2}$$

and this value may be adopted as characteristic both in determinist and semi-probabilistic studies in view of the nature of the variables intervening in its evaluation.

7.2.3.9. Clearance for safety and control of the vessel's manoeuvrability

This clearance for the vessel's manoeuvrability and control (rv_{sm}) is the minimum thickness of the sheet of water which must be below the keel for the vessel to be able to maintain navigation control. The values given in Table 7.2. will be taken to determine this clearance. It was there assumed that the Safety Margin (rv_{sd}) specified in article 7.2.3.10 is always used and, therefore, values of «rv_{sm} + rv_{sd}» lower than those indicated in that Table measured in the vessel's centreline may never be accepted in any event (see section 7.2.3.11).

These figures will be taken as characteristic whether the study is performed by determinist or semi-probabilistic methods.

7.2.3.10. *Safety margin*

The safety margin (rv_{sd}) is the vertical clearance which shall always be available between the vessel's hull and the seabed. The values given in Table 7.2., which tend to minimize the risk of the vessel touching the seabed whilst heeding the latter's nature, will be taken for determining such margin. This safety margin shall always be taken into account whether determinist or semi-probabilistic methods are used, as specified in section 2.5.

Table 7.2. Clearances for the vessel's manoeuvrability safety and control (rv_{sm}) and safety margin (rv_{sd})

	rv_{sm}	rv_{sd}	$rv_{sm} + rv_{sd}$
1. *Large displacement vessels (>30,000 t)*			
– Navigation over silty or sandy seabeds			
• Unlimited vessel speed (> 8 knots)	0.60	0.30	0.90
• Limited vessel speed (≤ knots)	0.30	0.30	0.60
• Vessel at rest (quays, berthings, etc.)	0.00	0.30	0.30
– Navigation over rocky seabeds			
• Unlimited vessel speed (> 8 knots)	0.60	0.60	1.20
• Limited vessel speed (≤ knots)	0.30	0.60	0.90
• Vessel at rest (quays, berthings, etc.)	0.00	0.60	0.60
2. *Vessels with a medium and small displacement (≤ 10,000 t, except small, recreational and fishing boats)*			
– Navigation over silty or sandy seabeds			
• Unlimited vessel speed (> 8 knots)	0.30	0.30	0.60
• Limited vessel speed (≤ knots)	0.20	0.30	0.50
• Vessel at rest (quays, berthings, etc.)	0.00	0.30	0.30
– Navigation over rocky seabeds			
• Unlimited vessel speed (>8 knots)	0.30	0.60	0.90
• Limited vessel speed (≤ knots)	0.20	0.60	0.80
• Vessel at rest (quays, berthings, etc.)	0.00	0.60	0.60
3. *Vessels with displacements between 10,000 and 30,000 t*			
– Linearly interpolate as a function of the displacement given in sections 1 and 2			
4. *Small, recreational and fishing vessels*			
– Navigation over silty or sandy seabeds			
• Unlimited vessel speed (>8 knots)	0.20	0.20	0.40
• Limited vessel speed (≤ knots)	0.10	0.20	0.30
• Vessel at rest (quays, berthings, etc.)	0.00	0.20	0.20
– Navigation over rocky seabeds			
• Unlimited vessel speed (>8 knots)	0.20	0.40	0.60
• Limited vessel speed (≤ knots)	0.10	0.40	0.50
• Vessel at rest (quays, berthings, etc.)	0.00	0.40	0.40

To the effects of applying Table 7.2. criteria, it will be taken that in the case of quays with foundations on breakwater banquettes or with blocks or tetrapods located in front of the quay's outer facing, the seabed is rocky.

This Recommendation does not establish additional clearances in keeping with types of vessels or nature of the cargo since it is considered that navigation must be equally safe in all cases. Should it be desired in some particular case to take additional safety precautions in this respect, more restrictive operating conditions are recommended for certain types of vessel (e.g., lower wind speed limit) instead of increasing the requirements of greater depth.

4.2.3.11. *Checking on vessel related factors*

The following assessments will be made for determining the lowest level the vessel can reach, including clearances for safety and control of manoeuvrability and the safety margin, in relation to the reference water (which is analysed in section 7.2.4), and the more unfavourable of both will adopted:

- Determining on the vessel's centreline:

$$H_l = D_e + d_s + d_g + d_t + 0.7\, d_w + rv_{sm} + rv_{sd}$$

- Determining on the vessel's port and starboard sides

$$H_l = D_e + d_s + d_g + d_t + d_w + d_v + d_c + d_r + 0.7\,.\, rv_{sm} + rv_{sd}$$

where the different variables have the meaning as defined in the foregoing paragraphs.

Specific values for H_l associated to the most unfavourable vessels (Design Vessel) will be available for studies with determinist method. For studies with semi-probabilistic method, the values of H_l will depend on the probabilities of maximum wave exeedance («m», according to Note 1 to Table 7.1), which will enable a more precise analysis to be made as a function of maximum acceptable Risks, the fleet's characteristics, the traffic forecast and other specific factors of the Area being analysed, according to the general procedure as described in section 2.5 in which «m» is the probability p_{ij} of the lowest level of a vessel of type «*i*» under the operational conditions of the interval «*j*» reaching the value H_l.

7.2.4. Water level related factors

The following factors must be analysed and known beforehand for determining the water level in which the vessel is located:

7.2.4.1. Astronomical tide

7.2.4.1.1. The astronomical tide is a regular, alternating rise and fall movement of the sea water caused by the attraction of the Sun, the Moon and other stars which is regularly repeated (every 12 hours 24 minutes on average on Spanish coasts). The simplest method of graphically representing this regular movement of the water level is by plotting a curve whose X-axis is time and Y-axis height from an assumed zero level. These curves are easy to plot by means of tide scales, and tide gauges plot them directly. Tide level curves are generally irregular in shape making it difficult to represent them by simple mathematical expressions. Nevertheless, an analysis thereof for Spanish coasts may be simplified by assuming that each tidal wave responds to a sinoidal profile of a period $T_m = 12^h 24^m$ and a variable amplitude as a function of the Tide Coefficient «*C*» (Tide and Tidal Current Tables are available in all Spanish ports. They exactly define the tidal wave's shape without having to use this approximation by means of the sinoidal function, and, therefore, finding tide related water levels does not entail any uncertainty).

Wave amplitude is determined by means of the Tide Coefficient «*C*» which is referred to an invariable unit of comparison for each port, called the Height Unit «U.A.», which is the tide's height above the mean sea level on days of equinoctial spring tides when the Moon's declination is null and the Moon and the Sun are at their mean distances from Earth. With this definition, the Height Unit, U.A., is the half-amplitude in metres of the mean of the equinoctial spring tides, to which corresponds a Tide Coefficient $C = 100$.

The Tide Coefficient has extreme values of 118 and 26. The first is for high equinoctial spring tides and the second for the neap tides of the solstices. The pertinent Tide and Tidal Current Tables show both the daily value of Coefficients *C* and the Height Units in the different ports which makes it easy to find each tidal wave's half amplitude with the expression:

$$AMC = U.A. \frac{C}{100}$$

Therefore, if nautical charts are referred to the mean sea level at the port being considered, the LAT would be located at the level:

$$LAT = -U.A.\frac{118}{100}$$

If, as is most frequent in Spanish tidal ports, nautical charts are referred to the LAT, the mean level would be located at 1.18 U.A. and the HAT at the level:

$$HAT = -U.A.\frac{118}{100}$$

In this case of nautical charts being referred to the LAT, High-Tide and Low-Tide for a tidal wave with C coefficient would be respectively located at levels:

$$PM_C = U.A.\left(1{,}18 + \frac{C}{100}\right) \qquad BM_C = U.A.\left(1{,}18 + \frac{C}{100}\right)$$

Since other nautical charts normally used in the international sphere (Admiralty, USA, etc.) are not referred to the LAT, it is recommended to perfectly identify the Datum of the charts available prior to using them.

It must be pointed out that regardless of what the level used as a chart datum is, the «Zero» Level of the Port or Area being considered does not usually coincide with the nautical charts' zero nor with that of the topographical maps of a general nature, which produces a difference between the Area's topographical levels referred to «zero», the bathymetric ones and the topographical levels of a general nature, which is why a prior examination of these three datums is recommended to prevent subsequent confusion.

Assuming a tidal wave with C coefficient and accepting the sinoidal simplification of its profile, the graphic representation as shown schematically in Fig. 7.08 would result. This allows the water height due to the astronomical tide's action to be known at that point and at all times.

In inland seas and lakes, astronomical tides may be studied in a similar way, although the physical phenomenon may be altered by the smaller dimensions of these areas and the tidal range may even disappear.

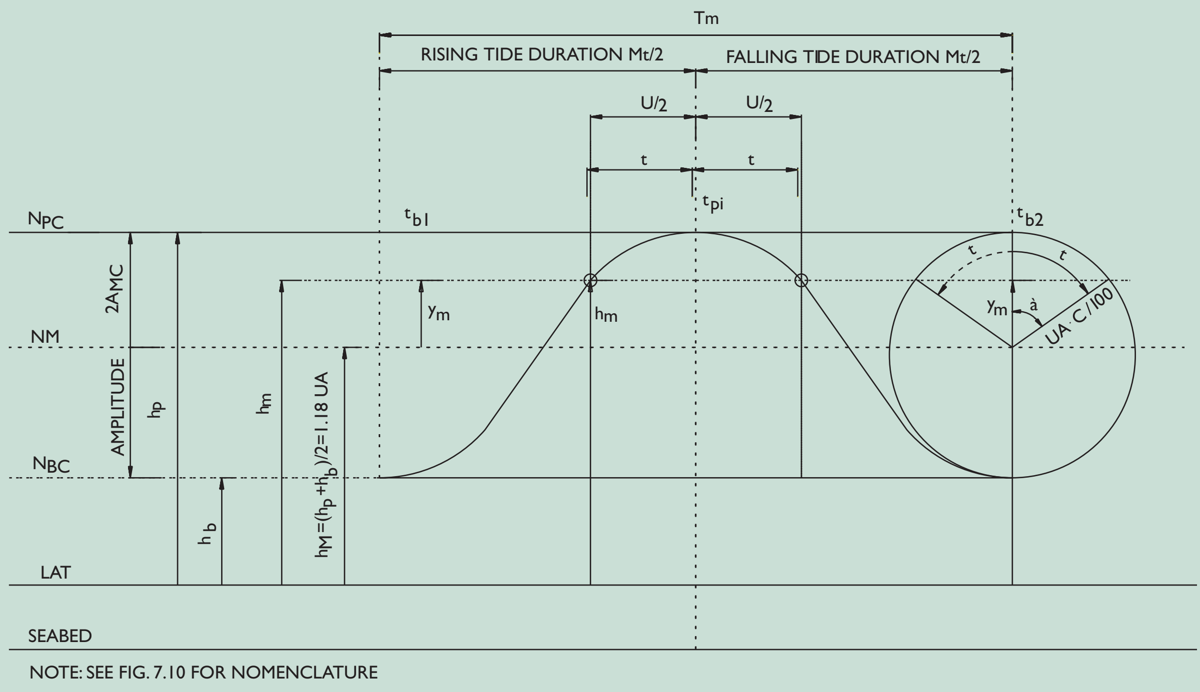
The Sun, Moon and other stars do not generally cause noticeable tides in rivers but, on the other hand, others derive from the tidal waves of the sea into which they flow that advance upriver and cause oscillations in the water level, the amplitude of which reduces until being cancelled out at what is called the «tide limit». This phenomenon is influenced by the actual river flow, producing a complex regime specific to each case which cannot be generalized for other fluvial currents.

7.2.4.1.2. The presence of a tidal wave in a Navigation Channel or a Harbour Basin means that the actual depths available vary over time and there are periods of high-water («windows») in which the water depth available would allow nautical manoeuvres and operations to be performed which, however, could not be in low-water periods. Adopting a lower reference water level means that the «windows» in which the Navigation Channel or the Harbour Basin remains operational are longer but, as a counterpart, the depths of water required increase.

Should the reference level be located at the LAT, this would mean that the Area would remain permanently open, at least as far as this parameter is concerned. In general, as we are dealing with tidal range areas, the foregoing condition may prove excessive, at least for transit vessel areas, for which reference levels somewhat higher than the LAT could be adopted, so that a balance point would be reached between the amount of investment required to increase and maintain the water depth, vessel traffic forecast, especially those with largest draught, and the percentages of Area downtime for navigation as caused by limitations imposed on depths.

Should the manoeuvre being analysed affect a single area with dimensions below 5 km (port entrance/exit mouth, basin, quay, etc.) the tidal wave will be considered as representative of all points. If, on the contrary, an Area with an appreciable longitudinal dimension (≥ 5 km), such as a fairway, were being analysed, it might result that the Tidal Wave were different at different points in the Area, or at least that it would occur with a time lag between some points and others, as is shown in schematic form in fig. 7.09. It can be seen in this case that the time width of the window defining the operating time for the manoeuvre under analysis may be reduced or increased in relation to the Tidal Wave without a lag.

Figure 7.08. **Typical tidal wave (applicable in Spanish waters)**



$$y_m = A_{MC} \cdot \cos\frac{(2\pi t)}{T_m}$$

Note: See fig. 7.10 for nomenclature.

With the purpose of facilitating calculation of a «window» for a predefined water level for a C Coefficient Tidal Wave, is recommended making out a non dimensional graph of the type shown in fig. 7.10 for the case applicable to Spanish coasts in which the Tidal Wave shape may be approximated via the sinoidal function assumption. In this hypothesis, all tidal waves on non-dimensional coordinates are coincident, which facilitates the calculation as expounded in the said figure. Should this be an area represented by two Tidal Waves lagging in time, the representative curve of all Tidal Waves would have to be moved to the left or right, as appropriate, by the same amount of time lag between both Waves.

It must be pointed out that a window's width represents the time during which a water level equal to or greater than the predefined is available, i.e., it is the operating time for carrying out the vessel's manoeuvre which needs to have that water level available. However, it is not the effective operating time since it will be necessary to deduct the time necessary for performing the manoeuvre therefrom. For the case shown in fig. 7.09., the time necessary for navigation from the beginning to the end of the stretch must be available, in order to know what the really effective time is for being able to commence the manoeuvre with the certainty of finishing it in the periods available with sufficient water level. It will be considered in all cases that the manoeuvre is carried out with the lowest speed possible compatible with the operational criteria of the stretch under analysis for determining these effective operating times.

Knowing the Tidal Wave shape for any C Coefficient and knowing the mean annual distribution of the tides in an Area, as a function of its pertinent tide coefficients (for which it would suffice to have the Tide and Tidal Current Tables for a minimum 3 consecutive years), curves like that shown in fig. 7.11. could be obtained defining the probability of getting a certain water level as a function of that level, or, in other words, the mean annual operating time of all «windows» for a preset water level. This information facilitates economic studies for selecting the water level which will be set for vessel operation. It would not be necessary to make out these curves if the Mean Rates of Accumulated Frequencies of water levels associated to tides in the area under analysis are available.

7.2.4.2. Meteorological tide

This concept includes changes in water height due to changes in atmospheric pressure, as well as those caused by wind action. The atmosphere does not exert an even pressure on water surfaces. A reduction in pressure at a given point causes a rise in the water level and, on the contrary, an increase means a drop. These changes are imperceptible when the barometer rises and falls relatively quickly but when a system of high or low pressures is maintained for a long time, the water level falls or rises. The correlation between these changes in water level and the pressure system is not elemental since the coast's configuration influences the unhindered course of the current which is caused by the difference in water level. Winds also influence water levels since when they blow persistently in one direction, they produce currents which cause a rise in level in the area toward which the current is running and a depression in the area from where it is coming.

Figure 7.09. **Operating times with several tidal waves**

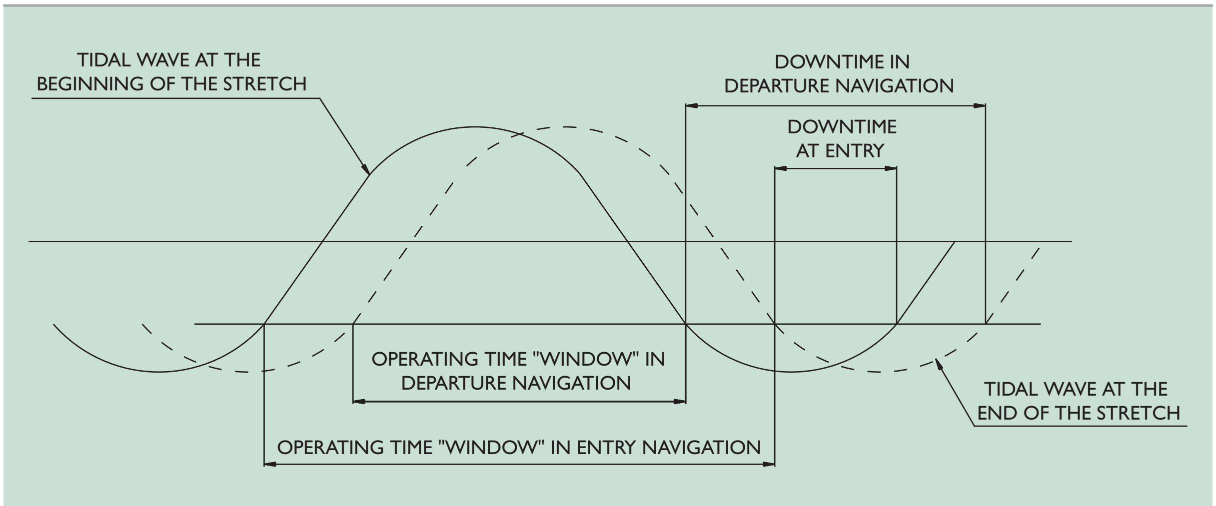
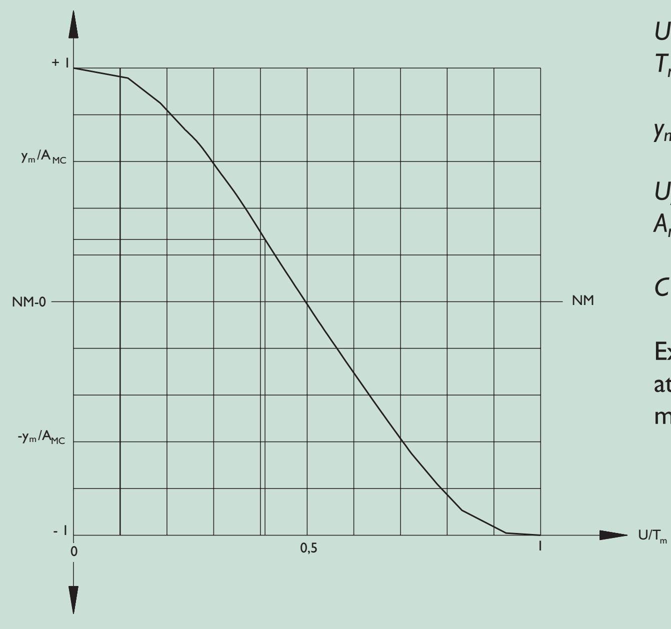


Figure 7.10. **Non-dimensional graph for calculating the width of a «window» in a tidal wave**



U = Width of a window.

T_m = Tide period.
$T_m : t_{p2} - t_{p1} = t_{b2} - t_{b1}$

y_m = Height of tide above mean level (NM).
$y_m : h_m - h_M$

U_A = Unit of height.

A_{mc} = Half amplitude of the coefficient tide.
$C = U_A \cdot C$

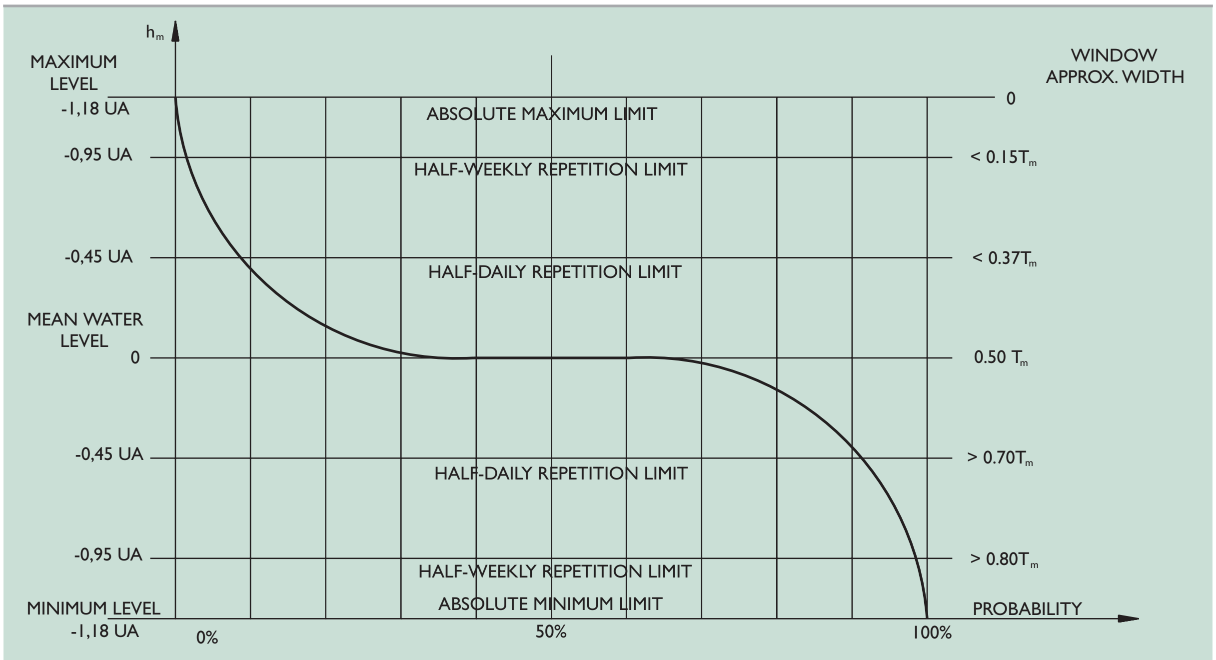
C_l = Tide coefficient covering the window.

Example: Calculate the window width for a height at the moment h_m = 5.60, in a port with U_a = 4 mts with a tide of C = 0.8 and T_m = 12h30m

$$y_m = h_m - h_M = 5.60 - 1.18 \times U = 0.88$$
$$y_m / A_c = 0.88 / 4 \times 0.8 = 0.275$$
$$U / T_m = 0.41$$
$$U = 0.41 \times 12.5h = 5.14$$
$$U = 5h8m$$

Note: Curve for a sinusoidal profile.

Figure 7.11. **Probability of having a specific water level (hm) available (curve to be determined in each case)**



In the absence of specific studies which jointly analyse the rate at which water levels caused by astronomical and meteorological tides occur for the site under consideration, it is recommended that the determinist method be used, adopting a value of the meteorological tide with water level rises of +0.50 m and falls of –0.30 m in all Spanish ports and coasts showing a significant astronomical tide (U.A. > 0.50 m). These figures represent approximately 70% of their maximum values and are therefore the «Combination value» of this variable, assuming therefore that the astronomical tide is the variable with the predominant effect. This consideration of the meteorological tide would involve shifting the astronomical tide curve 0.30 m downwards when analysing water depths and raising that curve by 0.50 m when what is being analysed are quay heights and above water clearances (see sections 7.3 and 7.4). This simplification also assumes that the meterological conditions remain constant during the whole tide curve.

Should water level statistics be available, the extreme values associated to the maximum acceptable risk will be taken as the expectable maximum and minimum Levels of the joint Tidal Waves, for which a value of 0.10 will be adopted in the absence of specific considerations. In this case, optimization studies for choosing the reference water level for vessel operation as recommended in this Chapter, related to the Tidal Wave analysis, will be replaced by a study of the Mean Rates of occurrence of the water level. It must be pointed out that the risk here established for setting the Maximum and Minimum Levels solely refer to the probability of some water levels or others occurring and do not therefore coincide with those specified in Table 2.2. which presuppose these areas being used by vessels.

Astronomical and meteorological tides for ports and coasts with no significant astronomical tide (U.A. ≤ 0.50 m) may be equivalent and, therefore, unless the mean and extreme rates of water level occurrence are available, in which case the criteria expressed in the foregoing section will be followed, it is recommended to consider both effects as a single wave which will have its maximum values (HAT equivalent) at elevation +1.00 m and its minimum values (LAT equivalent) at elevation –0.80 m, both measured on the Mean Sea Level in the area. In any case, omitting the optimization study of the reference water level described in section 7.2.4.7. is recommended in these ports with no significant astronomical tide, considering that this level is the lowest, i.e., –0.80 m below the Mean Level of water for operations that bear with them vessel staying (quays, berthings, basins, etc.) and at elevation –0.60 m below the Mean Sea Level for transit vessel operations (channels, approaches, manoeuvring areas, etc.) (see section 7.2.4.6.).

7.2.4.3. Resonance from long wave phenomena

In confined enclosures, whether natural (bays) or artificial (basins), special care will be taken in checking the possibility of resonance phenomena due to long wave penetration. In this case, when periods coincide, the level may be altered by as much as 3.00 m over those provided for, which is why the effect may be of great importance. Corrective measures to prevent this occurring are recommended.

7.2.4.4. Fluvial regimes

Should Navigation Channels or Harbour Basins be affected by river channels, the pertinent hydraulic regime must be taken into account. Should overall statistical data on the water level incorporating tidal and hydraulic regime influence be available, the extreme values associated to the maximum acceptable risk will be adopted as minimum and maximum values expectable, for which a value of 0.10 will be taken in the absence of specific considerations. In this case, the optimization studies for selecting the reference water level for vessel operation which are recommended in this chapter related to the Tidal Wave, will be replaced by a study of the mean rate of occurrence of the water level. Should this overall statistical base not be available, the lowest value resulting from locating the astronomical and meteorological tidal waves centred at the fluvial regime Level corresponding to an acceptable risk of 0.50 in the extreme Regime of the minimum annual fluvial Regimes ($N_{min}RH$) shall be considered as the minimum water level and the highest value resulting from locating the astronomical and meteorological tidal waves centred in the fluvial regime Level corresponding to an acceptable risk of 0.50 in the extreme Regime of the maximum annual fluvial Regimes ($N_{max}RH$) as the maximum water level. In this case, the optimization studies for selecting the reference water level for vessel operation, which are recommended in this chapter related to the Tidal Wave, will be replaced by a study of mean water level regime occurrence, which should be drawn up by combining the mean hydraulic regime with the mean regime of the tides, assuming they are separate phenomena.

Should they be Areas with no significant astronomical tide (U.A. < 0.50 m) in which the hydraulic regime has a range ($N_{max}RH$ - $N_{min}RH$) equal to or less than 1.00, it is recommended that the optimization study described in section 7.2.4.7 be omitted and the reference water level be located at an elevation of –0.80 m below the $N_{max}RH$ for operations involving vessel staying (quays, berthings, basins, etc.) and at elevation –0.60 m below the $N_{max}RH$ for transit vessel operations (channels, approaches, manoeuvring areas, etc.). These figures are found by assuming there exists an astronomical and meteorological tide. Should there only be an astronomical tide, –0.50 and –0.30 will be taken respectively. Consequently, should the fluvial current not be affected by any type of tide, the reference level for determining water depths would be located at the $N_{min}RH$ level.

7.2.4.5. Locks and locked basins

Should navigation areas be located in locks or locked basins, the maximum and minimum water levels imposed by their operating conditions will be considered.

For the case of locks, on the usual assumption that the lock is not a limitation on navigation, the same conditioning factors existing downstream of the lock will be taken as applicable to minimum water levels. The most unfavourable conditioning factors that may occur upstream or downstream of the lock will be considered for maximum water levels. In the case of locked basins, the reference water level inside the basin must be optimized, taking into account the costs of dredging performance and maintenance in relation to foreseeable traffic volumes and the cost involved in any waiting time that might occur.

7.2.4.6. Reference water level

Determining the Level of water in which the vessel is located, from which the water depths required thereby will be considered including clearances and Safety Margins, basically depends on the degree of operability with which it is desired to provide the Area being analysed. Should the Area have to be permanently operational, at least as far as these parameters are concerned, it would suffice to set the reference water level at the lowest foreseeable extreme values. The recommendations given in previous sections correspond to this design criterion to select these minimum extreme levels in cases where maximum variations in water level, measured as the difference between the extreme high and low water Levels, are unimportant. If water level variations were greater, an optimization study is recommended, at least for the transit vessel Areas, in view of the fact that significant savings could be made with a minor effect on operability.

Table 7.3. gives recommendations on water levels to be adopted for the different Navigation Channels or Harbour Basins targeted by this ROM, as a summary of the foregoing. The term "optimizable" used in this table means that water levels higher than the expectable minimum extreme values can be adopted following the procedure described in 7.2.4.7.

As can be seen in that Table, the reference water level was set at extreme values associated to very low occurrence risks in all Areas where it is planned for vessels to stay (anchorages, basins, quays, etc.), except for locked basins, i.e., it is intended that these areas are permanently operational as far as these factors are concerned. However, it was decided to select an «optimizable» water level as a function of the operability/economy of the facility under consideration for transit vessel Areas, except for cases of very small tidal ranges or hydraulic regimes.

Table 7.3. **Reference water level for determining depth**

Area´s characteristics	Transit vessel area	Staying vessel area
A. Areas with a significant astronomical tide (U.A. ≥ 0.50 m)		
– With no fluvial regimes		
• Astronomical tide only	Optimizable	LAT
• Astronomical and meteorological tide	Optimizable shifting the tide curve - 0.30 m	LAT –0.30 m
– With fluvial regimes		
• Astronomical tide only	Optimizable	Extreme minimum: Risk: 0.10
• Astronomical and meteorological tide	Optimizable	Extreme minimum: Risk: 0.10
B. Areas with a non significant astronomical tide (U.A. ≤ 0.50 m)		
– With no fluvial regimes		
• Astronomical tide only	NM = 0.30 m	NM = 0.50 m
• Astronomical and meteorological tide	NM = 0.60 m	NM = 0.80 m
– With non significant fluvial regimes ($N_{max}RH$ - $N_{min}RH$ ≤ 1.00 m)		
• Astronomical tide only	$N_{min}RH$ - 0.30 m	$N_{min}RH$ - 0.50 m
• Astronomical and meteorological tide	$N_{max}RH$ - 0.60 m	$N_{max}RH$ - 0.80 m
– With significant fluvial regimes ($N_{max}RH$ - $N_{min}RH$ > 1.00 m)		
• Astronomical tide only	Optimizable	Extreme minimum: Risk: 0.10
• Astronomical and meteorological tide	Optimizable	Extreme minimum: Risk: 0.10
C. Locks	Downstream level	Not applicable
D. Locked Basins	Optimizable	Optimizable

Legend:

LAT	=	Low Astronomical Tide
NM	=	Mean sea level = (LAT + HAT) / 2
HAT	=	High Astronomical Tide
$N_{min}RH$	=	Extreme level of the fluvial regimen's annual minimums expectable associated to an acceptable risk
$N_{max}RH$	=	Extreme level of the fluvial regimen's annual maximums expectable associated to an acceptable risk
Transit vessel area	=	Approaches, waterways, channels, harbour entrances, manoeuvring areas, etc.
Dwelling vessel area	=	Anchorages, mooring areas, dock basins, quays, berthings, terminals, etc.

The reason for this difference in criteria is that operating restrictions can be imposed on vessel transit much easier than on vessel staying and without a great loss of service quality. Nevertheless, if it were desired to optimize the water level in vessel staying Areas, it could be done in a similar way, although the procedures to be followed to prevent damage (which might not be «accidental» in view of the non-random nature of the variables considered) must be clearly shown in the operating Regulations.

This Table also shows that the water level in some cases was set by determinist criteria as a function of levels representative of the water's vertical movements (LAT, NM, etc.). The statistical data base would therefore only be that necessary in these cases for knowing such representative data. In other cases, a study of extreme regimes or of mean regimes is recommended for optimization which, in general, calls for a larger volume of statistical information to be available.

It must be pointed out that the water levels to which this ROM refers basically relate to operational criteria and do not need to coincide with the extreme values linked to structural design criteria as given in other ROMs.

7.2.4.7. Criteria for optimizing the reference water level and depth of water required

7.2.4.7.1. The possibility of adopting a higher value than the minimum expectable as the reference water level for positioning the vessel bears with it the risk of the Navigation Channel or Harbour Basin under analysis remaining out of service to the larger vessels being considered for a certain period of time.

For the more usual case of an Area with astronomical tides and assuming any tidal wave representative of the water level in the Area under analysis, it was already seen in fig. 7.08 that water depths were determined strictly from the Reference Water Level, the fact that this Level is located above low-water means there is a time «window» during which the operation is feasible whilst the operation could not be carried out the rest of the time through the lack of the water depth required.

Should the area be appreciably long with tidal wave differences over the whole stretch, fig. 7.09 also showed that the operating time window is set between the representative tidal waves of the beginning and end of the stretch and that this window has a different duration depending on the direction in which the vessel navigates.

The schemes shown in figures 7.08 and 7.09 are the most usual, although other cases could be considered, for example, the relatively frequent case of an analysis of the complete cycle of the vessel's entry, unloading and departure, in which the depth requirements might vary throughout time as a result of unloading.

7.2.4.7.2. If the study is performed not only for an isolated tidal wave, but for a continued succession of tidal waves (or for the pertinent hydraulic regime in each case), an assessment of the operating times available may be made as a function of the reference water level adopted. The parameters usually considered to decide the optimum water level are:

- The mean annual time when the Area is out of service which may be determined immediately if curves have been made out like that shown in fig. 7.11 or if the Mean Annual Rates of water level occurrence associated to tide are available.

- The mean monthly time for each month or at least the most unfavourable month, in which the Area is out of service, which may also be easily analysed if graphs equivalent to fig. 7.11's are made out by months or if the Mean Annual Rates of water level occurrence associated to tide are available.

- The maximum continued time expectable in which the Area remains out of service, for which the function of frequency of occurrence or Duration Regime of the «continued downtime» variable must be known.

7.2.4.7.3. It must be pointed out that should the Areas be the type with only astronomical tides, the water level is not a random variable since it can be predicted as much in advance as is required and does not therefore bear with it an uncertainty related risk. Neither does this uncertainty situation exist should meteorological as well as astronomical tides occur and it is decided to move the tide values by the maximum extreme value expectable for the meteorological tide, which is what is recommended on Spanish coasts and Areas in view of the minor effect of the meteorological tide.In this case, it will be possible to follow the systematics of downtime assessment as described for the case of Areas solely affected by the astronomical tide.

For more complex cases in which there may be several causes affecting water levels (astronomical tides, meteorological tides and fluvial regimes), the Mean Annual, Monthly and Duration rates must be available so that the downtime parameters mentioned above may be quantified as a function of the water level adopted. In these cases, if the water level variation were not predictable in advance bearing a risk with it, more complex studies would have to be undertaken in view of the multiple variables which would ihave to be considered in assessing vessel occupied areas.

7.2.4.7.4. The reference water level selected to position the vessel does not have to be the only one for all types of vessel and all operating conditions. The same requirements of minimum levels used by vessels can be obtained by adopting different criteria according to each case (e.g., the most unfavourable vessels operate with greater tide associated water levels or with smaller waves); i.e., the sum of the factors H_1 and H_2 which were defined in section 7.2 may be interpreted to the effect of determining the lowest level for the most unfavourable vessels under limit operating conditions or to the effect of determining what the operating conditions are going to be for the different types of vessel as from the lowest preset level. Selecting the reference water level and, consequently, determining the water's nominal depth in the Area under consideration is a result of an economic and operability analysis suited to the specific characteristics of each case. Nevertheless, with the purpose of having homogeneous criteria, reference water levels are recommended to meet at least the requirements as shown in table 7.4. Adopting the minimum requirements as shown in that Table as a criterion for determining the reference water level and the consequent water depths would allow them to be calculated with no need for an economic optimization study. The value adopted in that case will fulfil the requisites of this Recommendation but would not allow it to be known whether the best area has been chosen. In addition, it is recommended that the Area's downtime because of environmental conditions above the Operating Limit Conditions be calculated, as is specified in section 8.12, and that they be contrasted with those usually accepted for the said Areas.

7.2.5. Seabed related factors

The sum of the following factors (H_3) needs to be taken into account for the required nominal water depth in Navigation Channels and Harbour Basins to be guaranteed.

7.2.5.1. Margin for bathymetry inaccuracies

This concept includes the additional clearance which must be provided to cover bathymetry inaccuracies. In bathymetric research state-of-the-art using echo-sounders and lateral sweeping sonar equipment or equivalent systems, it may be considered that the accuracy of the records obtained is more than 99% of the water depth existing; bathymetry inaccuracies do not normally originate in the recording equipment but in oscillations which, in turn, are basically due to the maximum waves accepted during the data taking campaign, which may be avoided with a wave compensation system. The following margins may be considered assuming that this wave action is limited to waves of 0.50 m significant height in outer waters and 0.25 m in inner waters:

	With wave compensation systems	Without wave compensation systems
◆ Outer waters	1% of the water depth	0.25 m + 1% of the water depth
◆ Inner water	1% of the water depth	0.10 m + 1% of the water depth

The foregoing criteria cannot be used if bathymetry has not been performed with lateral sweep sonar or an equivalent system enabling possible high points to be found between two lines recorded with the echosounder. Accurate bathymetry controlled with total sweep sonar is recommended in all navigation areas where water

Table 7.4. ***Minimum service requirements recommended for determining reference water levels***

Area´s characteristics	Maximum operating times (1)(2) (calculated for values of H^l, for Design Vessels)	
	In hours	In n° of times
A. Transit vessel Areas (approaches, fairways, channels, harbour entrances, manoeuvring areas, etc.)		
1. Ports of general interest		
– Areas open to all types of vessel.	100 h. year / 10 h. month. 6 consecutive h.	10 a year / 1 a month No 2 successive uninterrupted closures
– Areas open to Fishing and pleasure boats (3)	10 h. year / 2 h. month 1 consecutive h.	1 a year / 1 a month No 2 successive uninterrupted closures
2. Ports of refuge		
– Areas open to all types of vessel	150 h. year / 15 h. month 6 consecutive h.	15 a year / 2 a month No 2 successive uninterrupted closures
– Areas open to Fishing and pleasure boats (3)	10 h. year / 2 h. month 1 consecutive h.	1 a year / 1 a month No 2 successive uninterrupted closures
3. Other ports	200 h. year / 20 h. month 6 consecutive h.	20 a year / 2 a month No 2 successive uninterrupted closures
4. Specialized terminals		
– Passengers, Containers, Ferries and other terminals operating with regular lines	100 h. year / 10 h. month 6 consecutive h.	20 a year / 2 a month No 2 successive uninterrupted closures
– Bulk carriers of any type and other terminals not operating with regular lines	200 h. year / 20 h. month 6 consecutive h.	20 a year / 2 a month No 2 successive uninterrupted closures
B. Areas of dwelling vessels (Anchorages, mooring areas, dock basins, berthings, terminals, etc.)		
1. Ports of any type	20 h. year / 10 h. month 6 consecutive h.	2 a year / 1 a month No 2 successive uninterrupted closures
2. Specialized terminals		
– Passengers, Containers, Ferries and other terminals operating with regular lines	100 h. year / 10 h. month 6 consecutive h.	5 a year / 1 a month No 2 successive uninterrupted closures
– Bulk carriers of any type and other terminals not operating with regular lines	200 h. year / 20 h. month 6 consecutive h.	20 a year / 2 a month No 2 successive uninterrupted closures

(1) The downtimes as shown in this table only refer to those occurring through insufficient reference water level for the Design Vessels' Operational Limit Conditions and therefore do not include Area closures for reasons other than this.
(1) The minimum requirements in this Table are based on a 30% use of the Area made by Design Vessels, as calculated on the total useful time available (therefore deducting the Area's downtime for any reason: insufficient water level, maritime climate, night-time, etc.). Should this percentage of use be equal to or less than 20%, figures of double those given in the Table may be used. Likewise, if the area's percentage of use were equal to or more than 40%, figures of half those given in the Table should be used. They may be interpolated for intermediate values.
(1) Maximum downtimes will be calculated for maximum values of H_l for fishing and pleasure boat Design Vessels.

depth is strict in relation to the largest vessels sailing through them, in order to avoid risks that might arise for navigation in these cases. Water depths less than 150% of the most unfavourable fully loaded vessel when seabeds are silty or sandy and less than 200% when rocky will be taken as strict.

7.2.5.2. Sediment deposit between two dredging campaigns

The additional water depth that must be provided for for silting up which may occur between two dredgings will depend on the littoral or fluvial dynamics of the site under consideration and the time elapsing between two successive dredging operations. This phenomenon shall be particularly taken into account in the case of river channels or stretches of coast subject to cross or longitudinal sediment transportation involving appreciable amounts. In the absence of littoral or fluvial dynamics studies, at least forecasts based on the historical evolution of water depths with regular contrast measurements to guarantee that forecasts are not exceeded are recommended.

7.2.5.3. Dredging performance tolerance

Dredging performance tolerance basically depends on the ground characteristics, the dredging equipment used and the limit environmental conditions in which the equipment is allowed to operate. As an indication, the adoption of tolerances of 0.30 m for soft ground and 0.50 m for rocky ground are recommended.

This additional water depth will not be taken into account should tolerances by defect be admitted in the design and performance of dredging work since, in these cases, dredging work quality control shall guarantee that no points above the level required remain.

7.2.6. Empirical procedures

This section gives empirical criteria usually used solely for prior studies which quantify vessel related factors, including draught and Safety Margins (H_l) as a function of the features of the Harbour Basins under analysis and the draught (C) of the vessel being considered.

	H_l
◆ Outer harbours, anchorages and outer fairways. Harbour entrances.	
• Sheltered by the shape of the coast	1.10 C
• Low degree of protection	1.20 C
• Open water with waves H_S < 1.00 m	1.30 C
• Totally open water with waves $H_S \geq$ 2.00 m.	1.50 C
◆ Inner fairways	
• Sheltered	1.10 C
• Low degree of protection	1.15 C
◆ Manoeuvring areas	
• Sheltered	1.08 C
• Low degree of protection	1.12 C
◆ Protected quays and berthings	
• For large vessels (D > 10,000 t)	1.08 C
• For small and medium vessels (D ≤ 10,000 t)	1.05 C
◆ Quays and berthings with low degree of protection	
• For large vessels (D > 10,000 t)	1.12 C
• For small and medium vessels (D ≤ 10,000 t)	1.10 C

In any case, the minimum gross clearance must be 0.50 m, except in the case of fishing and pleasure boats where this minimum may be reduced to 0.30 m.

7.2.7. Operating manuals

The water depth determining procedure as given in the foregoing sections is a design criterion based on analysing the most unfavourable vessels operating under environmental limit conditions for the different manoeuvres analysed. The method used bears with it an analysis of the different isolated factors which are gradually conditioned by introducing some simple correction procedures to take into account the least probability of the simultaneous occurrence of separate variables. An overall statistical analysis of all the factors simultaneously acting is not feasible at the present time.

The method expounded enables it to be used not only as a design criterion but also as an Operating Rule, developing any combination of parameters required in each specific case as a function of each port's characteristics and function. Thus, as an example, tide or wave conditions in which vessels smaller than the design maximums might operate or the maximum wind conditions that larger design vessels could accept should the most unfavourable tides not occur, or many other combinations could be studied. Drawing up Operating Manuals which first quantify the most frequent applicable cases by means of tables or graphs is recommended in order to facilitate this application automatically. When computerizing this Recommendation, the ROM programme has planned the incorporation of an operating programme which will enable this analysis to be made in all cases.

7.3. CLEARANCE ABOVE HARBOUR BASINS

Above water clearances necessary in different Navigation Channels and Harbour Basins will be determined in each case by taking into account the following factors:

- The height of the masts or highest elements of vessel upper works as well as vessel related factors which might lead to some point reaching an elevation higher than that corresponding to a flat plate keel under static conditions in seawater.
- The level of Water being considered and factors affecting its variability which will determine the reference plane for positioning the vessel.
- Safety margins established to prevent a vessel contacting with elements crossing over Navigation and Harbour Basins.

Table 7.5. *Mean water level under operating conditions for vessels staying areas*

Area´s characteristics	NMO
A. Areas with no fluvial currents – Astronomical tide only – Astronomical and meteorological tide	 NM NM + 0.10 M
B. Areas with fluvial currents – Astronomical tide only – Astronomical and meteorological tide	$NMF + \frac{A_{PMVE} - A_{BMVE}}{2}$ $NMF + \frac{A_{PMVE} - A_{BMVE}}{2} + 0.10M$
C. Locks	Upstream level
D. Locked Basins	Detail study

Legend:
NMO = Mean Operating Conditions of the free outer water.
NM = Mean Sea Level = (HAT + LAT) / 2
NMF = Mean level of the fluvial current = (NME + NMI) / 2
PMVE = Highest Astronomical Tide.
BMVE = Lowest Astronomical Tide.
NME = Mean Low Water Level in fluvial currents.
NMI = Mean level of annual maximums in fluvial currents.
A_{PMVE} = Half wave amplitude for the PMVE.
A_{BMVE} = Half wave amplitude for the BMVE.

There is currently no extensive, reliable statistical information available on the height of masts or highest elements in the superstructures of vessels which allow a strict analysis of this dimension to be made, which is why implementing a calculation model similar to that developed for water depths is of no practical use. On the other hand, statistics are available on bridges built over Harbour Basins which allow the above water space available to be correlated with the water depth in the area, without knowing, for sure, on the other hand, whether such water depth is being used or not for navigation. However, taking into account that where there are natural water depths, they can be foreseen as ending up accepting commercial maritime traffic compatible with them, it was decided to establish unhindered navigation clearances by means of a simple correlation with the commercially used water depths available at the site. Should it be planned to extend this water depth, the possibility of the Area being operable for larger vessels must be taken into account. The scheme recommended for calculating the unhindered navigation clearance is as follows:

Table 7.6. Maximum outer water level for above water clearance and drainage studies

Area´s characteristics	$N_{max}O$
A. Areas significant astronomical tide (U.A. > 0.50 m)	
– With no fluvial regimes	
• Astronomical tide only	PMVE
• Astronomical and meteorological tide	PMVE + 0.50 m
– With fluvial regimes	
• Astronomical tide only	Extreme maximum. Risk: = 0.10
• Astronomical and meteorological tide	Extreme maximum. Risk: 0.10
B. Areas with non significant astronomical tide	
– With no fluvial regimes	
• Astronomical tide only	NM + 0.50 m
• Astronomical and meteorological tide	NM + 1.00 m
– With non significant fluvial regimens ($N_{max}RH$ - $N_{min}RH$ < 1.00 m)	
• Astronomical tide only	NmaxRH + 0.50 m
• Astronomical and meteorological tide	NmaxRH + 1.00 m
– With significant fluvial regimes ($N_{max}RH$ - $N_{min}RH$ > 1.00 m)	
• Astronomical tide only	Extreme maximum. Risk: = 0.10
• Astronomical and meteorological tide	Extreme maximum. Risk: 0.10
C. Locks	Upstream level
D. Locked Basins	Extreme maximum. Risk = 0.10

Legend:
$N_{max}O$ = Maximum level of free outer water under operating conditions.
PMVE = Highest Astronomical Tide.
NM = Mean Sea Level = (HAT + LAT) / 2
BMVE = Lowest Astronomical Tide.
$N_{max}RH$ = Extreme level to be expected for annual maximums of the fluvial regime associated to an admissible risk.
$N_{min}RH$ = Extreme level to be expected for annual minimums of the fluvial regime associated to an admissible risk.

1°. Determine the Mean Operating Level *NMO* of the water, using the criteria given in table 7.5.

2°. Determine the water depth (*h*) for this Mean Operating Level, taking possible dredging operations which may be performed in the area into account. Should this water depth exceed the maximum values required for Design Vessels to navigate, the depth of water required by these Vessels will be taken as the value of (*h*).

3°. Assess the above water space (*a*) associated with this water depth with the following criteria:

◆ Transit of commercial vessels of any size (except passenger cruise liners):

$$a = 5\ h, (a_{max} = 60 \text{ m})$$

- Transit of passenger cruise liners:

$$a = 7\ h, (a_{max} = 70 \text{ m})$$

- Transit of sailing vessels:

$$a = 10\ h, (a_{max} = 50 \text{ m})$$

The maximum values of «*a*» given in the foregoing expressions refer to the vessels shown in Table 3.1.

4°. Determine the Maximum Water Level existing under Operating conditions, $N_{max}O$ with the criteria given in Table 7.6.

5°. Add the above water space «*a*» over the Maximum Water Level ($N_{max}O$) as defined above.

6°. Consider an additional Safety Margin of 10 m except in areas where only fishing and pleasure boat traffic with lengths overall less than 12 m is expected, when the additional Safety Margin could be reduced to 5 m. The unhindered clearance shall therefore be located at elevation:

$$N_{max}O + a + \text{Safety Margin}$$

Should clearances less than those recommended here be adopted, the pertinent limitations will be established in the Operating Rule for the Navigation or Floatation Area in question.

7.4. QUAY CROWNING LEVELS

Quay crowning levels measured at their ledge line or berthing edge will be equal to or more than the highest level resulting from applying the following criteria:

7.4.1. Operational criteria

The quay level is established as a function of the water's Mean Operating Level (NMO) increasing by the following amounts depending on the displacement of the largest ships operating at the quay.

- Large displacement vessels (∇ > 10,000 t) = + 2.50m
- Medium displacement vessels (10,000 $\geq \nabla$ > 1,000 t) = + 2.00m
- Small displacement vessels ($\nabla \leq$ 1,000 t) (except pleasure boats) = + 1.50m
- Pleasure boats (Length > 12 m) = + 1.00m
- Pleasure boats (length $\leq$ 12 m) = + 0.50m

The Mean Operating Level (*NMO*) will be determined as a function of the site's characteristics using the criteria given in Table 7.5, entitled «Mean Water Level under Operating conditions for Areas of transit or staying vessels». This Table is based on meteorological tide data for Spanish coasts which is why it is only valid for such geographic areas.

For the case of pleasure boat quays, if the difference between the water's Mean Operating Level (*NMO*) and the Minimum Reference Level for determining water depths as established in section 7.2.4.6. exceeds 0.80 m, a floating type quay is recommended. Likewise, in the case of Ro-Ro quays, if this difference exceeds 2.00 m, the installation of a movable ramp is recommended.

7.4.2. Criteria of non overtopping by free outer water

The quay level is set as a function of the highest free outer water Level (sea, river channel, etc.) under extreme design conditions associated to an acceptable risk of 0.10, which level will be increased by a minimum clearance of 0.50 m.

This level will be determined using the overall Extreme Regimes where they exist and, otherwise, by analysing combinations of hypotheses in which it is contemplated that one or the other variable (waves, tide, fluvial regime, etc.) may be the one with the predominant effect (to which will be assigned factor 1.00 and to the remaining combination factors, 0.7). When carrying out this study, wave modifications caused by the actual structures will be taken into account.

Should items (mooring lines, catwalks, etc.) which may accept overtopping under exceptional conditions with no significant losses of operability be considered, the levels previously established may be optimized by carrying out the pertinent techno-economic justifying study in this respect.

7.4.3. Criteria of exceeding the water table at the quay's rear

Quay level, both at the ledge line and over the whole of its area, will be established with sufficient clearance for paving and possible utility conduit (water, light, electricity, etc.) to be located above the Water Table of the water at the rear of the quay. To this end, quay levels will be kept at least 0.50 m above the Water Table determined under extreme design conditions associated to an admissible risk of 0.10.

7.4.4. Drainage criteria

Quay level, both at the coping line and over the whole of its area shall allow for rainwater drainage under the most unfavourable design conditions, assuming that the free outer water Level is at the levels as defined in Table 7.6. according to the site's characteristics.

Regardless of whether this drainage can be carried out on the surface, sufficient height for installing underground drain systems using gravity discharge pipes is recommended, and provision for changes in use which may not allow for surface drainage will be made.

Part VIII

Layout requirements

LAYOUT REQUIREMENTS

Part VIII

8.1. SCOPE OF THE CHAPTER

8.1.1. This chapter gives criteria for geometrically defining the layout of Navigation Channels and Harbour Basins and other harbour facilities whether maritimei, fluvial or lake located. Layout configuration and dimensions of the different Navigation Channels and Harbour Basins may vary and operating conditions accepted by them, tug-boat availability, the number and type of aids to navigation, vessel traffic characteristics and distribution, construction and maintenance costs and other aspects as given in Chapter 2 are established in each one, taking into account the facility's useful lifetime. The configuration and dimensions adopted shall allow vessel navigation, manoeuvres, staying and loading and unloading under safe conditions for the whole operating time and conditions established for the facility for all vessels using those Navigation Channels and Harbour Basins.

The procedure for determining this geometric definition follows the general criteria as established in section 2.5., i.e.:

- To calculate vessel occupied area, which depend, on the one hand, on the vessel and on factors affecting its manoeuvrability and, on the other, on the navigation marking system and aids to navigation.
- To increase these areas by Safety Margins.
- To compare these area requirements with those available or required at the site.

8.1.2. In view of the fact that approach and departure naigation of vessels to and from harbour and harbour facilities occurs in the initial and final stages, the chapter commences by giving an introduction in its section 8.2. to the general provisions on maritime traffic organization as established by the International Maritime Organization (IMO) which is the official body authorized to regulate these matters on an international level. The provisions relate to areas of maritime traffic convergence or high density or to those others where vessel freedom of movement is diminished through adverse meteorological conditions. These general regulations are basically applicable to navigation outside ports, although they should be considered as a guide for designing what are specifically port Navigation Channels and Basins, which are regulated in greater detail in this Recommendation.

8.1.3. These port Approach Channels and Basins are analysed in sections 8.4 to 8.11 with the following order and content:

- Fairways, which comprise approach routes, approach channels and inland canals.
- Harbour entrances.
- Manoeuvring areas comprising the areas necessary for vessel stopping and turning.
- Anchorage areas and outer harbours.
- Mooring areas and buoy systems.
- Basins and quays.
- Emergency areas.
- Special facilities (shipyards, locks, etc.).

8.1.4. Apart from these design criteria, section 8.12, called «Limit operating conditions», gives the values of the variable maritime and meteorological, i.e., environmental conditions (winds, waves, currents, etc.) which have usually been used as limits for carrying out the different vessel navigation, approach, turning, berthing, staying or departure manoeuvres in the different Navigation or Floatation Areas. Not only will the dimensions of the area being analysed depend on the values finally adopted, but also on tug-boat and aids to navigation requirements, as well as on the percentages of downtime of the area being considered. Should these values, or those established in each particular case, be adopted, they should be incorporated into the Operating Rules of the port or port facility under consideration, regardless of the improvements which may be established for operating vessels smaller than the design vessel (see section 3.1) or for different combinations of environmental variables, as sketched out in section 8.12.

8.1.5. This ROM sets criteria for designing different Navigation Channels and Harbour Basins as a function of the vessels which can operate in them but does not analyse the capacity of these Areas. The number of traffic lanes a Fairway must have or the number of anchoring stations or the number of quays or berthing points or any other aspect related to the capacity of these Areas basically depend on the traffic forecast for the different target years and on many other planning, operational and equipping aspects of the facility being considered, the technical and economic assessment of which exceeds the scope of this ROM.

8.2. GENERAL PROVISIONS ON MARITIME TRAFFIC ORGANIZATION

8.2.1. Scope of application

The content of section 8.2 is taken literally from Resolution A.572 (14) of the International Maritime Organization (IMO) adopted on 20 November, 1985. IMO is recognized as the only international body responsible for establishing and recommending measures on an international level concerning ship's routeing. (3.1).

The selection and development of routeing systems is primarily the responsibility of the Governments concerned. (3.7)

A Government proposing a new routeing system or an amendment to an adopted routeing system, any part of which lies beyond its territorial sea, should consult IMO so that such system may be adopted or amended by IMO for international use. (3.8)

Governments establishing traffic separation schemes, no parts of which lie beyond their territorial seas, are requested to design them in accordance with IMO criteria for such schemes and submit them to IMO for adoption. (3.12). Where, for whatever reason, a Government decides not to submit a traffic separation scheme to IMO, it should, in promulgating the scheme to mariners, ensure that there are clear indications on charts and in nauticalpublications as to what rules apply to the scheme. (3.13)

Resolution A.572 (14), which is reproduced in Annex no. II only in its technical aspects, also gives the Procedures for processing, approving and implementing Ship's Routeing Systems.

8.2.2. Objectives

a) The purpose of ship's routeing is to improve the safety of navigation in converging areas and in areas where the density of traffic is great or where freedom of movement of shipping is inhibited by restricted sea-room, the existence of obstructions to navigation, limited depths or unfavourable meteorological conditions. (1.1)

b) The precise objectives of any routeing system will depend upon the particular hazardous circumstances which it is intended to alleviate, but may include some or all of the following:

1. To separate opposing streams of traffic in order to reduce the frequency of head-on encounters;

2. To reduce dangers of collision between crossing traffic and shipping crossing established fairways and those navigating on them;

3. To simplify traffic the patterns of traffic flow in converging areas;

4. To organize safe traffic flow in areas of concentrated offshore exploration or explitation;

5. To organize traffic in or around areas where navigation by all ships or by certain classes of ship is dangerous or undesirable;

6. To reduce risk of grounding to providing special guidance to vessels in areas where water depths are uncertain or critical;

7. To guide traffic clear of fishing grounds or to organize traffic through them.

8.3. DETERMINING THE LAYOUT AND DIMENSIONS OF NAVIGATION CHANNELS AND HARBOUR BASINS

8.3.1. The layout configuration and dimensions necessary in different Navigation Channels and Harbour Basins will be determined in each case taking the following factors into account:

- The size, dimensions and manoeuvrability characteristics of vessels and vessel related factors, including the availability of tug-boats on which the surface area required for vessel navigation, manoeuvring or staying in the Area under consideration (B_1) depends.

- Aids to navigation available and factors affecting their accuracy and reliability, which will determine the reference lines or points for postioning the vessel (B_2).

- Safety margins that are established to prevent a vessel colliding with Navigation Channels or Harbour Basin boundaries or other ships or fixed or floating objects which may exist in the surroundings. An assessment of these safety margins is given in the (B_1) block of factors.

Taking the foregoing factors into account will quantify the minimum layout area and dimensions, or nominal dimensions that must be required of the nominal water depths if the use of water areas is analysed or in above water clearances if dealing with the sweeping of such areas, both calculated (nominal depth and clearance) with the criteria as given in Section VII. These horizontal areas will require a set of boundary related factors (B_3) to be taken into account in order to be guaranteed as areas available at the site which section 2.5. specifies.

Apart from these factors, which are specific to vessel navigation and floatation, other conditioning factors alien to this function which may prove to be determining factors for the design of the Area under analysis must be taken into account in each case.

8.3.2. There is no integral analysis model currently available which takes all factors into account, and this is why Navigation Channels or Anchorage layout design has usually been performed by some of the following procedures:

- Totally empirical methods setting dimensions as a function of good engineering practice criteria.

- Semi-empirical methods combining a mathematical analysis of some of the factors with the empirical consideration of the remainder.

- Computer model simulation with human pilots or using automatic pilots, in combination with a statistical analysis of the results obtained.

This Recommendation, as expounded in section 2.4.2., lays down two procedures: determinist and semi-probabilistic, of which the former is semi-empirical and the latter is based on using human pilot simulation models, and both enable design to be associated to the established operating conditions and to the risk accepted for the design. In both cases, Safety Margins (B_3) are empirically determined.

Section 9 of this ROM analyses the use of simulation models and recommendations are given on the advisability of using these types of study which, in general, will be most necessary in the following cases:

- When maritime or meteorological environmental conditions vary in the Area.

- When manoeuvres are undertaken with manual pilots and area availability does not enable the solutions as recommended to be developed by determinist methods.
- When it is wished to optimize the design by determinist methods, taking the design as comprising the elements defined in section 2.3 (geometric configuration, marking and navigation marking systems, limit environmental operating conditions and tug-boat availability).
- When laying down consensus solutions or for training operators who will be intervening in navigation or manoeuvres.

8.4. FAIRWAYS

8.4.1. Factors affecting design

Designing a fairway mainly depends on the following factors:

- The size, dimensions and manoeuvrability of the most testing vessels it is envisaged will be received (which might not be the largest which is why it will usually be necessary to analyse different types of vessel); should the study be carried out considering vessels as sub-divided into categories, the worst, most testing in each category will be considered.
- Traffic volume and nature as well as admissible navigation speeds.
- The type of navigation planned as a function of the number of fairways available.
- The geometric characteristics of the fairway's alignment and surrounding conditions.
- The type of aids to navigation, as well as their characteristics as regards accuracy and availability.
- The fairway's depth and cross geometric characteristics.
- The fairway's slope stability.
- The maritime and meteorological environmental conditions in the area, especially the nature and intensity of cross currents and, very outstandingly, the change in these currents along the fairway's axis.
- The fairway operators' experience.

A track of fairway will be used for applying either of the two methods established in this ROM (determinist or semi-probabilistic) to then determine the width required in all its critical sections and subsequently establish the width transitions between the different stretches. The procedure will be iterative to the extent whereby consideration of the different factors forces some of the initial design parameters to be reconsidered.

8.4.2. General layout recommendations

Although the plan alignment of fairways largely depends on local conditions, the following general recommendations to be taken into account in the design may be made:

- A fairway should be as straight lined as possible, avoiding S alignments (bend followed by a reverse bend).
- If feasible, a fairway shall follow the direction of the main currents, so that the cross current effect is minimized. This criterion shall also be followed with winds and waves although this will be more difficult to achieve as they usually arrive from different directions.

- A fairway must avoid areas of sediment accretion or deposit to minimize maintenance costs.
- If feasible, approach fairways will be oriented so that storms on the ebam are avoided, i.e., preferably orienting them in the prevailing wave direction or at most forming an angle of up to 15/20° between the fairway's axis and the direction of these prevailing waves.
- Harbour entrance approach fairways must preferably be straight, avoiding bends in or close to the entrance so that the need for vessels to alter course in a difficult, critical navigation area is avoided. If bends were imperative, they will be located, if possible, so that the fairway fulfils the conditions recommended for passing narrow sections.
- Fairway alignments will endeavour to avoid vessels having to make their approach to quays or berths beam on, as this might cause an accident should control over the vessel be lost. If possible, a fairway should be located parallel to quays and berths so that such manoeuvre can be performed with a minimum of risk. Extreme care will be taken with respect to this precaution in the case of hazardous cargo traffic.
- Narrow sections (bridges, entrances, etc.) will be passed in well navigation marked, straight fairway stretches, keeping the alignment straight over a minimum distance of 5 lengths (L) of the maximum vessel, on either side of the narrow section.
- Should bends be necessary, a single bend is better than a sequence of small bends at short intervals provided the fairway is correctly navigation marked.
- The bend radius will be a minimum of 5 lengths (L) of the largest vessel it is envisaged will be using the fairway, but preferably using radii of 10 lengths (L) or more if feasible; the higher values will be used the larger the angle between the straight alignments defining the bend.
- The length of curved legs must not be greater than half the bend's radius, which means that the angle between straight alignments must not be greater than 30°, if feasible.
- Straight legs located between bends must have a length 10 times the length (L) of the largest vessel expected to be using the fairway, if viable.
- Visibility measured on the fairway's axis must be greater than the design vessel's stopping distance, assuming it is navigating at the maximum navigating speed admissible in the fairway.
- Transitions between stretches of a different width will be made by adjusting the limit or limitation lines by means of straight alignments with ground plan variations not greater than 1:10 (preferably 1:20) in each one.

8.4.3. Fairway width

8.4.3.1. General criteria

A fairway's width, measured perpendicular to its longitudinal axis will be determined by the sum of the following terms:

$$B_t = B_n + B_r$$

where:

B_t = The fairway's overall width.

B_n = The fairway's nominal width or clear space which must remain permanently available for vessel navigation, including Safety Margins. This nominal width therefore includes the influence of all factors designated as B_1 and B_2 in section 8.3.1.

B_r = An additional reserve width for taking into account boundary related factors (B_3). (For instance, reserve for slope instability in the case of the fairway's boundaries being made with this type of structure). This width may be different on either bank, «B_{ri}» or «B_{rd}», according to the latter's nature and characteristics.

The overall width «B_t» will be measured at the narrowest point of the fairway's cross section, which, being areas of water, will usually coincide with the width between slopes or structures of the fairway's banks measured at the fairway's nominal depth for the design vessel.

Should quays or berths or any other type of facility be built on the fairway's banks, the spaces required for their implementation and operation with the safety margins as established will be located outside the fairway's overall width «B_t» In the absence of specific criteria, a reserve of area 2.5 times the design vessel's beam will be kept between the channel's limit and any vessel which might be berthed at adjacent quays. This 2.5 B reserve space will be likewise kept between the channel's limit and the most advanced position a vessel anchored or moored in its vicinity may reach.

The nominal fairway width «B_n» will be calculated in accordance with the following criteria, depending on whether the determinist or the semi-probabilistic method is used.

8.4.3.2. Determinig nominal width «B_n» by the determinist method

a) SINGLE LANE FAIRWAYS

1. *Navigation in straight stretches under constant environmental conditions over the whole track*

The minimum nominal width of a straight stretch, single lane fairway (thus with no possibility of vessel passing or overtaking manoeuvres) should the maritime and meteorological environmental conditions (winds, waves and currents) be constant over the whole track, will be determined as the sum of the following dimensions (see fig. 8.01):

$$B_n = B + b_d + 2(b_e + b_r + b_b) + (rh_{sm} + rh_{sd})_i + (rh_{sm} + rh_{sd})_d$$

where:

B = Maximum beam of vessels which will sail over the fairway.

b_d = Additional width of the vessel's swept path produced by navigation with a certain angle –drift angle– to the fairway's axis, in order to correct the vessel's drift caused by the wind, wave, current or tug-boat effect. The additional width necessary (b_d) will be calculated with the following formula:

$$b_d = L_{pp} \bullet \sin \beta \text{ (for evaluating water spaces)}$$
$$b_d = L \bullet \sin \beta \text{ (for evaluating above water spaces)}$$

where:

L_{pp} = Length between the design vessel's perpendiculars.

L = Design vessel's length overall.

β = Angle of drift, which can be determined with the following formulas valid for values of b ≤ 25°.

- *For drift caused only by wind action* (also called cast in this case)

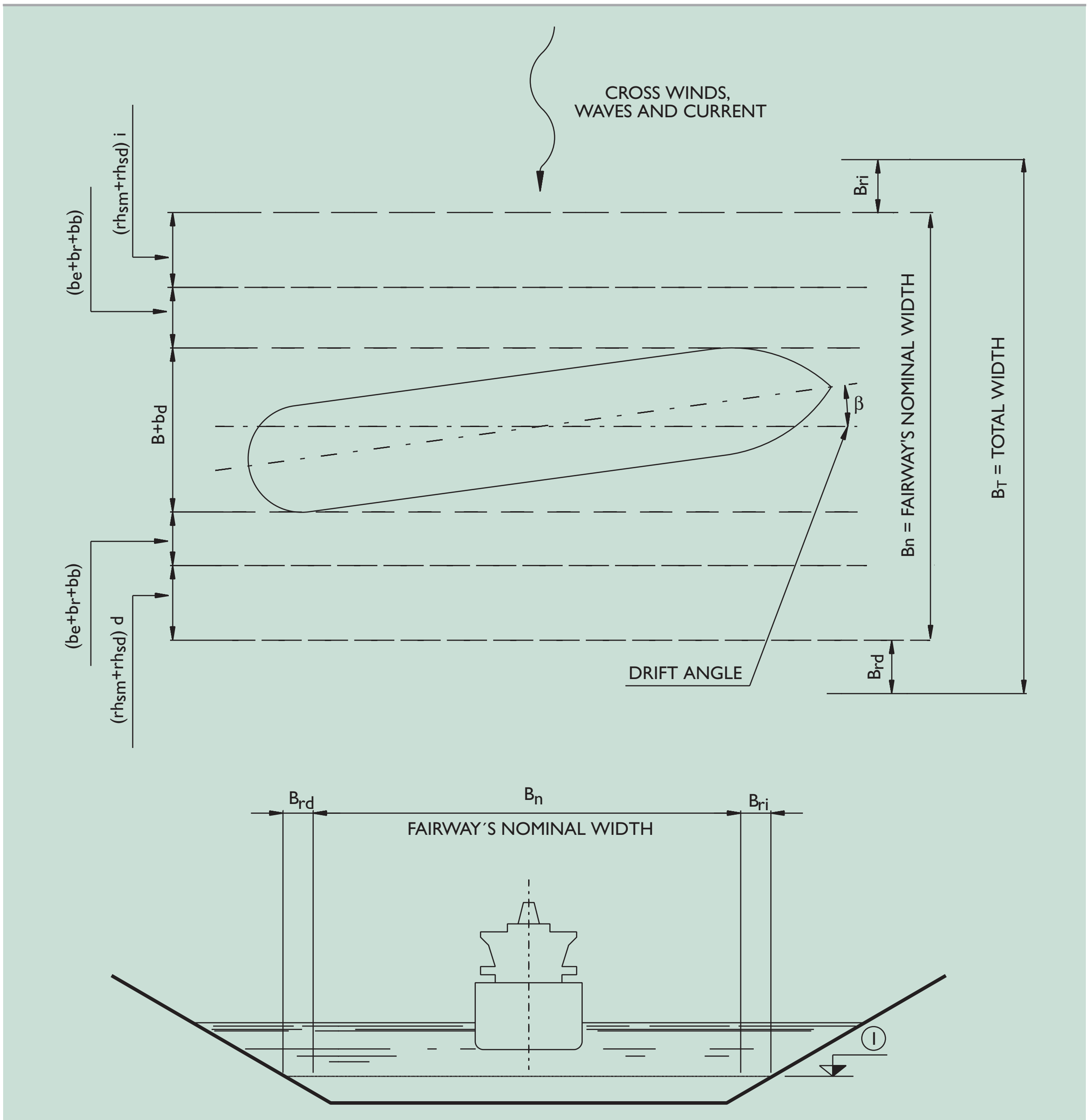
$$\beta = \arcsin \frac{K_v \cdot C_v \cdot V_{sr} \cdot \sin \alpha_{VT}}{V_r}$$

where:

K_v = Coefficient depending on the hull's shape, the ratio *h/D* between the site's water depth (*h*) and the vessel's draught (*D*) and the angle α_{vr}.
For bulbous bow hulls, the coefficient K_v may be obtained by linearly interpolating between the following values:

h/D	K_v			
	$\alpha_{vr} \leq 10°$	$\alpha_{vr} \leq 30°$	$\alpha_{vr} \leq 60°$	$\alpha_{vr} \leq 90°$
≤ 1.20	0.0343	0.0227	0.0184	0.0172
2.00	0.0402	0.0266	0.0216	0.0201
≥ 5.00	0.0423	0.0280	0.0227	0.0211

Figure 8.01. **Width of straight stretch fairways with a single navigation line**



(1) Fairway's nominal depth.

For conventional bow hulls, the coefficient K_v may be obtained by linearly interpolating between the following values:

h/D	K_v			
	$\alpha_{vr} \leq 10°$	$\alpha_{vr} \leq 30°$	$\alpha_{vr} \leq 60°$	$\alpha_{vr} \leq 90°$
≤ 1.20	0.0243	0.0161	0.0130	0.0121
2.00	0.0255	0.0168	0.0136	0.0127
≥ 5.00	0.0259	0.0171	0.0139	0.0129

$$C_v = \left(\frac{A_{LV}}{A_{LC}}\right)^{0.5}$$

A_{LV} = Windage of the vessel's longitudinal projection. See section 4.8 for determining same.
A_{LC} = Vessel's longitudinal submerged area projected onto the centre line plane. See section 4.8 for determining same.
V_{vr} = Wind speed relative to the vessel being analysed. The absolute wind speed values considered as the fairway's operating limit will be used to determine same.
V_r = Vessel's speed relative to the water. The criteria as given in section 7.2.3.4.3 will be used for quantifying same, adopting the lowest vessel speed values compatible with the navigation under analysis.
α_{vr} = Angle between the relative wind direction (incoming) and the vessel's centre line plane.

- *For drift caused only by current action*

$$\beta = arctg \frac{V_c \cdot \sin e \alpha_{cv}}{V + V_c \cdot \cos \alpha_{cv}}$$

where:
V_c = Absolute current speed considered as the fairway's operating limit.
V = Absolute vessel speed relative to the seabed. The criteria as given in section 7.2.3.4.3 will be used for quantifying same, adopting the lowest vessel speed values compatible with the navigation under analysis.
α_{vr} = Angle between the absolute current direction (incoming) and the vessel's absolute speed.

- *For drift caused only by wave action*

$$\beta = \arcsin e \left[K_w \cdot \left(\frac{g}{D} \right)^{0.5} \cdot \frac{H_s}{V_r} \right]$$

where:
K_w = Coefficient depending on the hull's shape, on the ratio *h/D* between the site's water depth (*h*) and the vessel's draught (*D*) and the angle α_w. (It is assumed in a first approximation that this coefficient is irrespective of the wave period and length, although a more detailed evaluation may be made as a function of these parameters by using the general formulation in Part 4). For bulbous bow hulls, the coefficient K_w may be obtained by linearly interpolating between the following values:

h/D	Kw						
	$\alpha_w \leq 10°$	$\alpha_w \leq 30°$	$\alpha_w \leq 60°$	$\alpha_w \leq 90°$	$\alpha_w \leq 120°$	$\alpha_w \leq 150°$	$\alpha_w \leq 170°$
≤ 1.20	0.0418	0.0725	0.1508	0.1871	0.1673	0.1025	0.0592
2.00	0.0490	0.0849	0.1768	0.2193	0.1961	0.1201	0.0693
≥ 5.00	0.0515	0.0892	0.1857	0.2303	0.2060	0.1261	0.0728

For conventional bow hulls, the coefficient K_w may be obtained by linearly interpolating between the following values:

h/D	Kw						
	$\alpha_w \leq 10°$	$\alpha_w \leq 30°$	$\alpha_w \leq 60°$	$\alpha_w \leq 90°$	$\alpha_w \leq 120°$	$\alpha_w \leq 150°$	$\alpha_w \leq 170°$
≤ 1.20	0.0296	0.0512	0.1067	0.1323	0.1183	0.0725	0.0418
2.00	0.0310	0.0537	0.1118	0.1387	0.1240	0.0760	0.0439
≥ 5.00	0.0315	0.0546	0.1137	0.1410	0.1261	0.0772	0.0446

α_w = Angle between the wave propagation direction (incoming) and the vessel's centre line plane.
g = Acceleration of gravity
H_s = Significant wave height of the waves considered as the fairway operating limit for the vessel being analysed.
V_r = Vessel's speed relative to the water. The criteria as given in section 7.2.3.4.3 will be used for quantifying same, adopting the lowest vessel speed values compatible with the navigation under analysis.
D = Draught of the vessel under analysis.

◆ *For drift caused only by tug-boat action*

$$\beta = \text{arcsine}\left[K_w \cdot \left(\frac{g \cdot F_{TR}}{A_{LC} \cdot \gamma_w}\right)^{0.5} \cdot \frac{1}{V_r}\right]$$

where:

K_r = Coefficient depending on the hull's shape, on the ratio h/D between the site's water depth (h) and the vessel's draught (D). It may be obtained by interpolating between the following values:

h/D	K_r	
	Bulbous bow	Conventional bow
≤ 1.20	0.63	0.45
2.00	0.74	0.47
≥ 5.00	0.78	0.48

g = Acceleration of gravity

F_{TR} = Component of the force resulting in the vessel's transverse direction from tug-boats acting on it.

A_{LC} = Vessel's submerged longitudinal area projected onto the centre line plane. See section 4.8. for determining same.

γ_w = Specific weight of water.

V_r = Vessel's speed relative to the water. The criteria as given in section 7.2.3.4.3 will be used for quantifying same, adopting the lowest vessel speed values compatible with the navigation under analysis.

◆ *For drift caused by the simultaneous action of wind, currents, waves and tug-boats*

The drift angle «b» will be calculated assuming that its sine is the sum of the sines of the drift angles for the different forces acting separately, i.e.;

$$\sin\beta = (\sin\beta)_{wind} + (\sin\beta)_{currents} + (\sin\beta)_{waves} + (\sin\beta)_{tug\text{-}boats}$$

This sum will be algebraic, and, therefore each drift will be considered with its pertinent plus or minus sign. It must be pointed out in this respect that drift for each effect occurs in the direction taking the bow towards the side where the action is received.

The limit navigation conditions are recommended to be selected so that drift angles above the following do not occur, in the event whereby the vessel is sailing at the lowest transit speeds admissible:

	β
◆ Fairways in areas with $h/D \geq 1.20$	
• Normal stretches	5°
• Singular points	10°
◆ Fairways in areas with $h/D = 1.50$	
• Normal stretches	10°
• Singular points	15°
◆ Fairays in areas with $h/D \geq 5.00$	
• Normal stretches	15°
• Singular points	20°

where (h) is the at rest water depth and (D) is the vessel's draught.

b_e = Additional width through positioning errors. This relates to the difference (only the component crosswise to the fairway's axis) between the vessel's true position and the position as estimated by the captain using the information methods and aids to navigation available in the Navigation or Floatation Area being analysed. The following will be used in the absence of further information on the accuracy of these aid systems. All values for electronic systems are for 95% predictable accuracy.

	Operation without a pilot or captain experienced in the site being considered	**Operation with a pilot or captain experienced in the site being considered**
◆ Visual positioning in open estuaries, without navigation marking:	100 m	50 m
◆ Visual positioning referred to buoys or beacons in approach ways:	50 m	25 m
◆ Visual positioning between buoy or beacon alignments marking the fairway's limits:	20 m	10 m
◆ Visual positioning by means of leading lines:	0.5°	0.5°
◆ Positioning by means of radioelectric systems (valid for locating on a nautical chart with no visual positioning)		
• Radiobeacons:	5.0°	5.0°
• Radar (aboard). S Band:	1.5°	1.5°
• Radar (aboard). X Band:	1.0°	1.0°
• RACON (distance/delay):	150 m / 0.3°	150 m / 0.3°
• TRANSIT.		
Dual Frequency:	25 m	25 m
GPS:	100 m	100 m
DGPS:	10 m	10 m

The difference in position in all the values expressed in degrees is the product of the distance multiplied by the sine of the pertinent angle and will not always coincide with the component transversal to the fairway's axis which is the value «b_e» sought.

Should the fairrway be dimensioned assuming «operation with pilot or experienced captain», this condition shall be shown in the pertinent Operating Rules or Manuals.

Should the characteristics of the aid to navigation system not be known, a value equal to the maximum beam «*B*» of vessels operating in the fairway will be taken as the measurement of this additional width «b_e» for preliminary studies.

b_r = Additional response width which assesses the additional deviation that may occur from the moment when the vessel's deviation from its theoretical position is detected and the instant when the correction becomes effective. This additional width will be determined as a function of the vessel's manoeuvrability characteristics, of the maximum beam (*B*), of the ratio between the site's at rest water depth (*h*) and the vessel's draught (*D*) and of the maximum Risk admissible (E_{max}) during the Useful Life of the Design Phase being analysed, by means of the expression:

$$b_r = (1.50 - E_{max}) \cdot b_{ro}$$

where:

E_{max} = Maximum Risk admissible determined with the criteria as given in Table 2.2.

b_{ro} = Additional response width for a value of E_{max} = 0.50, which can be determined with the following criteria:

Vessel´s manouvrability	bro	
	h/D ≤ 1.20	h/D ≥ 1.50
Good Medium Bad	0.10 • B 0.20 • B 0.30 • B	0.10 • B 0.15 • B 0.20 • B

where:

- Good manoeuvring capability vessels: Warships (except submarines), ferry and ro-ro vessels, small boats (fishing and pleasure).

- Vessels in the following paragraph could also be considered as having a good manoeuvring capability if their cargo status is less than 50%.

- Medium manoeuvring capability vessels: Oil tankers, bulk carriers, methane carriers, liquid gas carriers, container ships, general cargo merchant ships, multipurpose carriers and passenger vessels, with cargo statuses equal to or greater than 50%.

- Bad manoeuvring capability vessels: disabled and badly maintained old vessels.

  Medium vessel manoeuvrability conditions will be used for dimensioning general traffic fairways since, in general, bad manoeuvrability will relate to old ships which will not usually be the largest dimensioned or to disabled vessels whose transit through the fairway may be regulated with special aids to navigation so that risks are reduced.

b_b = Additional width for covering an error which might derive from the navigation marking systems. In the absence of greater information on the characteristics of these systems, the following criteria will be used:

- The maximum swing which a buoy may display in relation to its theoretical position will be calculated for buoy marking under the Limit Environmental Operating Conditions and under extreme tidal conditions which might occur. The possibility of buoy anchoring dead man drag will also be considered in the case whereby environmental or channel maintenance conditions do not guarantee the dead men will remain in their theoretical anchoring position.

- Optical leading line instrument errors: 0.5°.

  The difference in position caused by this error is the product of the distance multiplied by the sine of the angle and, therefore, it will be necessary in each case to calculate the one transversal to the fairway's axis, which is the value «b_b» sought.

rh_{sm} = Additional safety clearance which should be considered on each side of the fairway to enable the vessel to navigate without being affected by bank suction or rejection effects. This clearance may be different on either bank, $(rh_{sm})_i$ and $(rh_{sm})_d$, depending on their nature and will be determined as per the following criteria in which it has been assumed that the Safety Margin (rh_{sd}) specified in the following paragraph always exists. This is why values of «rh_{sm} + rh_{sd}» lower than those indicated here cannot be accepted in any event:

	rh_{sm}	rh_{sd}	$rh_{sm} + rh_{sm}$
◆ Fairways with sloping channel edge and shoals (V/H ≤ 1/3).			
• Vessel's absolute speed ≥ 6 m/s	0.6 B	0.1 B	0.7 B
• Vessel's absolute speed between 4 and 6 m/s.	0.4 B	0.1 B	0.5 B
• Vessel's absolute speed ≤ 4 m/s	0.2 B	0.1 B	0.3 B
◆ Fairways with rigid slopes (V/H ≥ 1/2) or with rocky or structural banks			
• Vessel's absolute speed ≥ 6 m/s	1.2 B	0.2 B	1.4 B
• Vessel's absolute speed between 4 and 6 m/s.	0.8 B	0.2 B	1.0 B
• Vessel's absolute speed ≤ 4 m/s	0.4 B	0.2 B	0.6 B

where (*B*) is the vessel's maximum beam and (*V/H*) the bank slope gradient calculated by the ratio between the vertical and horizontal projection of a unit of length measured on the slope.

rh_{sd} = Safety Margin or unhindered horizontal clearance which must always be available between the vessel and the fairway's banks, slopes or boundaries. It will be determined from the values given in the foregoing paragraph which tend to minimize the risk of the vessel making contact, in keeping with the nature of the fairway's banks. This clearance may be different on each bank $(rh_{sd})_i$ $(rh_{sd})_d$ according to their nature and characteristics.

2. *Navigation in straight stretches with environmental conditions varying over the track*

Should environmental conditions vary in short stretches along the fairrway's axis, which frequently occurs in harbour entrances, where channels meet, changes of fairway alignment not matching the current flow and in other similar cases, vessel navigability conditions must be adjusted to this varying system by modifying their angle of drift to different, even opposing values, which produces curvilinear or zig-zag paths with a larger occupied area of the path being swept by the vessel. The path and greater larger path swept by the vessel can only be accurately determined by means of physical models, complex mathematical models or by simulation studies. The additional width necessary for these manoeuvres may be approximately estimated by assuming that drift caused by the unbalanced cross forces increasing the width of the swept path followed by the vessel in the time in which the ship moves from one balance status to another. Under this assumption, the waterway's nominal width in the varying stretch will be determined by applying the criteria expounded in paragraph 1 of this section 8.4.3.2.a, increasing the additional width «b_d» of the vessel's swept path by an additional amount «b_{dv}» determined by the expression:

$$b_{dv} = V_{rr} \cdot t_c \cdot (\sin \beta_0 - \sin \beta_1)$$

where:

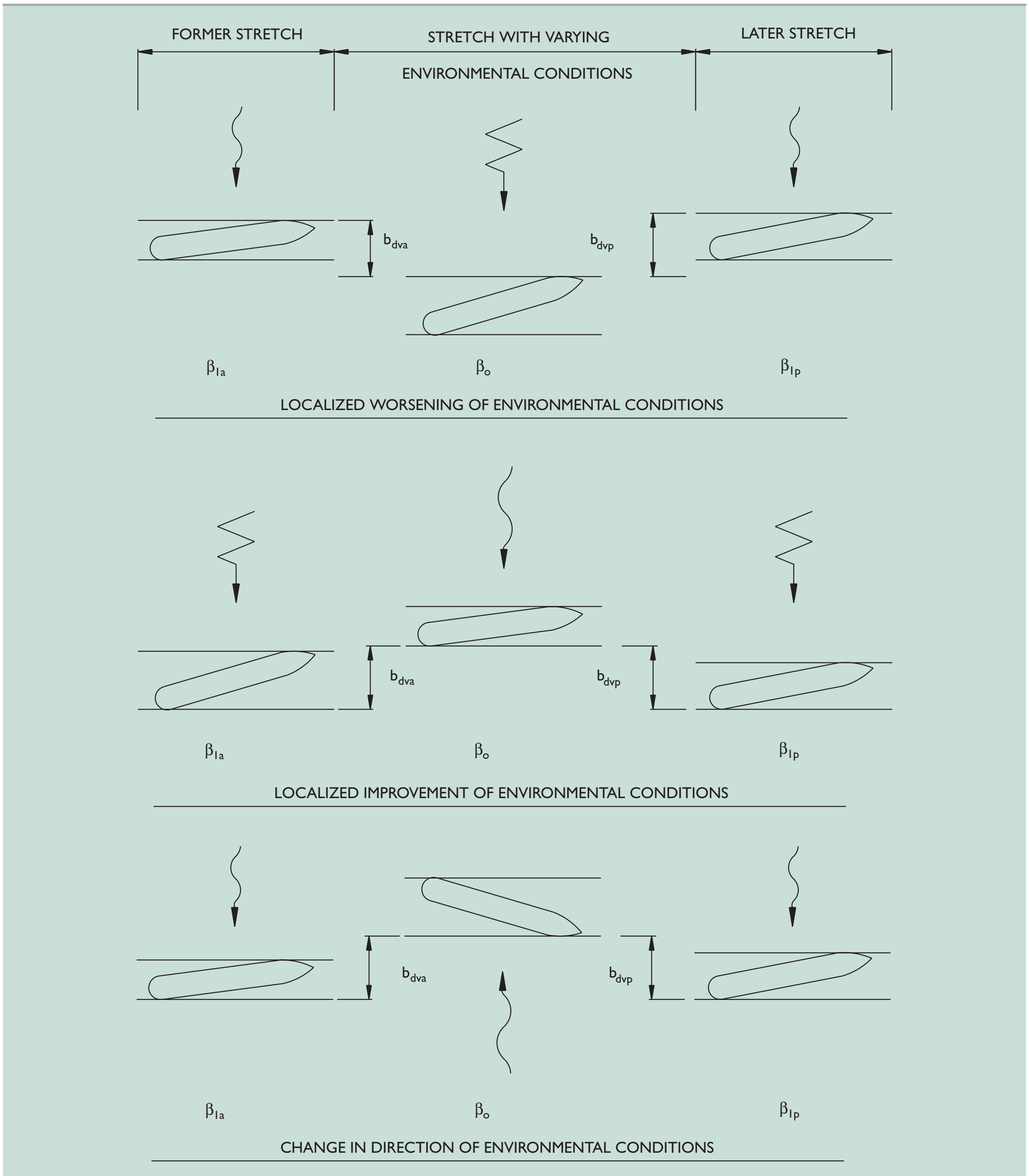
b_{dv} = Additional width of the vessel swept path caused by the varying environmental conditions.

V_{rr} = Vessel's speed relative to the fairway current's speed in the same direction as its route. The criteria as given in section 7.2.3.4.3 will be used for quantifying same, adopting the lowest vessel speed values compatible with the navigation under analysis.

t_c = Time necessary to correct the vessel's manoeuvre, determined with the following criteria:

	Operation without a pilot or captain experienced in the site being considered	**Operation with a pilot or captain experienced in the site being considered**
◆ Good		
• Fishing and pleasure	120 s	60 s
• Other types of vessel	135 s	75 s
◆ Medium	150 s	90 s
◆ Bad	180 s	120 s

Figure 8.02. **Navitation in straight stretches with varying environmental conditions along the track**



Medium vessel manoeuvrability conditions will be used for dimensioning general traffic fairways since, in general, bad manoeuvrability will relate to old ships which will not usually be those with the greatest dimensions or to disabled vessels whose transit through the fairway may be regulated with special aids to navigation so that risks are reduced.

Should the fairway be dimensioned assuming «operation with pilot or experienced captain», this condition shall be shown in the pertinent Operating Rules or Manuals.

β_0 = Maximum drift angle in the environmental condition varying area.
β_1 = Drift angle on the navigation stretch before (β_{1a}) or after (β_{1p}) the area of environmental condition variation. The algebraic value will be taken in relation to β_0, i.e., with a minus sign should the drift angle have a contrary sign.

In most cases, determining the additional width will require checks to be made for navigation in both directions, and two alterations to course in each one will be analysed:

- That occurring between the permanent prior navigation area and the varying environmental condition area.
- That occurring between the varying environmental condition area and the rear permanent navigation area.

Fig. 8.02 shows the most frequent navigation cases for:

- Localized worsening of transversal environmental conditions.
- Localized improvement in transversal environmental conditions.
- Change in direction of transversal environmental conditions.

Having determined the above, the additional width of the path swept by the vessel caused by navigating with an angle of drift will be available in the following three areas:

	For water space assessment	For above water space assessment
◆ At the end of the prior stretch	$L_{pp} \bullet \sin \beta_{1a} + b_{dva}$	$L \bullet \sin \beta_{1a} + b_{dva}$
◆ At the beginning of the rear stretch	$L_{pp} \bullet \sin \beta_{1p} + b_{dvp}$	$L \bullet \sin \beta_{1p} + b_{dvp}$
◆ In the varying stretch	$L_{pp} \bullet \sin \beta_0 + (b_{dva}$ or $b_{dvp})$ the worst of the 2 if they go in an opposite direction or the sum of both if they go in the same direction	$L \bullet \sin \beta_0 + (b_{dva}$ or $b_{dvp})$ the worst of the 2 if they go in an opposite direction or the sum of both if they go in the same direction

Figure 8.03. Configuration, straight stretches with varying environmental conditions, single navigation lane

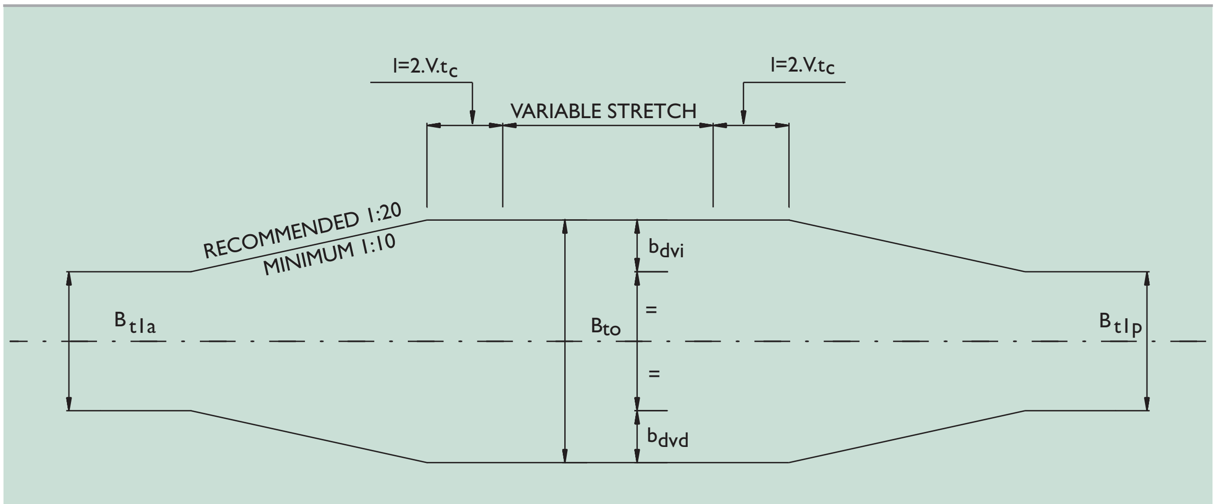
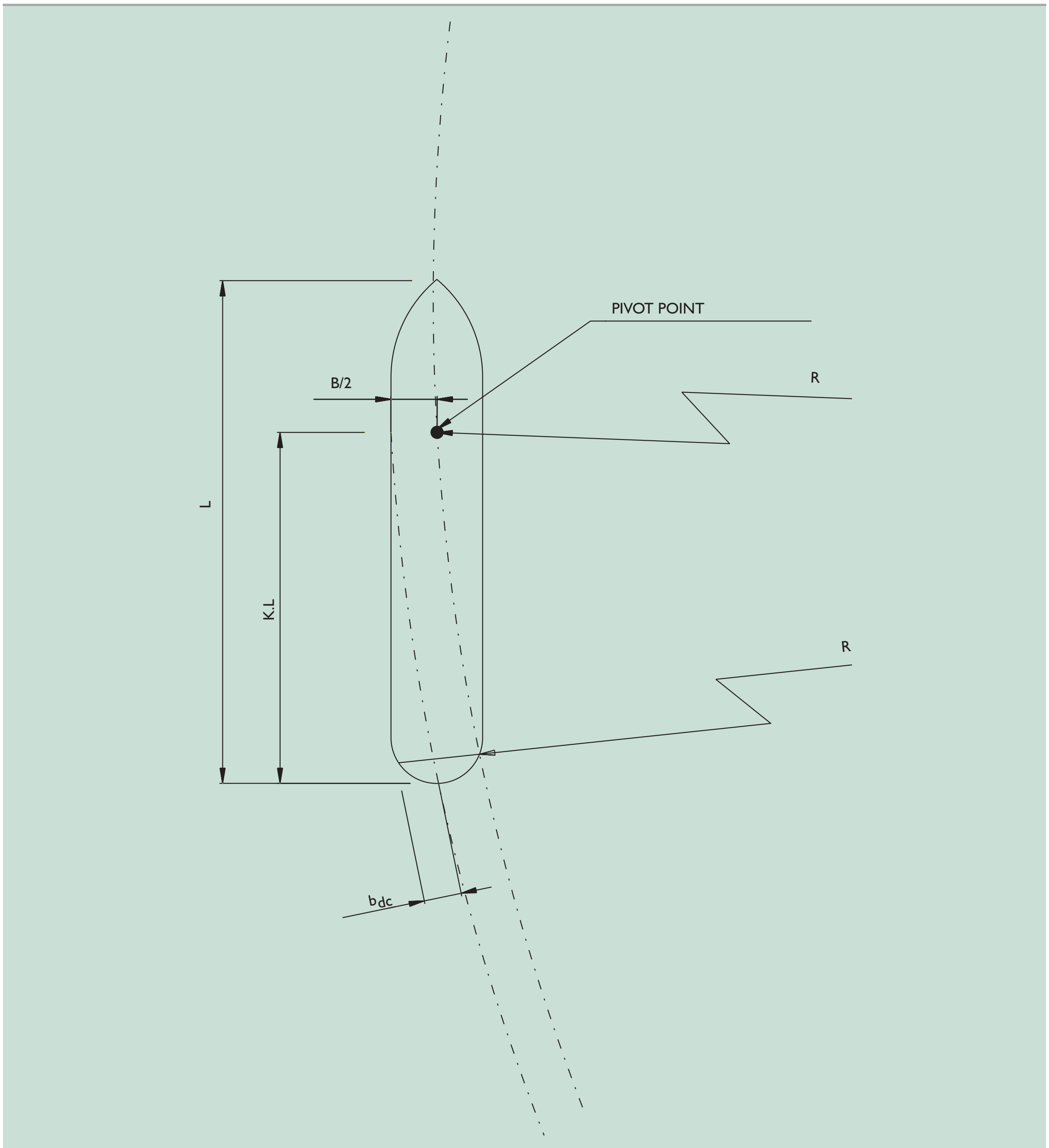


Figure 8.04. ***Additional width for stern turning***



The fairway's axis is recommended to be kept unvarying along the whole stretch in order to correctly locate these widths and additional widths. Should the additional drift «b_{dv}» always occur in the same direction (for example, when a river flow affects the fairway), the additional width «b_{dv}» will be considered on the pertinent side of the fairway. If, on the other hand, the additional drift were to occur in either direction (for example, when caused by a tidal current affecting the fairway crosswise), the additional width «b_{dv}» must be calculated on the right and left of the fairway, applying the pertinent correction on each side; in this case, the overall width required may be diminished if a vessel reaction anticipation manoeuvre were to be effected, which were to at least partially correct the drift effect that might be expected in the varying environmental condition area. This operation would only be applicable in the event the manoeuvring were carried out with a pilot or captain experienced in the site being considered and should be incorporated into the port's Operating Rules should the fairway's additional width be optimized by using this procedure.

The additional width required for this straight stretch navigation with varying environmental conditions will be kept over the whole of the stretch affected plus an additional length (*l*) upstream and downstream with the value

$$l = 2 \bullet V \bullet t_c$$

where the maximum values admissible for the Design Vessel in keeping with the fairway's Operating Rules will be taken for the vessel's absolute speed «*V*» and the values given in this section for calculating «b_{dv}» will be taken for the time «t_c». The transition to the width required in the fairway's prior and rear stretches will be effected with ground plan variations not greater than 1:10 (preferably 1:20) on each of the banks. Figure 8.03 shows the total width B_t over the varying stretch (B_{t0}) and over the prior ($B_{t\,l\,a}$) and rear ($B_{t\,l\,p}$) stretches.

3. *Navigation in curved stretches with constant environmental conditions over the whole track*

When navigating over curved stretches under constant environmental conditions over the whole track, the fairway's nominal width («B_n») will be determined with the same criteria as expounded for navigating over straight stretches, increasing the additional width «b_d» of the vessel's swept path produced by navigating with a drift angle and the additional width «b_r» due to the vessel's response speed by the following amounts:

- Increase in the vessel's additional swept path width caused by navigation with a drift angle.
- This increase «b_{dc}» will be determined to correct the effect of the vessel's stern turning (see section 6.2.4.), by applying the following formula (see fig. 8.04):

$$b_{dc} = \sqrt{\left(R + \frac{B}{2}\right)^2 + (K \cdot L)^2} - \left(R + \frac{B}{2}\right)$$

which may be approximated using the following simplified expression applicable to the assessment of both water and above water spaces:

$$b_{dc} = \frac{K^2 \cdot L^2}{2R}$$

where:

b_{dc}	=	Additional width of the path swept by the vessel and caused by curved stretch navigation.
R	=	Path radius for which the fairway's bending radius will be adopted.
K	=	Distance from the pivot point to the vessel's stern (or bow if greater) expressed as a fraction of the vessel's length overall (*L*).
L	=	Vessel's length overall
B	=	Vessel's beam

For vessels in which the pivot point is in the centre of the length, $K = 0.5$ and the foregoing expression becomes the following, which is that normally used in bibliography:

$$b_{dc} = \frac{L^2}{8R}$$

For larger displacement vessels with full underwater forms (oil tankers, bulk carriers, etc.) which are usually critical for dimensioning fairways, $K = 0.5$ if the ratio between the at rest water depth (*h*) and the vessel's draught (*D*) is $h/D \leq 1.20$ whilst, if this ratio $h/D \geq 1.50$, $K = 2/3$ and the foregoing expression then becomes:

$$b_{dc} = \frac{2L^2}{9R}$$

For fast boats (vessels with thin underwater hull shapes and pleasure boats) $K = 1$ and the additional width would be:

$$b_{dc} = \frac{L^2}{2R}$$

Should the fairrway be dimensioned for general traffic, the additional width for largest displacement vessels with full underwater hull shapes which usually prove critical for determining the fairway's dimensions will be taken, using the value of «b_{dc}» calculated for $K = 0.5$ or $K = 2/3$ according to the design's h/D ratio (linear interpolation may be carried out for intermediate values):

- Increase in the additional width due to the vessel's response speed.

This increase (b_{rc}), which is additional to «b_r» defined for straight stretches, is established for taking into consideration the manoeuvring difficulties caused by the ship not immediately responding to the handler's instructions and, consequently, the pilot must anticipate the manoeuvre by deviating from the fairway's theoretical axis.
In the absence of more precise studies, provided the fairway's alignment is kept within the alignment recommendations given in section 8.4.2., this additional width may be as per the following values as a function of the Vessel's Beam (B), the Maximum Risk Admissible (E_{max}) during the Useful Life of the design being analysed, determined with the criteria as established in Table 2.2., and of the vessel's manoeuvrability (see the section for calculating (b_r) in this same point):

Vessel´s manouvrability	brc
Good	$0.20 \cdot (1.50 - E_{max}) \cdot B$
Medium	$0.40 \cdot (1.50 - E_{max}) \cdot B$
Bad	$0.80 \cdot (1.50 - E_{max}) \cdot B$

Medium vessel manoeuvrability conditions will be used for dimensioning fairways open to general traffic. Having determined the fairway's overall width at the bend (B_{tc}) and knowing the width of the straight legs (B_{tr}) running into it (which may be different in one or the other leg), its geometrical configuration and the alignment of its banks are usually determined by one of the following methods:

- Straight banks
- Curved banks

The geometric characteristics of the systems most used in both methods are shown in figs. 8.05 and 8.06. The straight bank methods are those that worst conform to the alignment's geometric conditions whilst at once having the disadvantage of causing unfavourable secondary currents. Nevertheless, they are simpler to navigation mark and to dredge. For curved bank methods, assuming that the track radius is not strict, it is preferable to develop solutions in which the additional width is located inwards of the bend (1st and 3rd configuration in the figure) because with the vessel having the inside bank as the navigation reference, it anticipates manoeuvres for taking the bend by gradually adjusting the rudder angle.

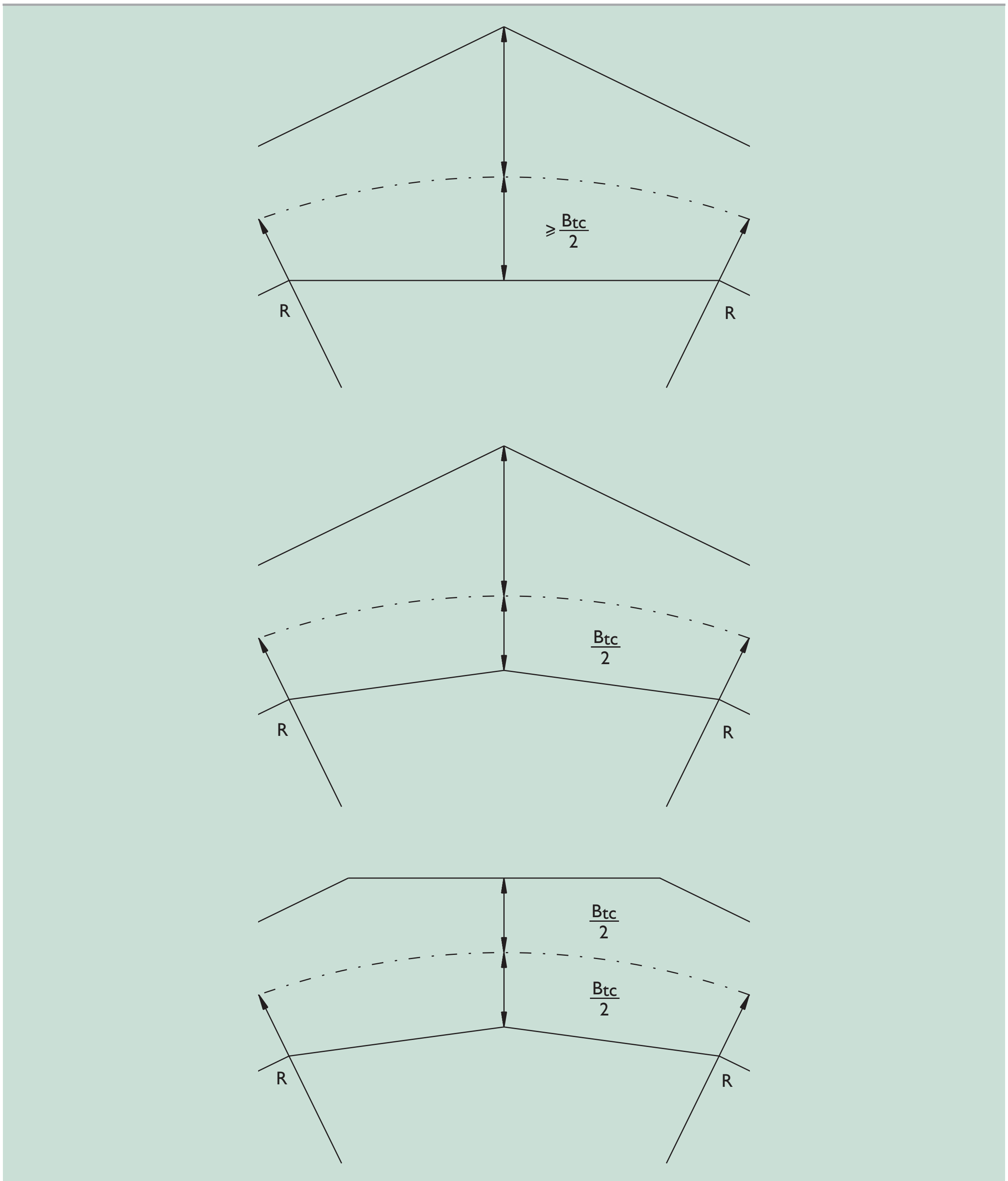
4. *Navigation in curved stretches with environmental conditions varying over the whole track*

When navigating over curved stretches with environmental conditions varying over the whole track, the fairway's width will be determined by adding the needs for space of both circumstances to the navigation width in straight stretches, as defined in points 2 and 3 of this sub-section 8.4.3.2.. The mathematical formulation of the fairway's nominal width (B_h) in the most complex case will be:

$$B_n = B + (b_d + b_{dvi} + b_{dvd} + b_{dc}) + 2(b_e + b_r + b_{rc} + b_b) + (rh_{sm} + rh_{sd})_i + (rh_{sm} + rh_{sd})_d$$

where all symbols have the meaning as given in previous paragraphs.

Figure 8.05. Geometric configuration, curved stretches, solutions with straight banks

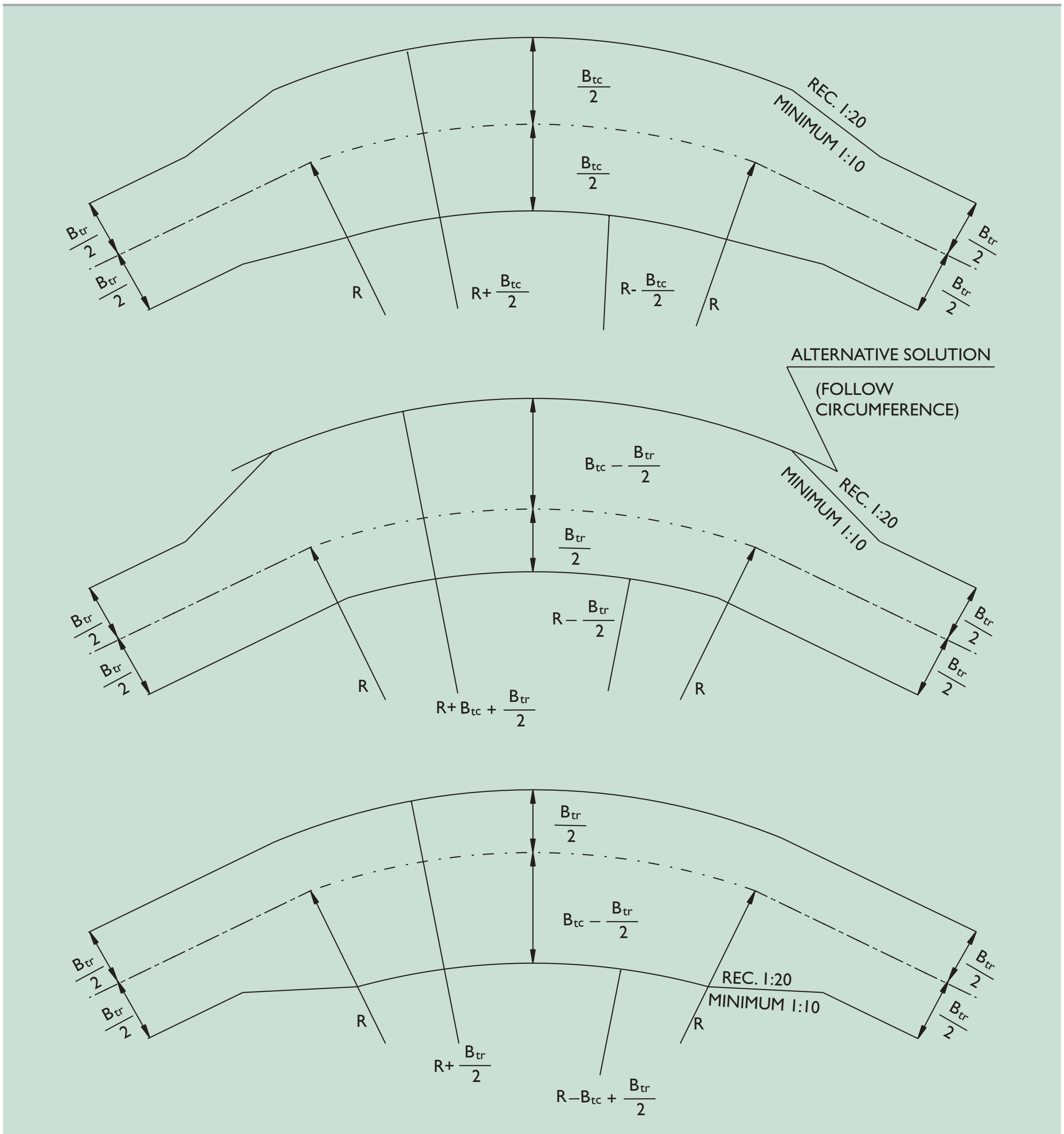


The resulting geometrical configuration will be established by applying the criteria as given for both circumstances but no single general solution can be found in the light of the variety of cases which could arise.

b) TWO SHIPPING LANE FAIRWAYS

The width of a two shipping lane fairway will be determined in a way similar to that defined for single lane fairways by firstly analysing navigation in straight stretches under constant environmental conditions and then

Figure 8.06. Geometric configuration, curved stretches, solutions with curved banks



addressing the effect of varying environmental conditions on navigation over the track or navigating round a bend. In view of the fact that these two cases do not display any peculiarity deriving from being a fairway with two or more shipping lanes, except, of course, to consider additional widths that may be given to each lane, only navigation over straight stretches under constant environmental conditions is analysed in detail.

The general design criterion for all cases consists in dimensioning each lane separately, setting up an intermediate passing distance with a different width (b_s) according to the fairway and traffic characteristics, and maintaining the additional safety clearance on each side of the fairway (rh_{sm}) to allow a vessel to navigate without being affected by bank suction and rejection, as well as the Safety Margin (rh_{sd}) which shall always be available between the fairway's slopes or structural boundaries. Both the Safety Clearance (rh_{sm}) and the Safety Margin (rh_{sd}) may be different on either bank according to their nature and the fairway's operating conditions.

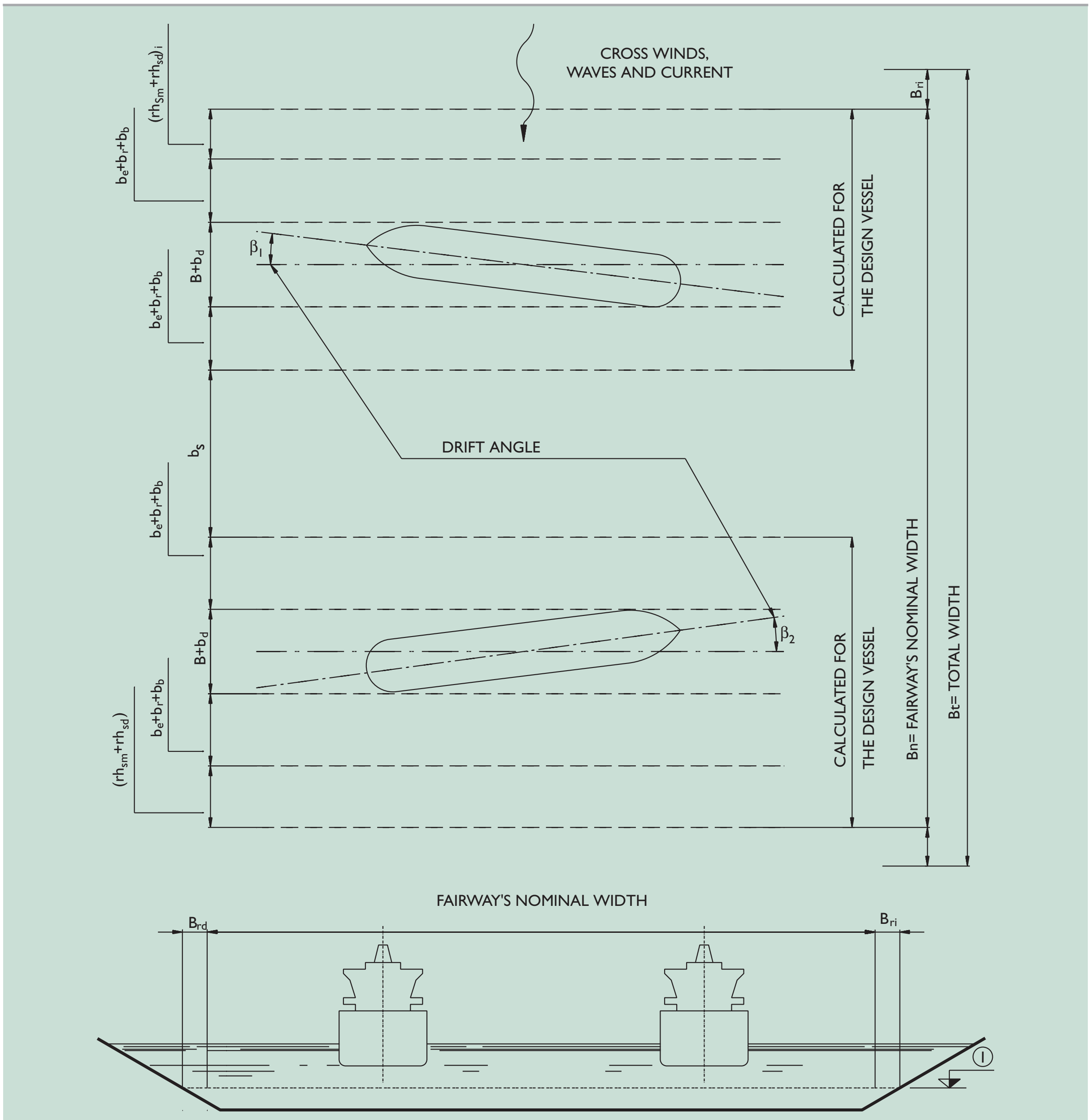
1. *Straight stretch navigation with constant environmental conditions along the whole track.*

In the case whereby the environmental, maritime and meteorological conditions (winds, waves and currents) are constant along the track, the nominal width of a straight stretch fairway with two lanes dimensioned for the same design vessel will be determined as the sum of the following components (see fig. 8.07).

$$B_n = 2[B + b_d + 2(b_e + b_r + b_b)] + b_s + (rh_{sm} + rh_{sd})_i + (rh_{sm} + rh_{sd})_d$$

where all the expressions have the same meaning as in point a.1 of this sub-section and «b_s» is the passing distance between the two lanes, calculated as the sum of that from the following two factors determined on the assumption that the operation is unedrtaken with pilots or captains experienced in the site under consideration:

Figure 8.07. ***Width of straight stretch fairways with two navigation lanes. Operation with two vessels of the same tonnage***



(1) Fairway´s nominal depth.

	b_s	
	Fairway in exposedareas	**Fairway in sheltered waters**
Fairways with overtaking forbidden (only passing)		
◆ First factor: Vessel's absolute speed		
• Greater than 6 m/s	2.0 B	–
• Between 4 and 6 m/s	1.6 B	1.4 B
• Less than 4 m/s	1.2 B	1.0 B
◆ Second factor: Traffic density		
• 0-1 vessels/hour	0.0 B	0.0 B
• 1-3 vessels/hour	0.2 B	0.2 B
• > 3 vessels/hour	0.5 B	0.4 B
fairways with overtaking allowed	Increase the foregoing factors by 50%	

where the vessel's absolute speed will be the highest compatible with the fairway's Operating Rules and the traffic density will be determined by taking the vessel motion in both directions into consideration (excluding fishing and pleasure boats, unless they are the fairway's Design Vessel).

Should the fairway's Operating Rules establish that large displacement vessels are only allowed to pass or overtake smaller vessels up to a certain range, the fairway's nominal width might be adjusted to the following dimensions (see fig. 8.08).

$$
\begin{aligned}
B_n \;=\; & 2\,[B + b_d + 2\,(b_e + b_r + b_b)] \textit{ of the design vessel} + \\
& + [B + b_d + 2(b_e + b_r + b_b)] \textit{ of the smaller vessel} + \\
& + [b_s] \textit{ of the design vessel} + \\
& + [(rh_{sm} + rh_{sd})_i + (rh_{sm} + rh_{sd})_d] \textit{ some of the design vessel and others of the smaller vessel}
\end{aligned}
$$

where all expressions have the meanings as defined in the foregoing paragraph.

2. *Straight stretch navigation with environmental conditions varying throughout the track*

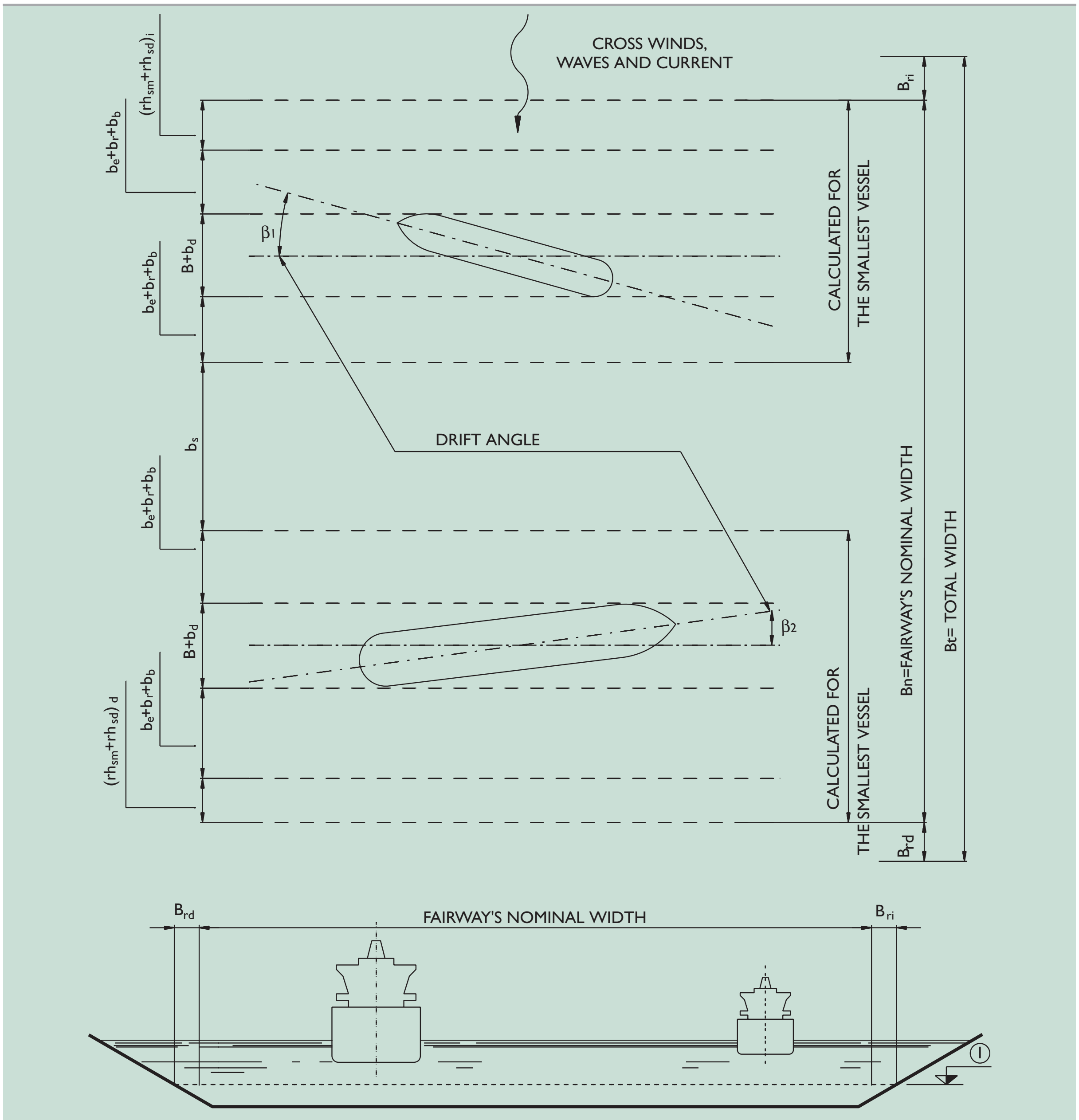
The criteria as established in point b.1 of this sub-section 8.4.3.2 will be kept to without considering anything further than the additional widths «b_{dv}» of each of the vessel's swept paths calculated as indicated in sub-section 8.4.3.2.a.2. These additional widths will be kept at a length equal to that established in the said section, i.e., over the whole stretch affected by the varying environmental conditions plus an additional length (l) upstream and downstream with a value

$$l = 2 \cdot V \cdot t_c$$

with the same meanings as given in the aforesaid section a.2.

In order to correctly locate the resulting widths taking into account the different additional widths that may be required on either side, it is generally recommended to keep the fairway's axis constant along the whole stretch (passing distance axis if both lanes are dimensioned for the same design vessels, or a line equidistant from the edges of the fairway's nominal width otherwise). Transition to the width required in the fairway's prior and rear stretches will be made with ground plan variations not greater than 1:10 (preferably 1:20) on each of the banks. See figure 8.09. This transition involves changing the axes of both shipping lanes in relation to the straight alignments they had upstream or downstream of the stretch with varying environmental conditions, which is a condition required for cutting dredging costs; should any of the upstream or downstream stretches not have area and depth restrictions (for example, in approach channels), keeping the straight alignment of the axes of each of the shipping lanes is recommended, separating them from each other the greatest distance required in this stretch to facilitate the fairway's navigation and navigation marking.

Figure 8.08. Width of straight stretch fairways with two navigation lanes. Operation with two vessels of a different tonnage



(1) Fairway´s nominal depth.

3. *Navigation in curved stretches with constant environmental conditions over the whole track*

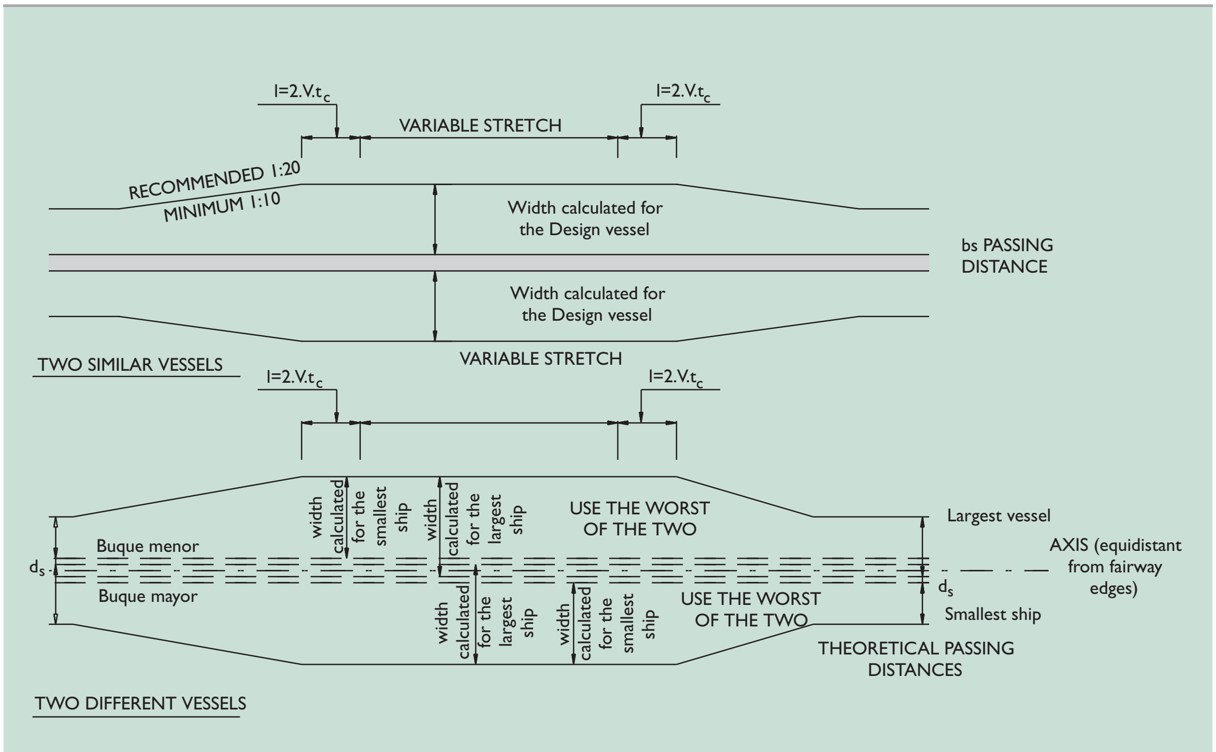
The criteria as established in section b.1 will be kept to, with nothing further than considering the additional widths b_{dc} and b_{rc} calculated as indicated in point a.2. for each of the two shipping lanes.

The scheme in figures 8.05 and 8.06 will be followed for defining the bend's geometric configuration and the routing of the banks, plotted from the axis of the bend's inside lane, which is the strictest for fulfilling minimum radius stipulations.

4. *Navigation in curved stretches with varying environmental conditions throughout the track*

When navigating in curved stretches with varying environmental conditions over the whole track, the fairway's width will be determined by adding the requirements of additional width needed for both

Figure 8.09. **Configuration, straight stretches with varying environmental conditions. Two lanes**



circumstances to the navigation width in straight stretches, as defined in points b.2 and b.3 in this sub-section.

The mathematical formulation of the fairway's nominal width (B_n) in the most complex hypothesis corresponding to the case whereby the two shipping lanes are dimensioned for the same Design Vessel would be:

$$B_n = 2\,[B + b_d + b_{dvi} + b_{dvd} + b_{dc} + 2\,(b_e + b_r + b_{rc} + b_b)] + b_s + (rh_{sm} + rh_{sd})_i + (rh_{sm} + rh_{sd})_d$$

The resulting geometric configuration will be established by applying the criteria set down for both cases, with no general solution being possible in the light of the variety of hypotheses which may be arise.

c) VESSEL OVERTAKING AND PASSING STRETCHES IN SINGLE SHIPPING LANE FAIRWAYS

In the case of single shipping lane fairways of a considerable length and transit time, it may be advisable to have specific stretches dimensioned for two fairways in which vessel overtaking and passing manoeuvres may be undertaken. Using these stretches will require vessel control systems to be set up from land or operation with on board pilots.

Should this solution be chosen, the two fairway stretches will be set up straight, with constant environmental conditions throughout the track and avoiding curved stretch solutions or varying environmental conditions.

The width of the two shipping lane stretch will be dimensioned with the criteria as defined in point b.1 in this sub-section 8.4.3.2., taking into account the fact that the manoeuvre may be performed by two Design Vessels or by one Design Vessel simultaneously with another, smaller vessel.

The same straight fairway alignment will be kept to in the double lane stretch, which will therefore coincide with the axis of the passing distance in the event of dimensioning for two vessels the same or with the line equidistant from the edges of the fairway's nominal width otherwise. Dimensioning criteria, general configuration and bank transitions will be established as follows:

1. *Stretch for vessel overtaking*

It will be assumed that vessels in the prior stretch navigate at a reduced speed (40% of the absolute maximum speed admissible in the fairway, «*V*») keeping a clear distance between both vessels equal to the stopping distance «*Dp*» plus the area covered during a reaction time «*t*» of 60 secs. This relative position will be kept to until the vessel overtaken is in the double lane stretch.

As from that position, it will be assumed that the vessel overtaken keeps to the reduced speed (40%) whilst the vessel that has overtaken it travels at a mean speed double the former (80% of the absolute maximum speed admissible in the fairway), which rate will be maintained for a time «T_a» until this vessel exceeds the overtaken one by a clear distance equal to that considered at the beginning of the manoeuvre. When this final position is reached, the vessel overtaken must still keep in the double lane stretch. The stretch will be dimensioned with these assumptions so that the spaces available are at least twice as long as the theoretically necessary. Width transitions will be made with ground plan variations not greater than 1:10 (preferably 1:20) on each of the sides. See figure 8.10 determined for the case whereby the two ships have the same dimension «*L*» (Length overall).

2. *Stretch for vessel passing*

Considering the length of the double lane stretch depends on the vessels reaching the beginning of the stretch either at the same time or with a lag, it will be assumed, as the most unfavourable hypothesis, that this coincidence does not occur and, therefore, either of the two vessels accessing the passing area with a reduced speed (40% of the absolute maximum admissible in the fairway, «*V*», can stop at least in a waiting area (quay, mooring area, anchorage, etc.) located at the beginning or end of the double width area (preferably at the place which allows vessels to depart without waiting and that therefore entering vessels are the ones which must wait), so the longitudinal development of the stretch will need space for the Stopping distance (*Dp*) plus the area covered during a reaction time «t_r» of 60 secs plus the design vessel's length overall «*L*». The stretch will be dimensioned with these assumptions so that the areas available are at least twice as long as the theoretically necessary. Width transitions will be made with ground plan variations not greater than 1:10 (preferably 1:20) on each of the sides. See figure 8.11.

The spaces necessary for the waiting area will be developed at the side of the fairway, keeping a reserve space of 2.5 B (B = design vessel beam) between the edge of the fairway and the most advanced position the anchored or moored vessel may reach.

d) DEVELOPING NAVIGATION LANES OVER THE SLOPES OF THE MAIN FAIRWAY'S BANKS

In the usual case that the fairway has sloping banks, fairways can be set up for smaller boats with maximum lengths of 20 m (fishing boats, pleasure boats, etc.), locating them parallel to and outside the main fairway, taking advantage of the depths available on these slopes. Should this solution be chosen, it will be considered that the main fairway and smaller boats are always separate, therefore keeping a passing distance with a width «b_s» between them (see point b.1 of this sub-section). The due navigation marking system will be implemented to prevent navigation errors. Should these specific fairways for smaller boats be set up, it will be compulsory for this type of boat to always use these lanes even though there is no traffic in the main fairway.

e) FAIRWAYS WITH MORE THAN TWO NAVIGATION LANES

Should fairways with more than two navigation lanes be designed, the design criteria established for two lane fairways will be kept to, so that each lane can attend to its function separately.

The geometric configurations will be designed so that vessels can navigate in as simplified a manner as possible, considering the navigation marking system provided for.

Figure 8.10. ***Vessel overtaking stretch***

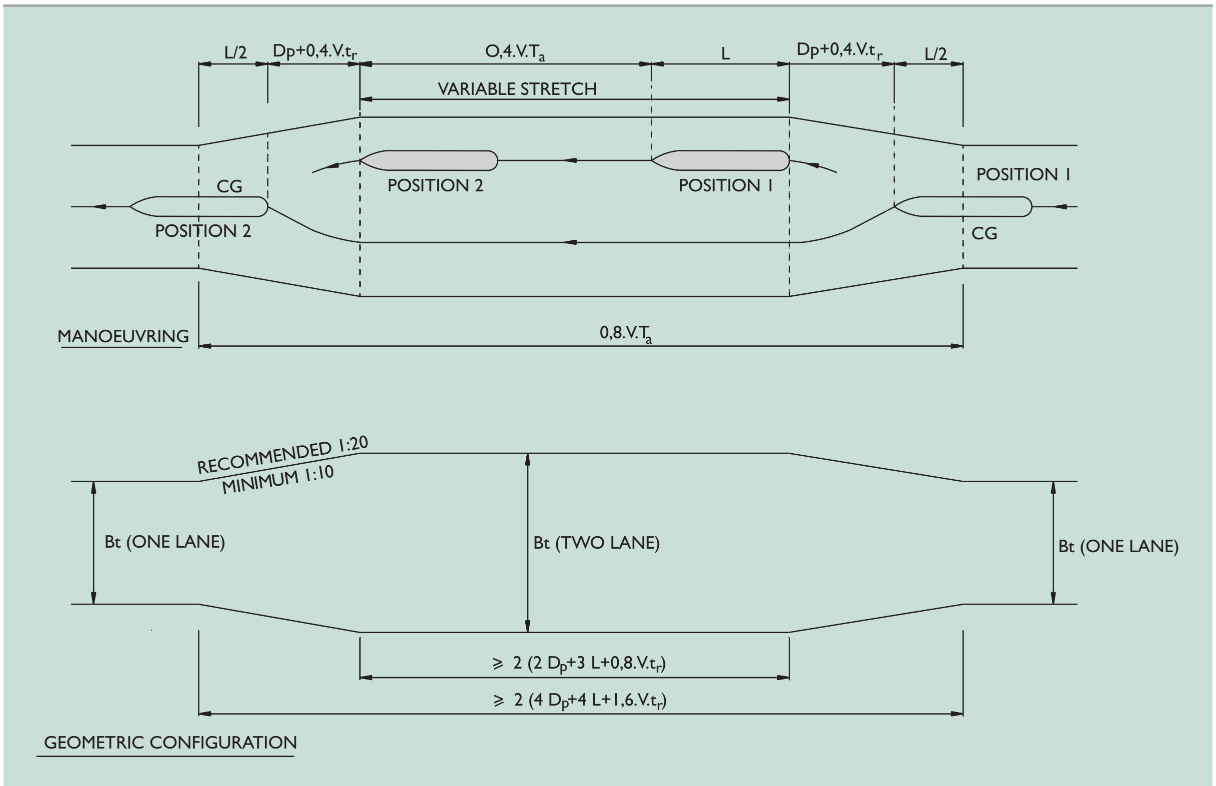
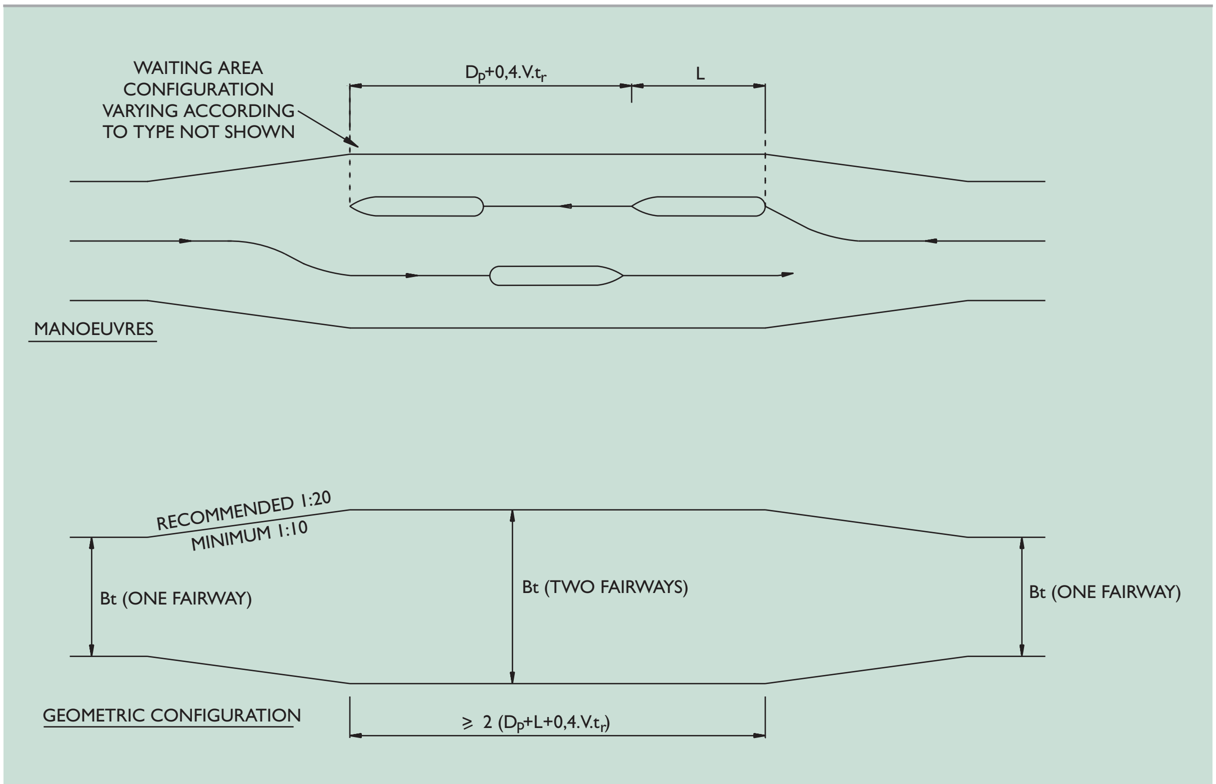


Figure 8.11. ***Vessel passing stretch***



8.4.3.3. Determining nominal width «B_n» by the semi-probabilistic method

A fairway's geometric design in this procedure is mainly based on statistically analysing the areas swept by vessels in the different manoeuvres considered, which, should a sufficient number of manoeuvre repetitions be available, will enable the resulting design to be associated to the risk preset in each case.

This method may be practically applied on the basis of simulator studies, reduced scale tests, real time measurements or similar procedures, which may reproduce the problem raised with greater or lesser accuracy. Part 9 of this ROM gives the main aspects of Simulation Models, which are the most frequently used tool for this kind of study.

The characteristics of the system used and its limitations must be accurately known before using this method. Those aspects of the situation which are not reproducible with the model used must be determined (e.g., navigation marking and the inaccuracies associated to it) since all conditions that cannot be modelled must be dealt with by other procedures. The scheme followed in this ROM is that the same criteria defined for the determinist model will be used for assessing all aspects that simulation models do not consider; in particular, Safety Margins (rh_{sd}) will be assessed exactly the same in both methods.

The analysis carried out with these procedures usually examines different vessel paths, covering complete stretches of the fairway, in which straight or curved stretches may occur, as well as constant or varying environmental conditions along the track, which may be studied overall whilst more accurately analysing the interaction between them. Most present day simulators analyse the case of one fairway on each path where there is only one vessel sailing and, therefore, in general, the study of fairways with two navigation lanes, in any of the hypotheses of section 8.4.3.2. will require an intermediate passing distance with a width (b_s) calculated as shown there to be taken into account.

The general design procedure will comprise the following phases:

1. Understanding the model to be used and its limitations, especially those aspects which cannot be reproduced in the study, which shall have to be addressed by determinist procedures.

2. Knowing the characteristics of the water and its surroundings (geometric definition of the track, bathymetry and water levels, marine environment existing in the area, etc.). The level of definition required in this respect may significantly vary according to the simulation system used.

3. Defining the marking and navigation marking systems which may be set up, as well as the way in which they are incorporated into the simulator.

4. Defining limit environmental operating conditions according to the type and dimensions of vessels, tug-boats available or any other particular condition that may be defined in each case.

5. Defining the tug-boats available and their participation in manoeuvres as a function of the type and dimensions of vessels, environmental conditions existing or any other condition that may be established.

6. Specifying the «scenarios» which will be reproduced on the simulator. «Scenario» is taken to mean the set of conditions defining a manoeuvre (which will be repeated several times to statistically process it), comprising at least the following aspects:

   - The type of vessel representative of the category of ships it is wished to study.

   - The limit environmental operating conditions representative of the stretch to be studied.

   - Tug-boats and other aids to navigation which will be available in this operation.

7. Defining the number of passes to be made on the simulator repeating the manoeuvre for a given scenario. To the extent whereby a greater number of passes is available, the study's accuracy will increase with the counterpart of increasing simulation costs. Between 12 and 15 passes are recommended for drafting final designs.

8. Specifying the cross sections of the fairway in which the vessel occupied area will be assessed (critical sections, all cross sections at a preset geometric or time separation and even a continuous record of all paths swept by the vessel in each of the tracks may be obtained).

9. Statistically analysing the results obtained on the simulator in keeping with the purpose of the study. If the aim is only to determine the fairway's width, interest will only lie in the limit values of occupied area on the fairway's port or starboard sides; if, in addition, it is wished to optimize the fairway's track, the vessel's centre of gravity deviations from the preset reference track must be analysed (see figure 8.12). In all cases, the process will involve determining the functions of density and exceedance, adjusting different distribution functions (Normal, Gumbel, Weibull, etc.)., for each of the study's cross sections, determining their coefficients of correlation and choosing those functions which best fit, which will generally be those of a symmetric type for studying the centre of gravity's position and those of an asymmetric type when occupied area is analysed on either of the two sides.

10. Choosing the distribution functions (preferably one type for the sides and another for the centre of gravity, if necessary). The mean values of the centre of gravity deviation density function will be used in each section to optimize the track axis. The exceedance probability function will be used to analyse the fairway's width and the most unfavourable 95% confidence intervals will also be determined (those which where highest occupancy occurs); the probability of exceedance (p_{ij}) that that fairway is exceeded in that section by a vessel of type (*i*) in the operating conditions of the stretch (*j*) - scenario analysed –will be calculated on these confidence intervals– entering the procedure described in subsection 2.5.6.

The single shipping lane fairway's nominal width determined by this semi-probabilistic method will be:

B_n = [width between sides calculated statistically as a function of the preset risk «*E*»] + [additional widths due to effects not addressed on the simulator which will be calculated with criteria as established by the determinist method] + [Safety Margin «rh_{sd}» assessed with the criteria established by the determinist method].

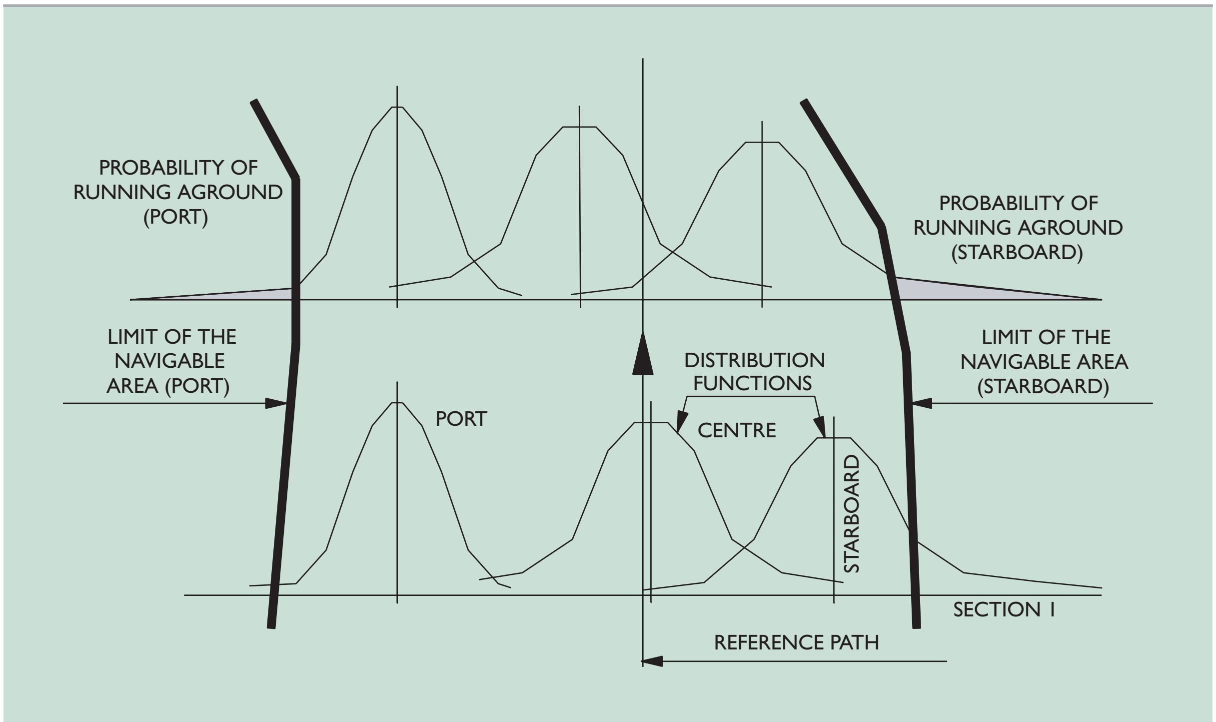
The fairway's nominal width «B_n» for two or more shipping lane fairways in any of the types as defined in points b, c, d or e of sub-section 8.4.3.2.a will be calculated by generalizing the foregoing criterion as a function of the simulation model used and including in any case an intermediate passing distance of width «b_s» calculated with the criteria as given for the determinist method. These schemes will be kept to for the geometric ground plan configurations shown in figures 8.09, 8.10 and 8.11, unless others based on simulation studies respecting thedesign criteria as given in this ROM for semi-probabilistic methods are justified.

8.4.4. Point of no return

In practice, there will be what is known as a «point of no return» in all port approach fairways, as from which a vessel will not be able to stop (without obstructing the fairway), to turn to change direction, or anchor leaving the navigation route free and, consequently, it must continue on its course to the harbour. This «point of no return» shall be located as close as possible to the actual harbour entrance, providing areas to allow turning, anchoring, provisional mooring manoeuvres or those provided for in each case, the dimensions of which will be determined as indicated in other sections in this Recommendation. The spaces required for anchorages and mooring areas are developed at the side of the fairway, keeping a reserve space of 2.5 B (B = fairway design vessel's beam) between the edge of the fairway and the most advanced position the anchored or moored vessel can reach. The space necessary for the turning area may be developed on the fairway should traffic density be equal to or less than 1 vessel/hour, considering two way vessel motion. Setting up the turning area outside the fairway is recommended for higher traffic densities so that it remains functional at all times.

In the case of very long fairways and as a function of the traffic intensities occurring, it may be necessary to arrange several areas along the fairway with the same purpose as a «point of no return».

Figure 8.12. ***Semi-probabilistic fairway desing***



8.4.5. Fairway navigation marking

a) GENERAL CRITERIA

Fairway navigation marking depends on its dimensions and geometry, on the dimensions of vessels using it, on traffic density and on limit operating conditions under which vessels travel over it including amongst the latter minimum navigation visibility as determined by the Service Level or percentage of time in which navigation cannot occur through lack of visibility.

In order to correctly define a fairway's navigation marking, a series of stretches must first be defined in it as a function of the manoeuvre being undertaken: alteration to course, transition and straight stretch navigation. The type of manoeuvre carried out in each stretch determines the information to be furnished to the vessel by the navigation marking system.

The stretch in which an alteration of course is made (curved fairway stretches) is where the most difficult manoeuvres are performed and in which the captain needs to be making frequent appraisals of the vessel's position both longitudinally and crosswise to the fairway as well as the speed at which it is sailing. This is why the greatest attention should be paid to navigation marking of curved fairway stretches and the number of aids to navigation should be intensified in such stretches.

Transition stretches are where the handler must make the greatest efforts to locate the next straight alignment and manoeuvre and direct the vessel towards it. In order to facilitate this function, the handler needs to avail of accurate information on the fairway borders and vessel's position in relation to them. Not only those stretches immediately before and after a curved stretch will be assumed as transition stretches but also all those in which navigation is performed under varying environmental conditions, as well as the appraoch to the fairway from the open sea.

The length of the transition stretches depends on the dimensions and speed of the vessel being considered and has been defined in most of the usual cases in section 8.4.3. The following transition lengths applicable to vessels travelling at speeds between 3 and 6 m/sec (approximately 6 to 12 knots) may be adopted for other cases not covered by the said recommendations.

Size of the vessel (DWT)	Lenght of the transition stretch (m)
30.000	1.300
50.000	1.900
70.000	2.400
90.000	3.000
110.000	3.500

The handler's interest in straight stretches is to keep to the fairway's axis with no intention of leaving it, which is why he has no need to accurately know the fairway's boundaries.

The number and quality of the aids to navigation used in these straight stretches will depend on the accuracy of the vessel's positioning required as a function of the criteria adopted for their design.

b) NAVIGATION MARKING SYSTEM AND TYPES OF AIDS TO NAVIGATION

The following types of aids to navigation may be used, depending on the fairway's requirements and location:

- Visual (transmit information visually, whether luminous or partially luminous).
- Radioelectric (transmit information by radioelectric waves)
- Mixture of both

Other aids may be considered apart from the foregoing, such as VTS (Vessel Traffic Service), piloting, the site's natural conditions, etc., which may be at the handler's disposal.

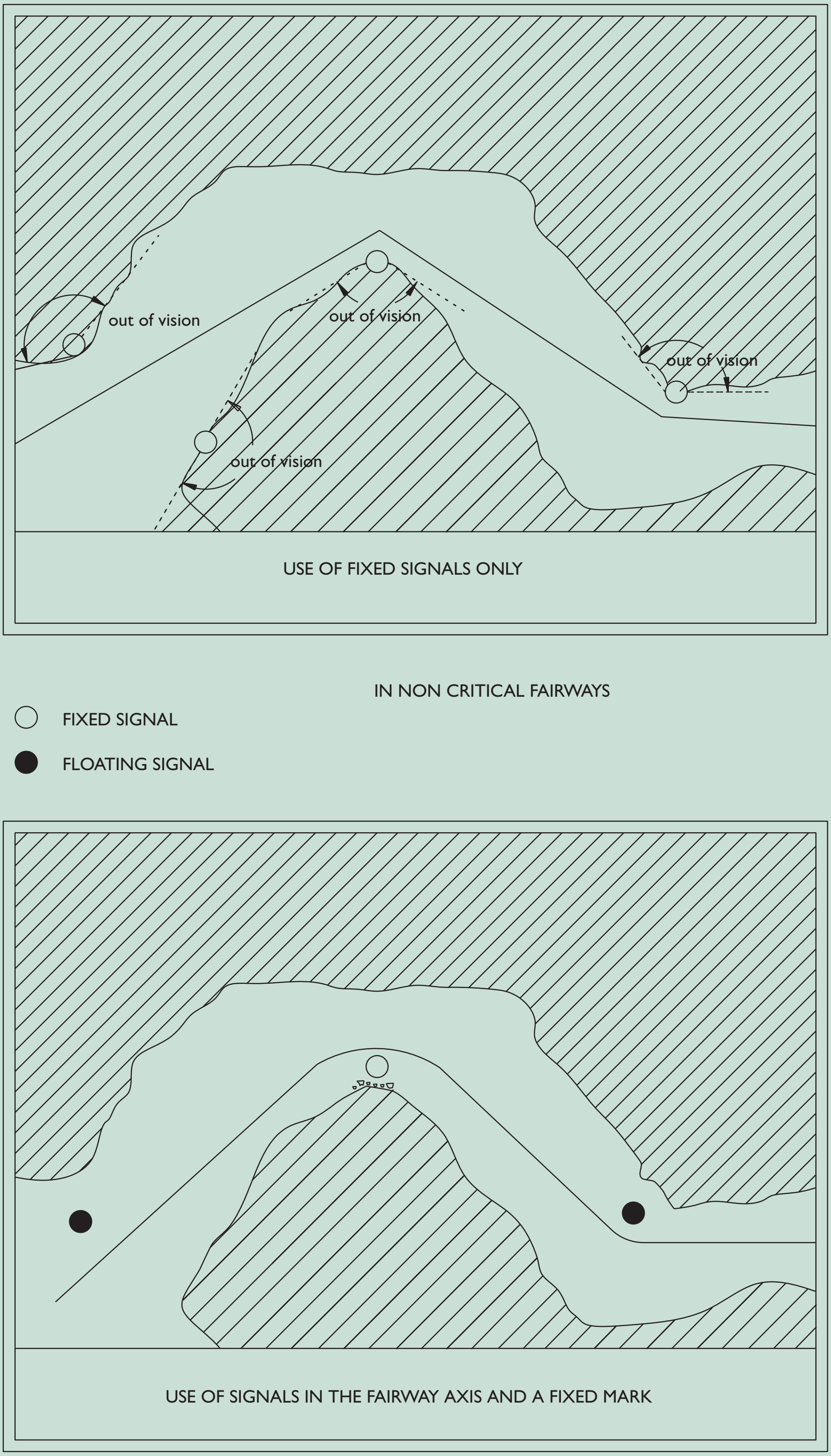
Buoys, beacons, leading lines, direction lights, sector lights, etc., shall conform to the Maritime System of Buoyage, the Guide for its Application and AISM Recommendations.

It is important, when using visual signals to mark fairways and when navigating ahead, to be able to see the signal located immediately ahead of the vessel before that located immediately behind is lost to sight so that two visual references are always simultaneously available. This can be achieved with buoys, beacons, direction lights and sector lights.

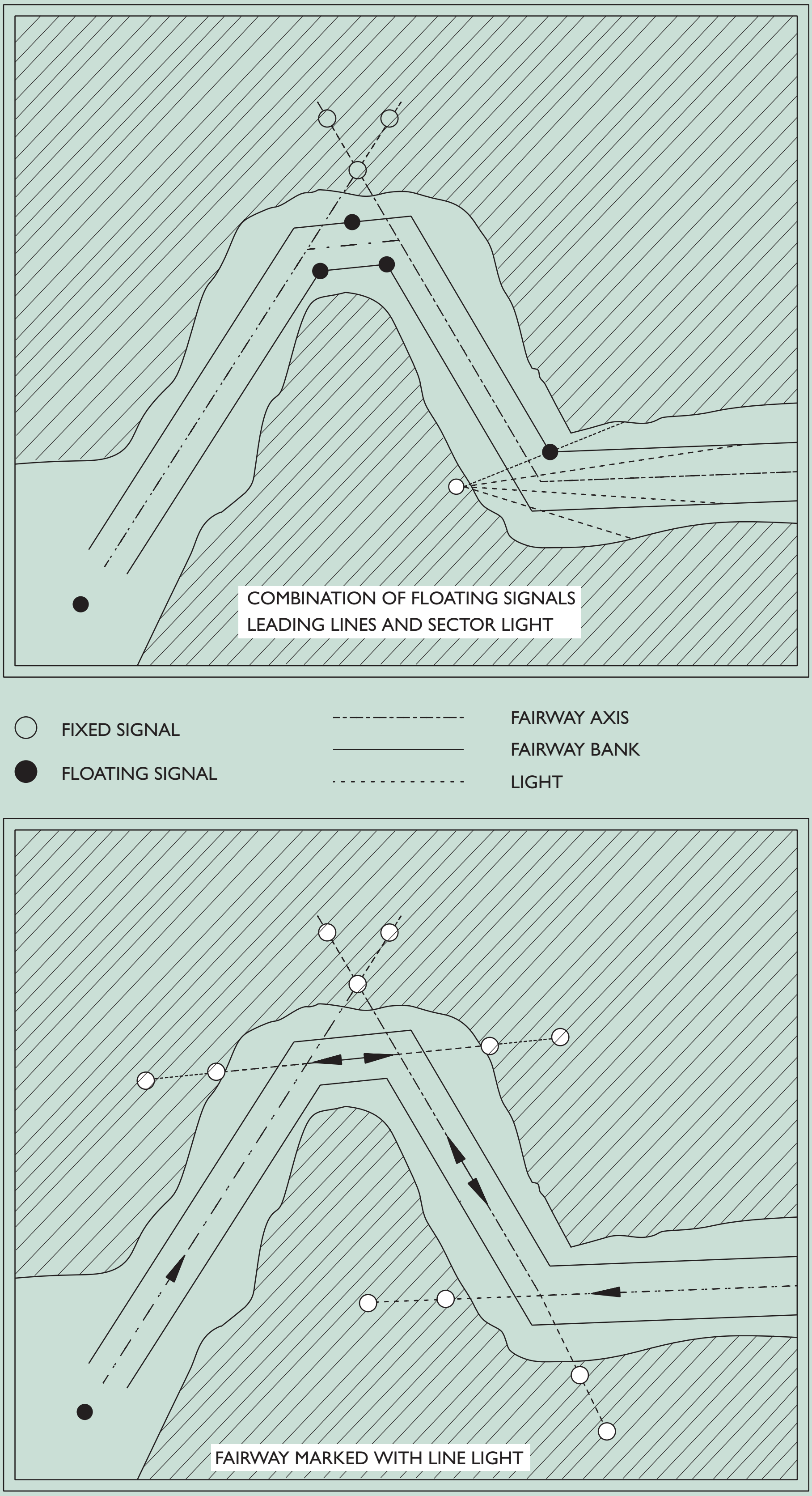
Figs. 8.13 to 8.20 schematically show some of the possible solutions to be used for fairway marking, taken from the AISM's Aids to Navigation Guide (NAVGUIDE).

Should fixed buoys or beacons be used to mark fairway banks, pairs of buoys or beacons are recommended, arranged crosswise to the fairway's axis. Figs. 8.21 to 8.25 show the minimum schemes that shall be used for marking curved stretches and certain other special stretches.

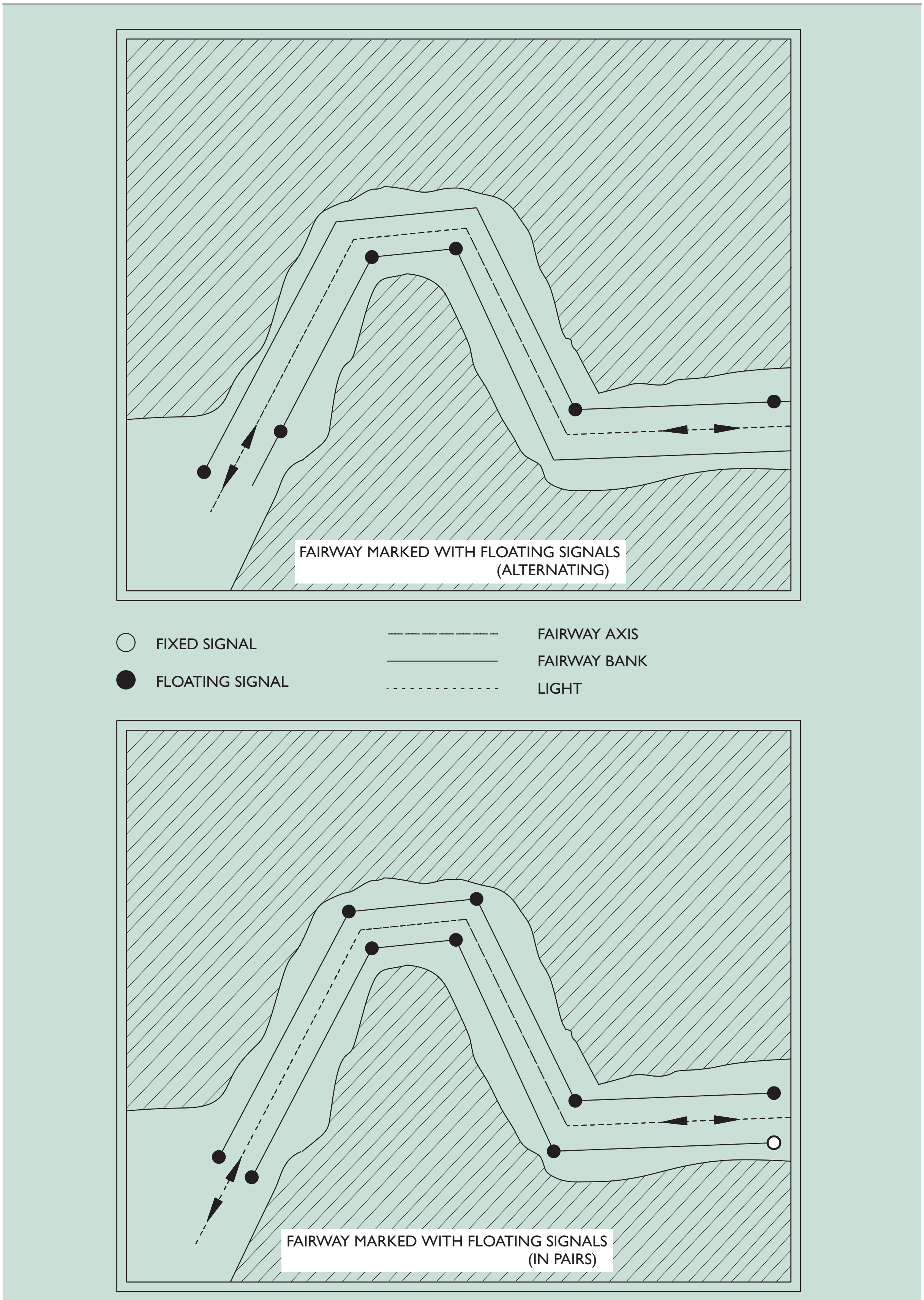
Figures 8.13 and 8.14. ***Maritime Navigation Marking Systems (AISM)***



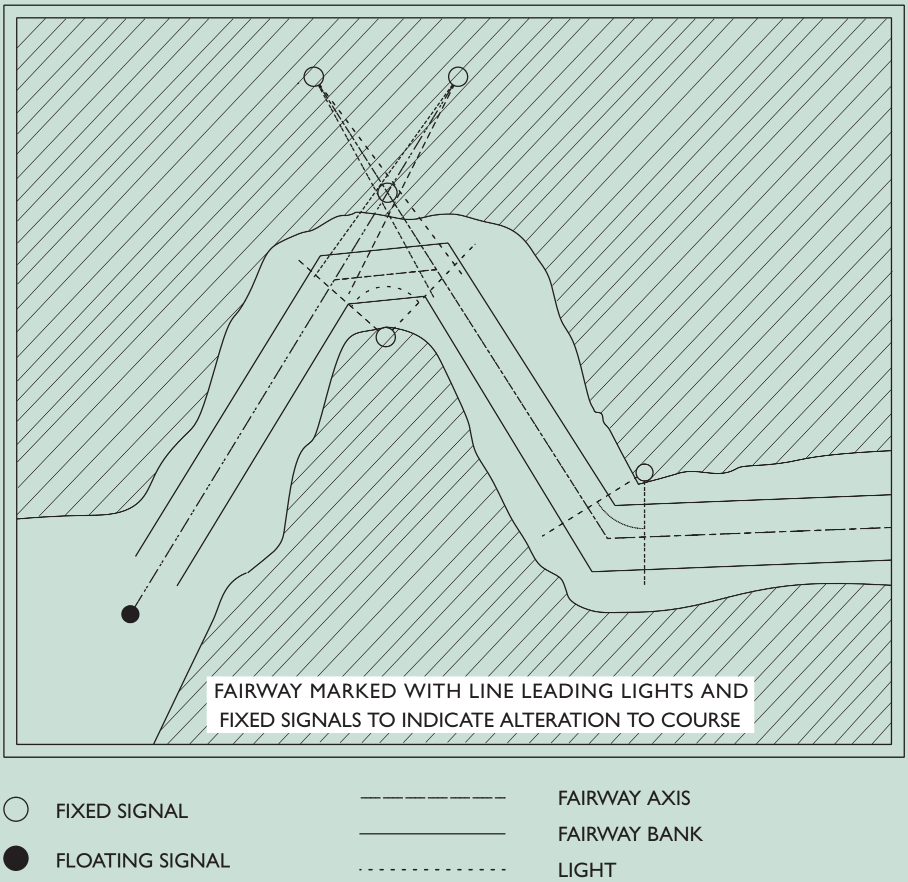
Figures 8.15 and 8.16. ***Maritime Navigation Marking Systems (AISM)***

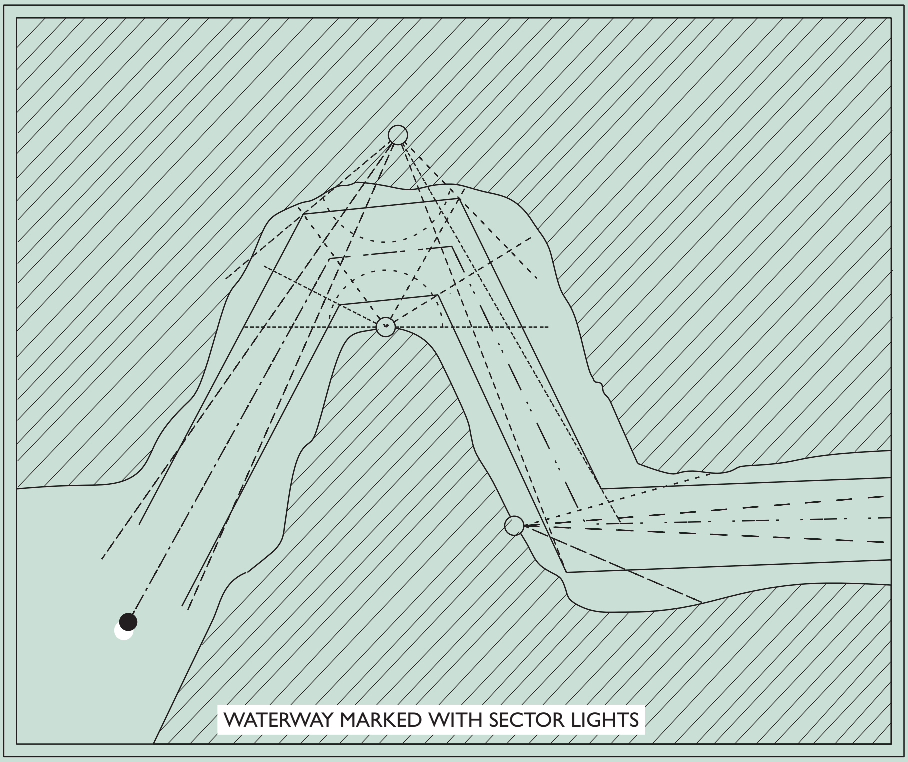


Figures 8.17 and 8.18. ***Maritime Navigation Marking Systems (AISM)***

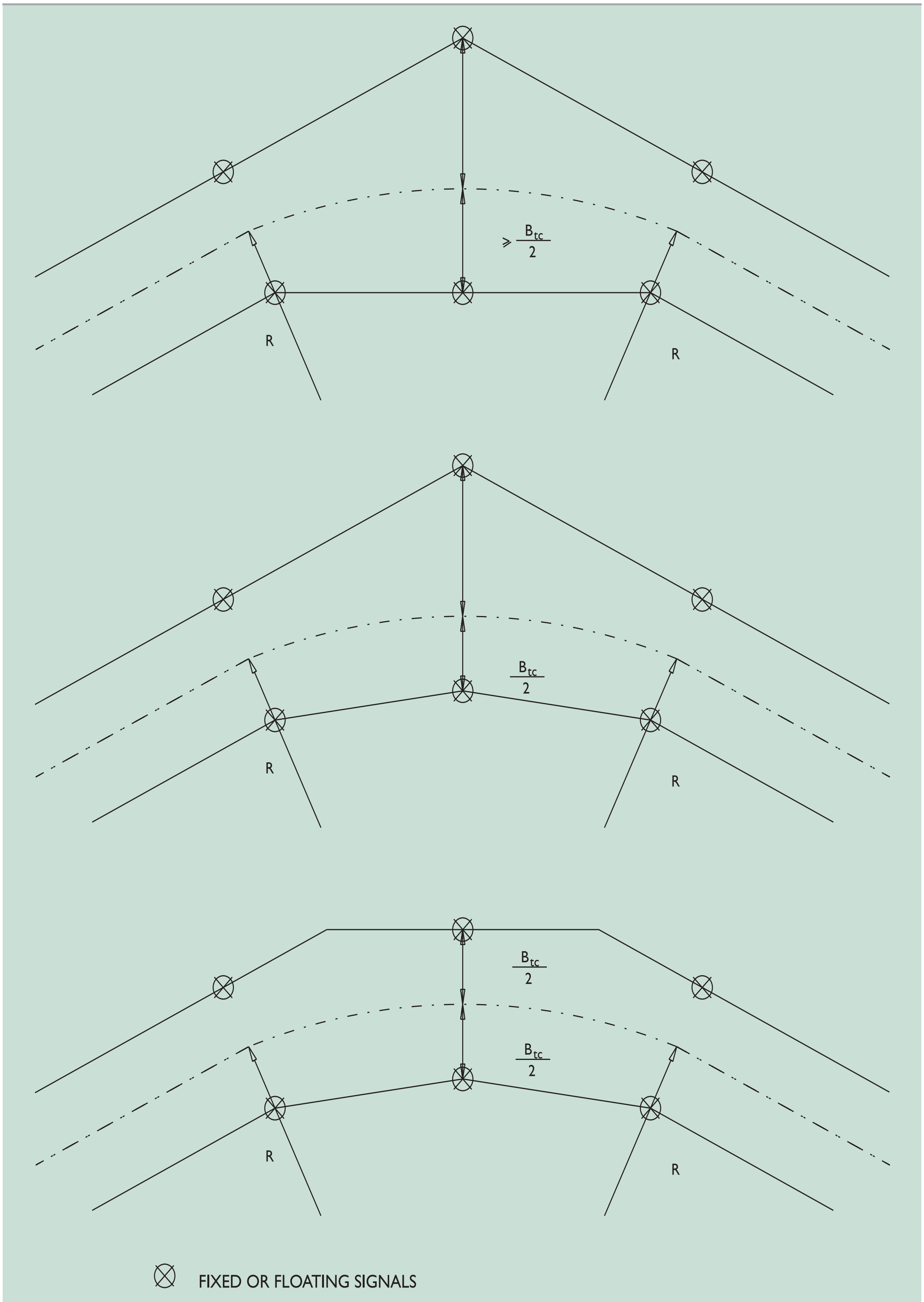


Figures 8.19 and 8.20. ***Maritime Navigation Marking Systems (AISM)***





Figures 8.21. ***Curved stretch marking. Solutions with straight banks***



Figures 8.22. **Geometric configuration, curved stretches. Solutions with curved banks**

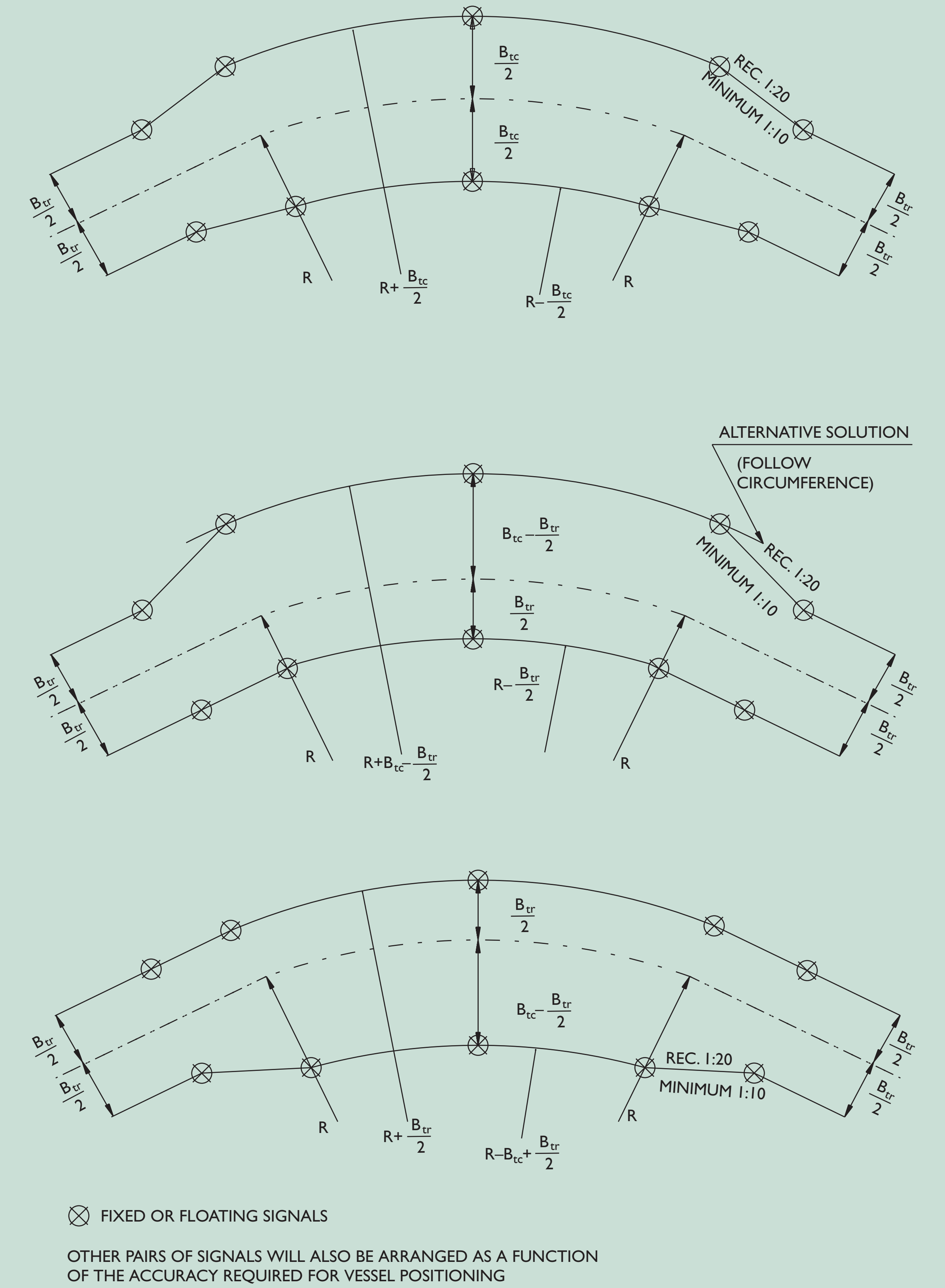


Figure 8.23. Straight stretch marking with varying environmental conditions. Two lanes

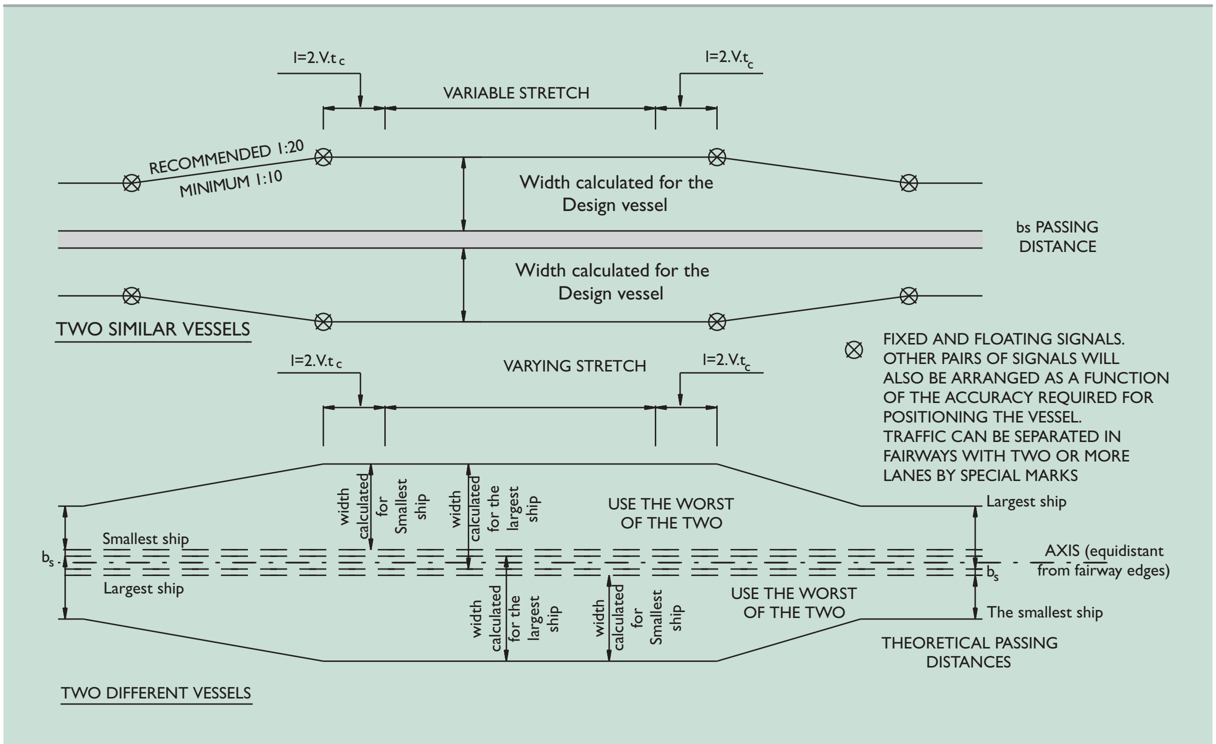


Figure 8.24. Navigation marking of vessels overtaking stretch

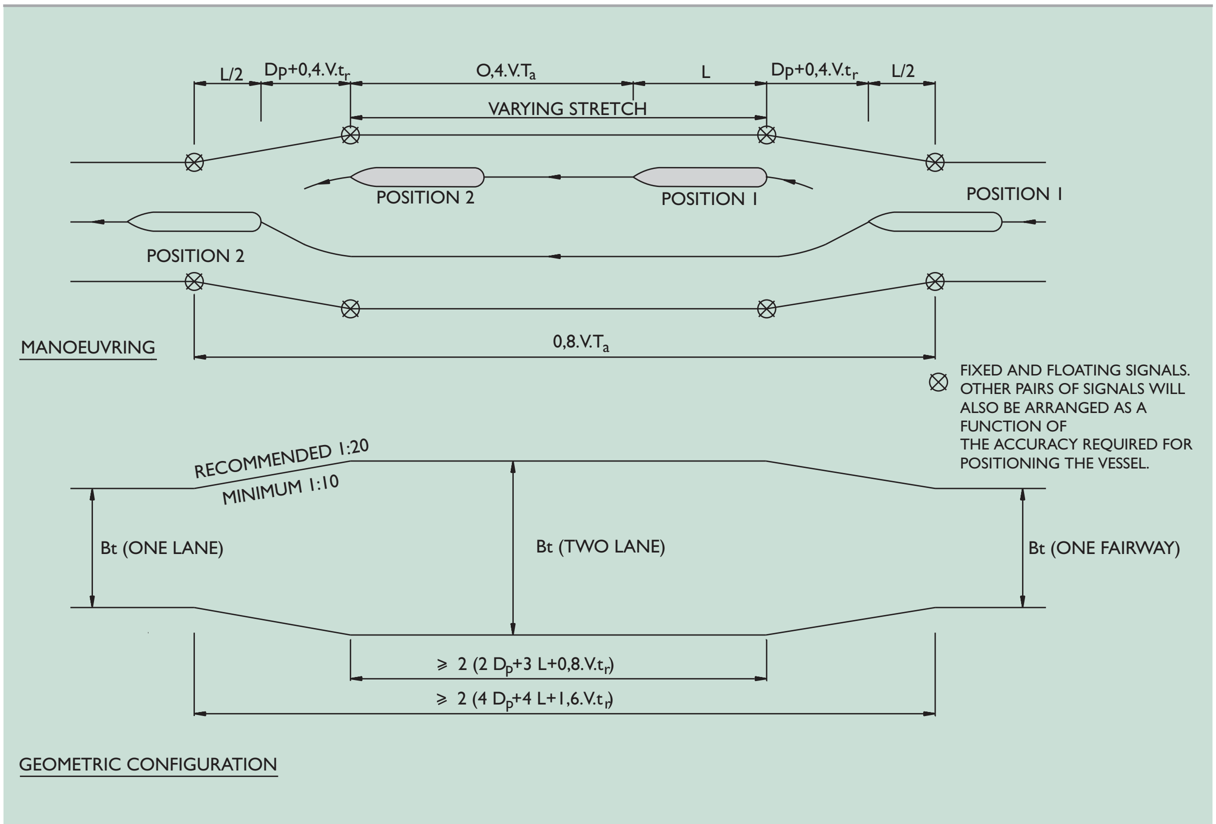
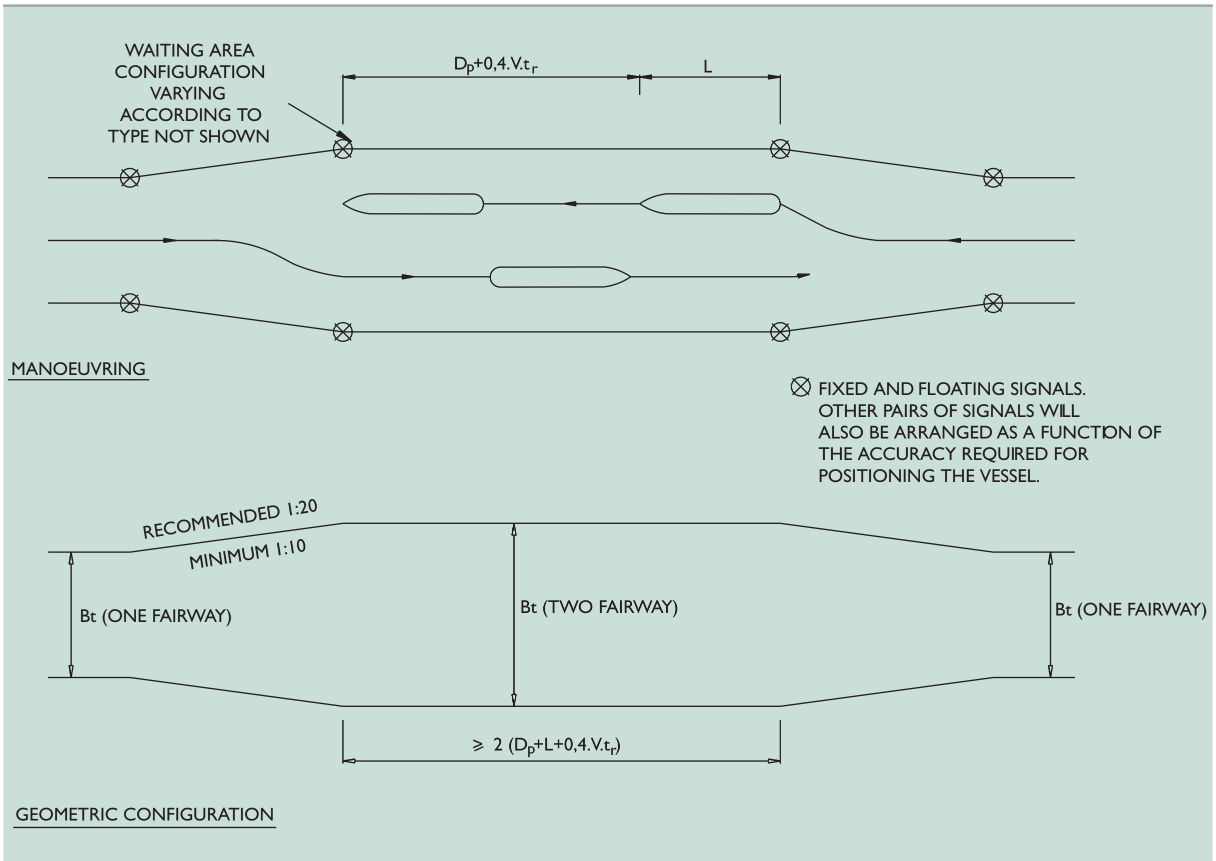


Figure 8.25. **Navigation marking of vessels passing stretch**



8.5. HARBOUR ENTRANCES

8.5.1. Factors affecting design

Harbour entrance and exit will be designed taking the following main conditioning factors into account:

- The harbour's general configuration and the integration of the harbour entrance into its infrastructures (breakwaters, secondary breakwaters, quays, dredgings, etc.) and into its floatation areas (fairways, anchorages, vessel manoeuvring areas, basins, etc.), as well as the morphology and structural type of the elements forming the entrance.

- Vessel harbour entry and exit navigation, addressing both foreseeable traffic densities and the largest design vessels envisaged as operating in the harbour under the limit operating conditions that may be established.

- Limitation on wave energy entering inside the harbour, in keeping with the maritime environment existing at the site such that wave disturbance occurring in the floatation areas used by the harbour is the least possible, as a function of the operations to be carried out in each one.

- The advisability of limiting harbour downtime occurring at the harbour entrance, caused by the marine environment conditions in the area and the configuration adopted for the entrance (waves breaking in the harbour entrance, heavy cross currents, etc.).

- Littoral dynamics in the area and modifications which may occur in them as a result of the port infrastructures, considering not only the alterations which may occur in the harbour (entrance and other navigation areas silting up), but also those which might occur in other close by or remote areas affected by the same littoral dynamics.

- The site's geological and geotechnical features and the consequent suitability of the ground for receiving infrastructure constructions or for developing floatation areas over it.

- Foreseeable harbour extensions and the limitations which the configuration adopted for the entrance might represent in this respect.

- Environmental impacts which might occur in both the construction and service phases, etc.

- The influence of other conditioning planning factors other than the strictly harbour factor, which might affect the specific site being analysed and, particularly, those deriving from urban and coastal planning.

In practice, considering all these conditioning factors will lead to compromise solutions in which an equilibrium will be reached between conditioning factors that will sometimes oppose each other (for example, the obtention of the best accessibility could bring with it inner harbour wave disturbance indices unsuited to the operation of the port being considered).

An analysis of all these factors is beyond the scope of this ROM and they will be analysed in detail in other Recommendations in the programme. This ROM 3.1 is restricted solely to analysing those navigation related aspects mentioned in point 2 of the foregoing list taking into consideration the influence other factors have on them (maritime environment, type of infrastructures shaping the entrance, nature of the ground, etc.).

8.5.2. Conditions imposed by navigability

Vessel manoeuvrability for passing through a harbour's entrance cannot be considered as a point event limited to the strict passage through the entrance. On the contrary, a complete stretch of the fairway extending from the upstream and downstream points where the navigation manoeuvres for passing through the entrance commence and end must be analysed.

The general analysis procedure is as described in section 8.4 above, whether using the determinist or semi-probabilistic methods, taking the following specific aspects into consideration:

- The stretch affected by the entrance will be navigated on a fairway with a completely defined alignment. Although this stretch is recommended to be straight, it will frequently be necessary to use mixed paths in which a straight stretch outside the harbour will be followed by a curved leg to quickly seek sheltered water. It will also be usual to navigate outside the harbour over several alternative routes, with suitable navigation control, which does not invalidate the hypothesis that there must be one (or several) totally defined routes.

- Since the usual approach routes are preset and cannot be matched to the characteristics of wind, waves or currents existing at all times, major cross component forces and, consequently, angles of drift close to the maximum values admissible must be provided for. Environmental conditions assumed to be operating limits will be determined as a function of the service level it is wished to obtain. In the absence of specific studies, the following cross environmental conditions are recommended and are those normally considered for dimensioning these areas:
  - Absolute wind speed $V_{10.1\ min}$ ≤10.m/s (20 knots)
  - Absolute current speed $V_{c\ 1\ min}$ ≤ 0.05 m/s (1 knot)
  - Wave height H_s ≤ 3.00.m

- Approach navigation routes allowing the ship to arrive at the harbour stern on to the storm or forming a small angle with the harbour, which is called sailing with the storm on a quarter, with angles of 15/20° between the route and the wave direction being considered in small boat ports of refuge (fishing and pleasure boats), as well as in all those designed to operate under severe environmental conditions.

The longitudinal environmental conditions considered as limits for analysing these storm entry routes will be established by statistically analysing the service levels required and, in the absence of specific criteria, the following operating limits are recommended:

- Absolute wind speed $V_{10,1\ min}$ ≤16.m/s (32 knots)
- Absolute current speed $V_{c\ 1\ min}$ ≤ 2.00 m/s (4 knots)
- Wave height H_s ≤ 5.00.m

◆ Vessels will generally navigate in the harbour entrance passing stretch under varying environmental conditions and, consequently, additional widths established to correct this effect will have to be considered (see section 8.4) and will be undertaken in the lengths and with the transitions recommended there.

◆ Although not the most favourable alignment, the stretch passing the entrance is frequently followed by a curved route to quickly find more sheltered water behind the harbour's breakwaters and, therefore, providing additional widths will also be frequent for curved stretch navigation (see section 8.4), as well as for developing the transitions accompanying such curved stretches.

◆ The following will also be taken into account for marinas:
- The marina sea approach must even allow for sailing ships whether all the year round for base or wintering marinas or during the season for marinas of call.
- This approach must allow sailing entrance and exit routes to be registered for any wind possible within the limit operating conditions for 8 m long vessels in the case of a 45° tacking capacity, 40 m headway run and 10 m drift in veering. These routes will leave a minimum 15 m clearance to the bathymetric limits.
- The entrance will be outside the breaking line of any significant wave with a 5 year return period.

8.5.3. Minimum harbour entrance width

Irrespective of the harbour entrance width resulting from an analysis of the fairway over the pertinent stretch, should the entrance be configured by the advanced ends of two artificial structures, the harbour entrance's nominal width measured at the depth required by the Design Vessel under the worst operating conditions accepted is recommended to be equal to or more than the said vessel's length overall (*L*) to prevent the possibility of the latter being stranded between both boundaries with the risk of splitting when resting on both ends at low tides.

8.5.4. Harbour entrance navigation marking

Considered as a specific fairway stretch, the harbour entrance will be marked for navigation as per the Maritime Marking System, the Guide for its Application and AISM Recommendations.

Should it be assumed suitable to mark the heads, underneath and bathymetric limits of rubble mound armour or other undersea constructions of harbour infrastructures, auxiliary marks or beacons will be used in accordance with current regulations in force on the matter.

8.6. MANOEUVRING AREAS

8.6.1. Concept

Areas with at least the following purposes are included in the manoeuvring areas concept:

◆ Stopping the vessel

◆ Turning the vessel

◆ Gaining the vessel headway

When a vessel is approaching a port or terminal, whether sailing in from the open sea or over a fairway, it must do so at a minimum speed sufficient to maintain controlled navigation as a function of the site's characteristics and of the environmental conditions existing. Before the vessel performs berthing manoeuvres, it should reduce its speed to practically zero and enough room for this vessel to come to a stop under safe conditions is required. Moreover, simultaneously with or subsequent to the foregoing operation, the vessel must change its heading in a large number of cases by veering in small spaces to adjust to the alignment required by the quay or berth it will be occupying.

The process is similar in departure manoeuvres where the vessel may be required to turn and accelerate its movement to reach the navigation conditions necessary to leave the harbour under safe conditions.

The spaces required for this double stopping (or acceleration) and turning function of a vessel are comprised in the concept of manoeuvring areas, since they are frequently interconnected operations which may be performed on occasions in a given area.

8.6.2. Factors affecting design

Manoeuvring area design mainly depends on the following aspects:

- The size, dimensions and characteristics of the worst vessels it is expected to receive (which may not be the largest, which is why various types of vessel will need to be analysed).
- Traffic volume and nature, as well as admissible navigation speeds at which vessels approach these areas.
- Geometric characteristics of the areas in which these manoeuvres are to be performed.
- The maritime environment existing in the area and, in particular, the limit operating conditions established for performing manoeuvres.
- Effects of a side veering of the stern occurring in the final manoeuvre phases, which are more noticeable in full form vessels at low speeds and more accentuated the deeper the water depth and the greater the engine astern speed used in the manoeuvre.
- The availability of tugs and their characteristics for undertaking the different manoeuvre associated operations.

The analysis made in the following sections assumes that two or more vessels are not manoeuvred simultaneously and, therefore, the dimensions established here are based on the areas required for a single vessel only.

8.6.3. Design of a vessel stopping area

8.6.3.1. Determinist design

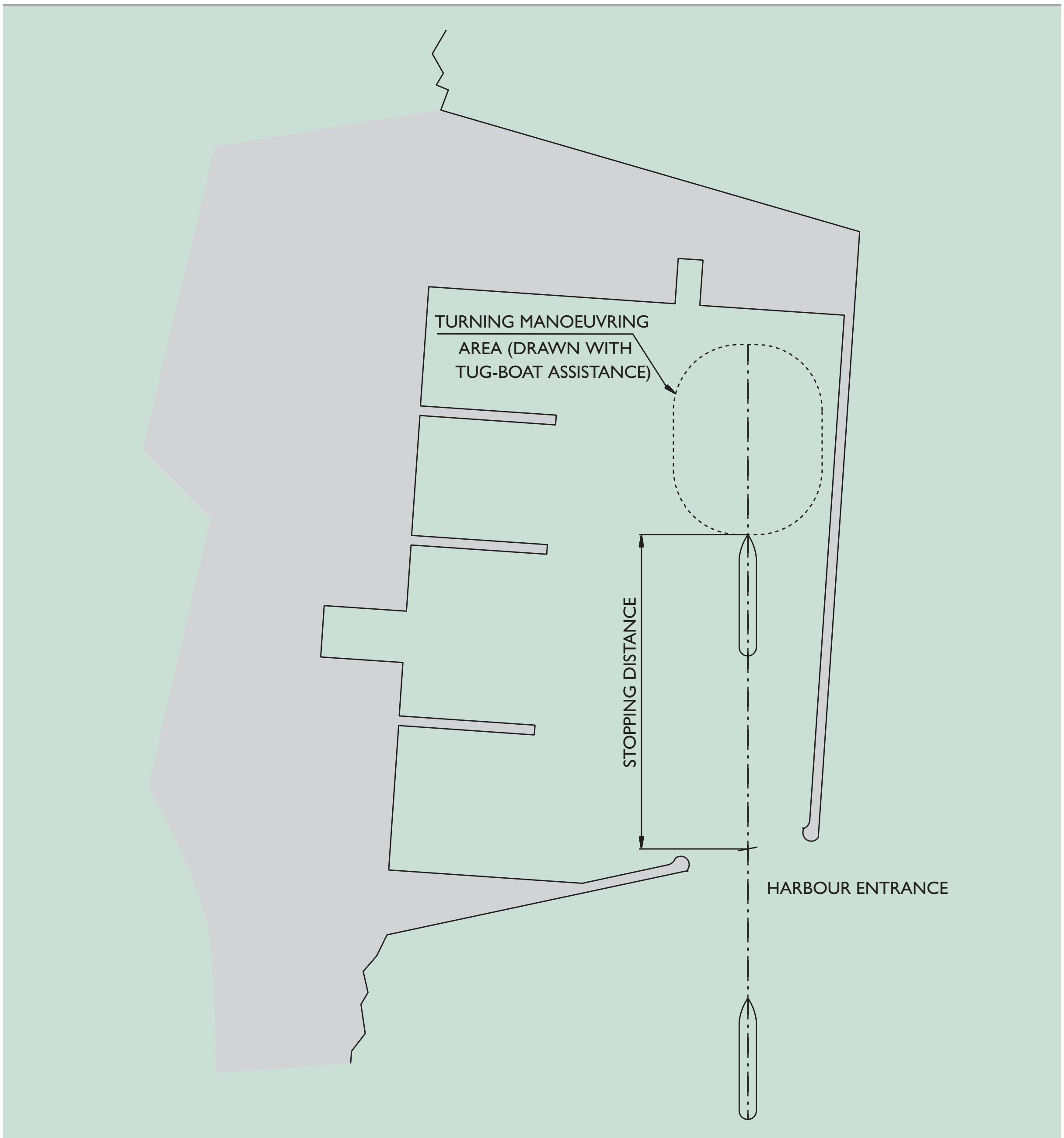
A vessel's stopping space (length and breadth) will be dimensioned with the criteria as expounded in section 6.3., assuming that vessels travel at the maximum navigation speeds admissible in approach fairways or routes. A safety factor of 2 will be applied to the distances thus calculated by determinist methods and, therefore, lengths twice those theoretically calculated will be provided for. The specific recommendations given in the following sub-sections of this chapter will be taken into account for determining widths.

The configuration given to this stopping area usually responds to one of the 3 following schemes, which may be applied to stopping manoeuvres in sheltered or open water. Should the stop have to be made outside waters suited to turning and berthing manoeuvres, the specifications of section 8.6.3.3. will also apply.

a) STRAIGHT STRETCH STOPPING

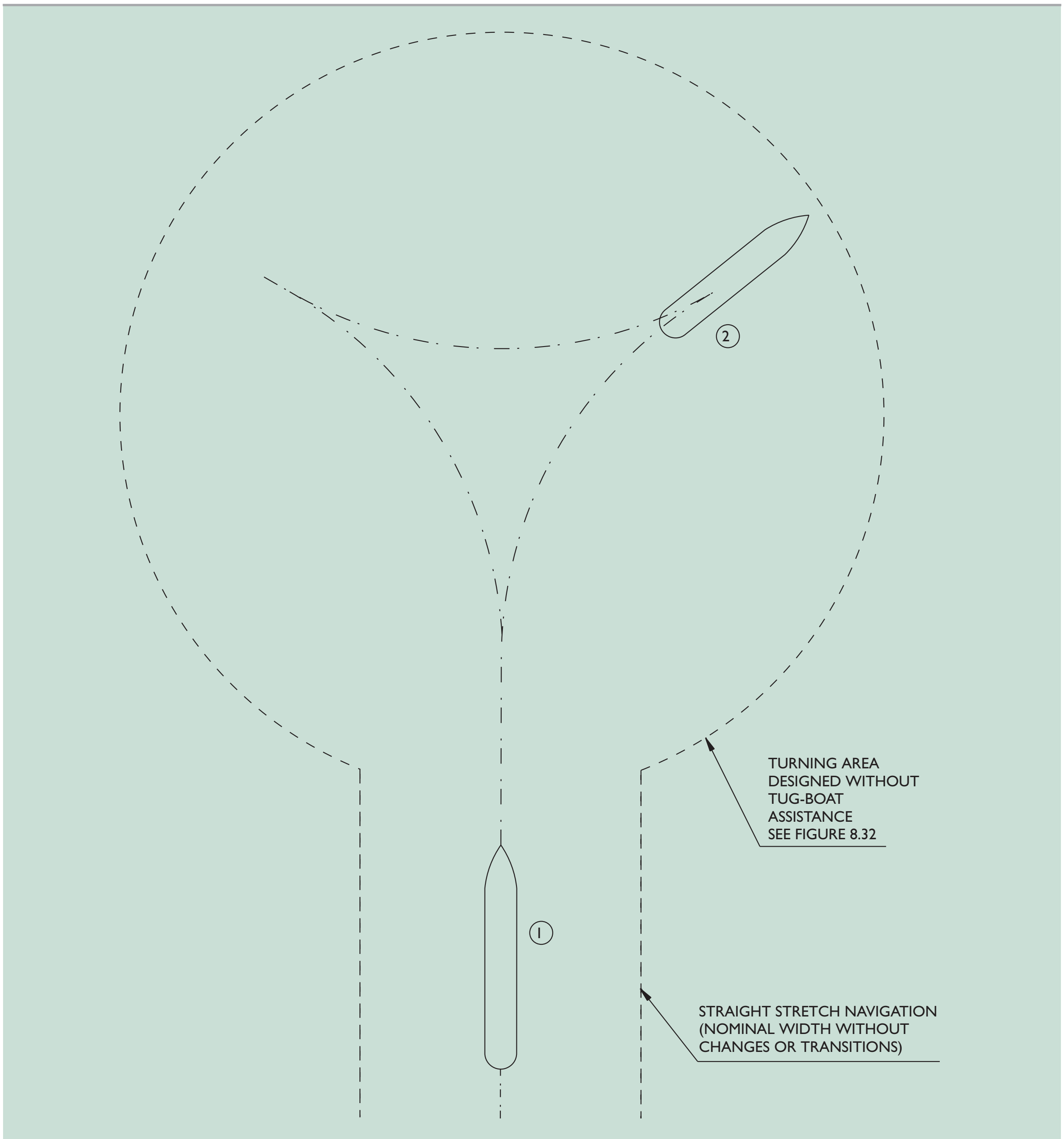
In this hypothesis, shown schematically in fig. 8.26 for the case of a stop inside a harbour, a straight alignment must be provided with a length equal to or greater than the stopping distance, increased with the aforementioned safety factor of 2 with a nominal width which will be determined by assuming that a fairway with environmental conditions compatible with those set as operating limits for the area from which the vessel is travelling is involved (it will be assumed that the vessel is navigating at the minimum speed established for that fairway for determining widths). This nominal width may be kept up to a distance of one length (*L*) from the final point of the stopping manoeuvre. This area is where the effects of the stern's side veer associated to the manoeuvre's final phase begin to be felt and will influence the width in the following way:

Figure 8.26. ***Stopping in a straight stretch***



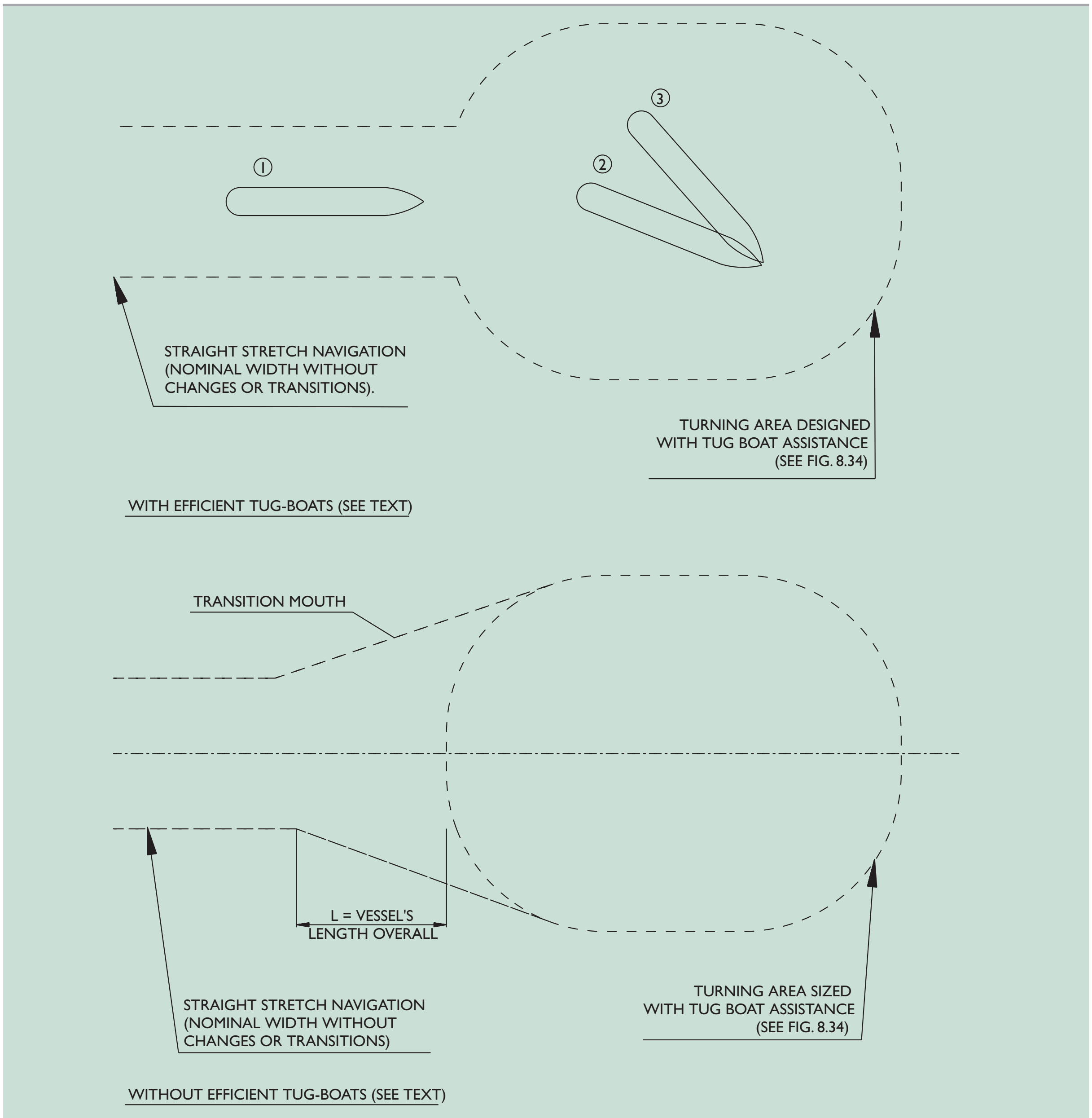
- Should the vessel be stopped without tug-boat assistance and the stopping area ends in a vessel Turning Area dimensioned for operating without tug-boats (see fig. 8.27), the Turning Area dimensions cover the veering that may occur at the manoeuvre's end and, therefore, no additional widths are necessary. In these cases, the vessel's final veer might even facilitate the beginning of the turning manoeuvre, depending on the environmental conditions existing and the type of vessel.

Figure 8.27. **Final stretch of the stopping distance ending in a turning area designed without tug-boats**



- Should the vessel be stopped with tug-boat assistance and the stopping area ends in a vessel Turning Area dimensioned for operating with tug-boats, the following solution will be adopted, depending on the type of tug-boats available (see fig. 8.28):

Figure 8.28. ***Final stretch of the stopping distance ending in a turning area designed with tug-boats***



- If the tug-boats available are efficient working abreast on vessels travelling at a speed relative to the water V_r = 1.5 m/sec, additional widths will not be necessary if the area's Operating Rules establish that the use of such tug-boats is obligatory, according to the requirements of the different types of vessel.
- If tug-boats are not efficient under the foregoing conditions, a transition entrance will be provided between the fairway's width and the Turning Area's width, which will start at a point located in the fairway one length (*L*) from the Turning Area.

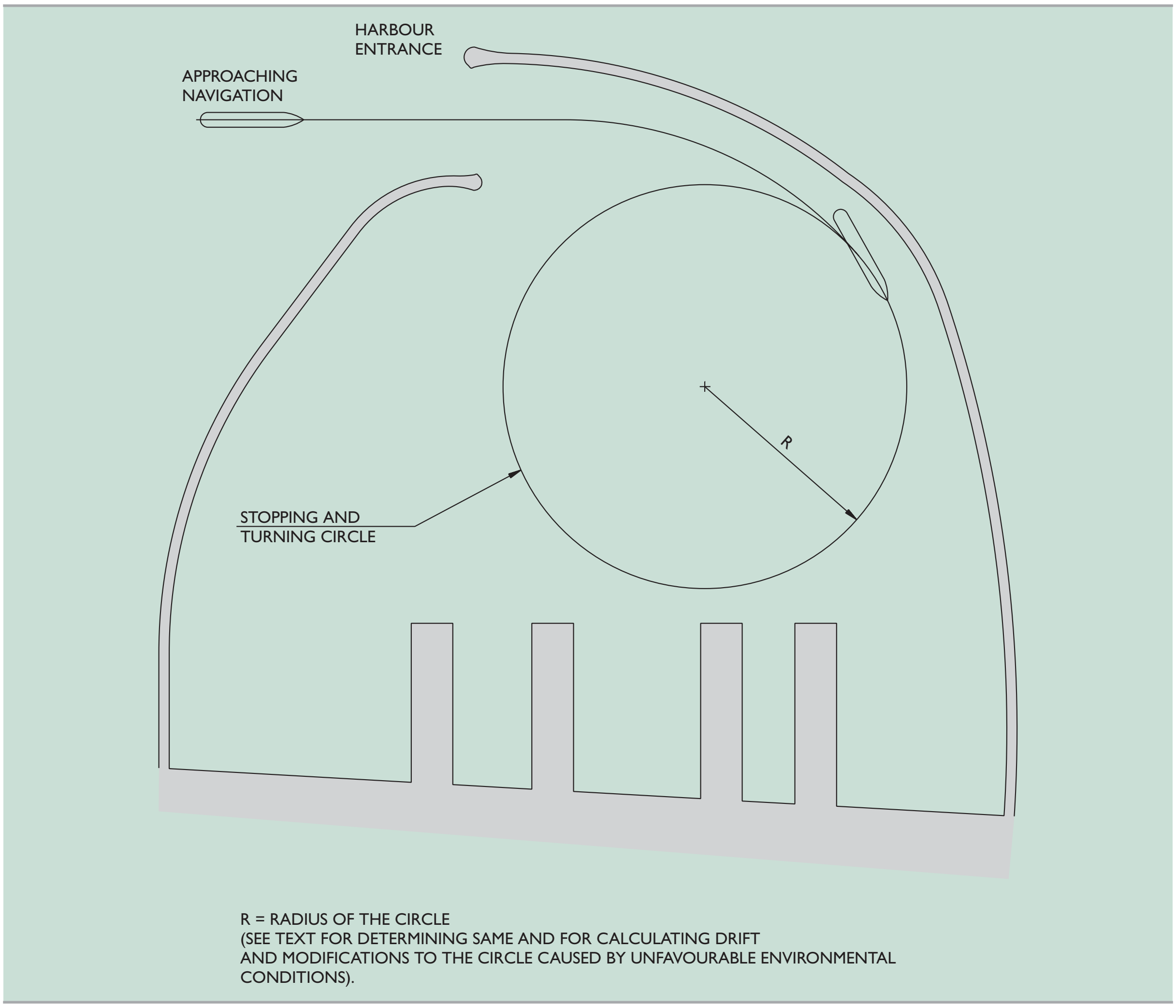
◆ Should it be planned for a vessel to stop at any point of a fairway where there might not be a Turning Area, and this fairway's width is dimensioned for normal navigating conditions with no additional width, the aid of tug-boats suited to the different types of vessel shall be provided for, to prevent excessive veering which might occur in these stopping manoeuvres. Such tug-boat requirements will be incorporated into the pertinent Floatation Area's Operating Rules.

The stopping distance necessary will usually be determined assuming that the manoeuvre is performed without the cooperation of holding tugs (which could intervene in controlling cross movements) and, therefore, solely with the vessel's own resources. As an exception, shorter stopping distances could be calculated when availing of tug-boats which might use their power to aid in holding the vessel; but for taking this possibility into account, suitable tug-boats which could sail parallel to the vessel, take heaving lines and reverse the pushing direction whilst maintaining the sailing course (Z-peller, Schottel, Voith-Schneider tugs, etc.) would have to be available. Should this procedure be followed, the port's Operating Rules should make it obligatory to use these tug-boats as a function of the type of vessel.

b) STOPPING IN A CIRCLE

The vessel is stopped in this case, which is shown schematically in fig. 8.29, around a circle which is used, in turn, to turn the vessel. Sufficient area for the worst complete circle to be developed must therefore be available to perform this dual function. The effects of the stern's lateral veer occurring in the manoeuvre's final phase are included and are more noticeable and irregular than those described for straight stopping which is why it will be advisable to provide for over-dimensioned diameters for the circle so that the end of the manoeuvre may be directed towards the inside of the circle avoiding greater additional areas. These circumstances make such types of solution generally unrecommendable due to the high cost usually involved in undertaking them.

Figure 8.29. ***Stopping in a circle***



The following circle diameter values may be used in the absence of greater detail:

- Single screw vessel operation

Depth of water	Circle´s diameter	
	Recommended	Minimum
≥ 5.0 D	8 L_{PP}	6 L_{PP}
1.5 D	10 L_{PP}	7 L_{PP}
≤ 1.2 D	16 L_{PP}	10 L_{PP}

where D is the vessel's draught and L_{pp} the Length between perpendiculars.

- Twin screw vessel operation

Reduce the foregoing figures by 10% for the two cases of water depths $\geq 1.5\ D$ and by 20% for the case of water depths $\leq 1.2\ D$.

The twin screw vessel figures may only be used for design when the Floatation Area is restricted solely to this type of vessel.

The widths and additional widths due to navigation around a bend must be considered as from these geometric circle dimensions using the criteria specified in section 8.4.3.2.

The said dimensions relate to operating conditions not exceeding the following values:

- Absolute wind speed $V_{10.1\ min}$ $\leq$10.00 m/s (20 knots)
- Absolute current speed $V_{c\ 1\ min}$ $\leq$ 0.50 m/s (1 knot)
- Wave height H_s $\leq$ 3.00.m

It must be pointed out that even though the environmental conditions are transversal, any direction may also be transversal at some time in the manoeuvre because of the very configuration of the curve and of the manoeuvre, and, therefore, these limit operating conditions may be assumed as non-directional to practical effects.

Should it be planned to operate with higher environmental conditions, the modifications such variables bring in to the turning circle must be considered, and tug-boat assistance to offset these deviations cannot be relied on since this manoeuvre is planned to be performed with the sole aid of the vessels navigation control elements. Additional drift may be calculated with the following criteria:

- Wind caused drift
  - The limit drift speed will be determined by balancing the stresses caused by wind action on the vessel in excess over those corresponding to the absolute wind speed of 10.00 m/sec, with those generated by a current equal to the drift speed acting as a resistant force on the vessel's hull, using the criteria as established in section 4.8. in this respect.
  - It will be assumed that this limit drift speed acts as from the very first moment, and, therefore, the acceleration period until this steady speed is reached will be ignored.
  - The time during which this drift speed occurs will be determined by assuming that the vessel linearly reduces its speed from the maximum admissible at the beginning of the manoeuvre to «0» at the end of the stopping distance, calculated assuming straight stretch navigation. The stopping distance increased by the factor of safety or not depending on which proves most unfavourable will be used.
  - It will be assumed that the wind can blow in any direction unless restrictions are adopted as regards the operating conditions established. It will be assumed that the wind force direction stays constant during the whole manoeuvre.

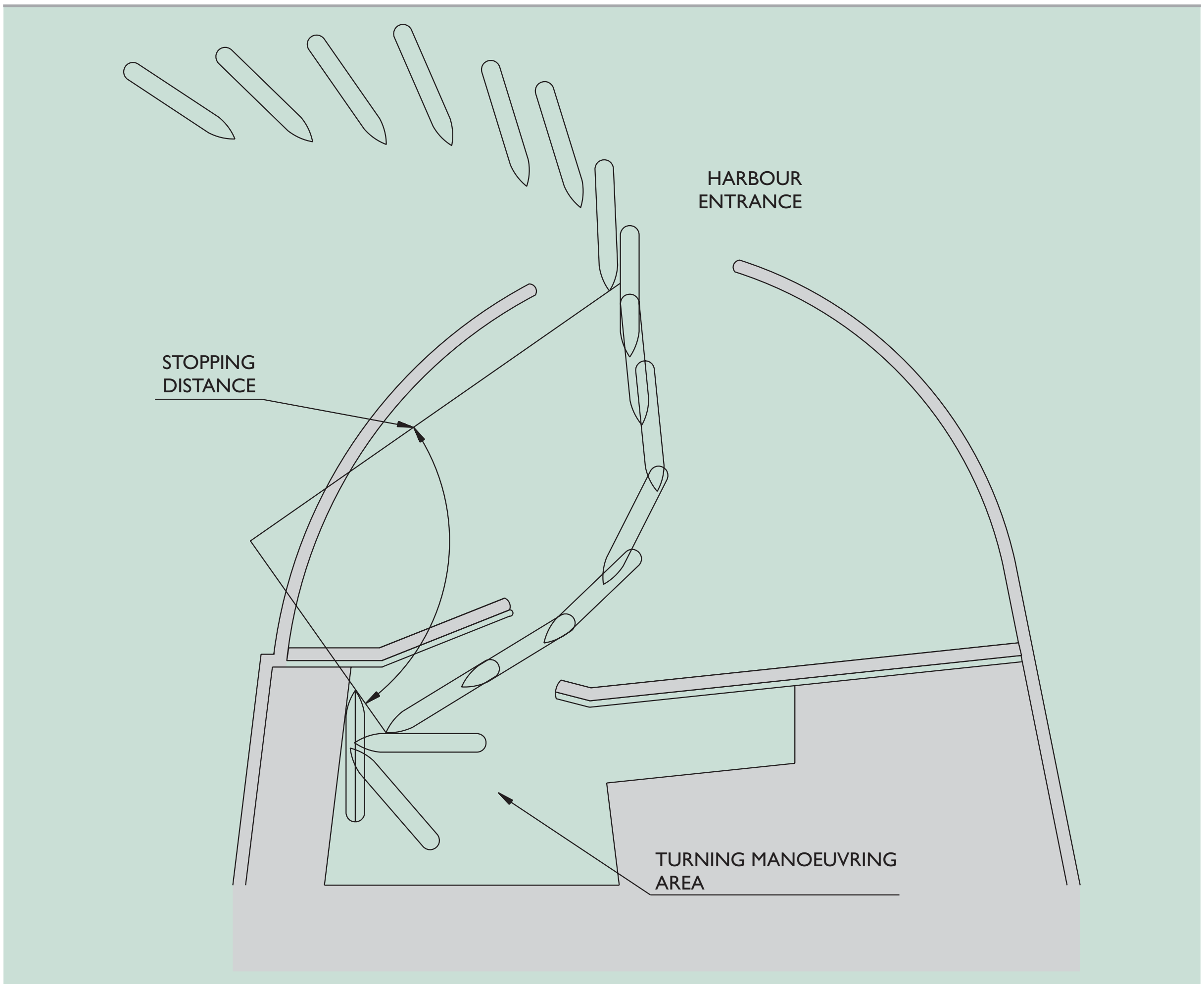
- Wave caused drift
  - This will be determined by the same procedure as established for calculating wind caused drift although the limit drift speed will be calculated by balancing the stresses caused by wave action on the vessel, in excess of the 3.00 m wave height stresses, with those generated by a current equal to the drift speed acting as a resistant force on the vessel's hull.
  - Waves may be considered as acting in all directions compatible with the geometry and protection conditions of the area being analysed, taking into account the pertinent wave transformation factors. The wave force direction will be assumed as remaining constant during the whole manoeuvre.

- Current caused drift
  - This will be determined using the foregoing procedure assuming that the limit drift speed coincides with the excess of the current's speed over the absolute value of 0.50 m/sec.
  - The current will be considered as acting in any direction with values compatible with the configuration of the area being analysed. The direction in which the current acts will be assumed as remaining constant throughout the manoeuvre.

c) STOPPING IN MIXED PATHS

In this case, shown schematically in fig. 8.30, the vessel is stopped in mixed-line paths formed by a combination of straight and curved stretches, generally following the geometry as imposed by the physical space

Figure 8.30. ***Stopping in a mixed path***



available without sufficient area being available to make a straight stop and subsequent turn or a complete stopping and circle turn manoeuvre. These paths will usually need a turning area after the stopping distance to perform vessel quay approach, berthing and departure manoeuvres.

The areas required for this manoeuvre will be determined using the criteria as expounded in point a), applying them to the path's straight stretches, and using the criteria as expounded in point b) together with those applicable to curved stretch navigation for curved stretches along the path. The pertinent transitions between both types of stretch will be established. The overall length of the stretch required for vessel stopping, measured along the axis, will be at least equal to that required for straight stretch navigation.

Should the geometric spaces available not allow inmplementation of the configurations to which the foregoing paragraph's criteria are applicable, manoeuvres must be fully studied on a simulator, particularly analysing their final phase given the importance and heterogeneity of the vessel's stern veer occurring in the final curved stopping stages.

The stopping manoeuvre is generally recommended to end on straight and not curved stretches in order to minimize these problems and such curved stretches are recommended to be used only for braking manoeuvres without the vessel travelling over them at speeds which do not allow it to be controlled under the Limit Operating Conditions being considered.

8.6.3.2. Semi-probabilistic design

In this procedure, geometric design of vessel stopping space is fundamentally based on a statistical analysis of the areas swept by vessels in the different manoeuvres being considered which enable the resultant dimensions to be associated to the risk preset in each case should a sufficient number of manoeuvre repetitions be available.

This method may be applied in a practical manner on the basis of simulator studies, small scale tests, real time measurements or similar procedures which may reproduce the problem posed with greater or lesser accuracy. Part 9 of this ROM deals with the main aspects of Simulation Models, which are the tools most frequently used for this type of study.

Prior to using this method, the characteristics and limitations of the system used must be accurately known, and what aspects of the situation are not reproducible with the model used must be determined (e.g., navigation marking and associated inaccuracies), since all those conditions that cannot be modelled must be dealt with by other procedures. The scheme as followed in this ROM is that in all these aspects which simulation models do not consider, the same criteria will be used for assessing them as were defined for the determinist method. In particular, the Safety Margins (rh_{sd}) will be appraised exactly the same in both methods.

The analysis made with these procedures usually studies different vessel stopping manoeuvres in which the engine speed to be used in the stopping procedure is considered as one of the variables, apart from other factors affecting the dimensions of these areas (type of vessel, marine environment, tug-boat availability, etc.).

The general design procedure will comprise the following phases:

1. Knowing the model to be used and its limitations, especially those aspects that cannot be reproduced in the study, which must be addressed by determinist procedures.

2. Knowing the characteristics of the Manoeuvring Area and its surroundings (geometric identification of the track, bathymetry and water levels, marine environment existing in the area, etc.) The definition level required in this respect may significantly vary depending on the simulation system used.

3. Defining the marking and beaconing systems which may be set up, as well as the manner in which they are incorporated into the simulator.

4. Defining the limit operating environmental conditions according to vessel type and dimensions, tug-boats available or any other particular condition that may be defined in each case.

5. Defining the tug-boats available and their participation in the manoeuvres taking into account the vessel type and dimensions, environmental conditions existing or any other condition that may be established.

6. Specifying the «scenarios» to be reproduced on the simulator. «Scenario» is taken to be the set of conditions defining a manoeuvre (which will be repeated several times to statistically process it), comprising at least the following aspects:

   - The type of vessel representative of the fleet category to be studied.
   - The engine speed to be used in the stopping manoeuvre.
   - The limit operating environmental conditions representative of the interval to be analysed.
   - The tug-boats and other aids to navigation which will be available in this operation.

7. Defining the number of simulator runs to be made, repeating the manoeuvre for every scenario. The study's accuracy will increase as a greater number of runs becomes available, with the counterpart of a rise in simulation costs. Between 12 and 15 runs are recommended for final designs.

8. Specifying the cross sections of the Manoeuvring Area where spaces swept by a vessel are to be evaluated (critical sections, all cross sections may be analysed at a preset geometric or time separation and a continuous record of all vessel occupied tracks in each of the paths may be obtained, which is the procedure recommended for the final manoeuvring phase where the greatest vessel veerings may occur).

9. Statistically analysing the simulator results in keeping with the purpose of the study. If the target is only to determine the Manoeuvring Area's surface, interest will lie solely in the limit occupied area values. If, in addition, it is wished to optimise the fairway's track, the vessel's centre of gravity deviation from the preset reference track must be analysed. In all cases, the process will be to determine the functions of density and exceedance, adjusting different distribution functions (Normal, Gumbel, Weibull, etc.) for each of the study's cross sections, determining their correlation coefficients and selecting the functions that best fit in, which, in general, will be the symmetric type for studying the centre of gravity's position and those of an asymmetric type when analysing the occupied area on either of the two sides.

10. Selecting the distribution functions (preferably one type for the sides and another for the centre of gravity, if necessary). The mean values of the centre of gravity's deviation density function will be used in order to optimise the track's axis. The functions of the probability of exceedance will be used to analyse the Manoeuvring Area's width and, in addition, the most unfavourable confidence bands (those causing larger occupied area) corresponding to 95% will be determined. The probability of exceedance (p_{ij}) of that Navigation Area being exceeded in that section by a vessel of type (i) under the operating conditions of the interval (j) – the scenario being analysed –will be calculated on these confidence intervals– entering with the procedure as described in section 2.5 and, particularly, in sub-section 2.5.6.

The nominal width of each section studied in the Manoeuvring Area, determined by this semi-probabilistic method, will be:

B_n = [Width between bands statistically calculated as a function of the preset risk «E»] + [additional width due to effects not addressed on the simulator, which will be calculated with the criteria established by the determinist method] + [Safety Margin «rh_{sd}» evaluated with the criteria established by the determinist method].

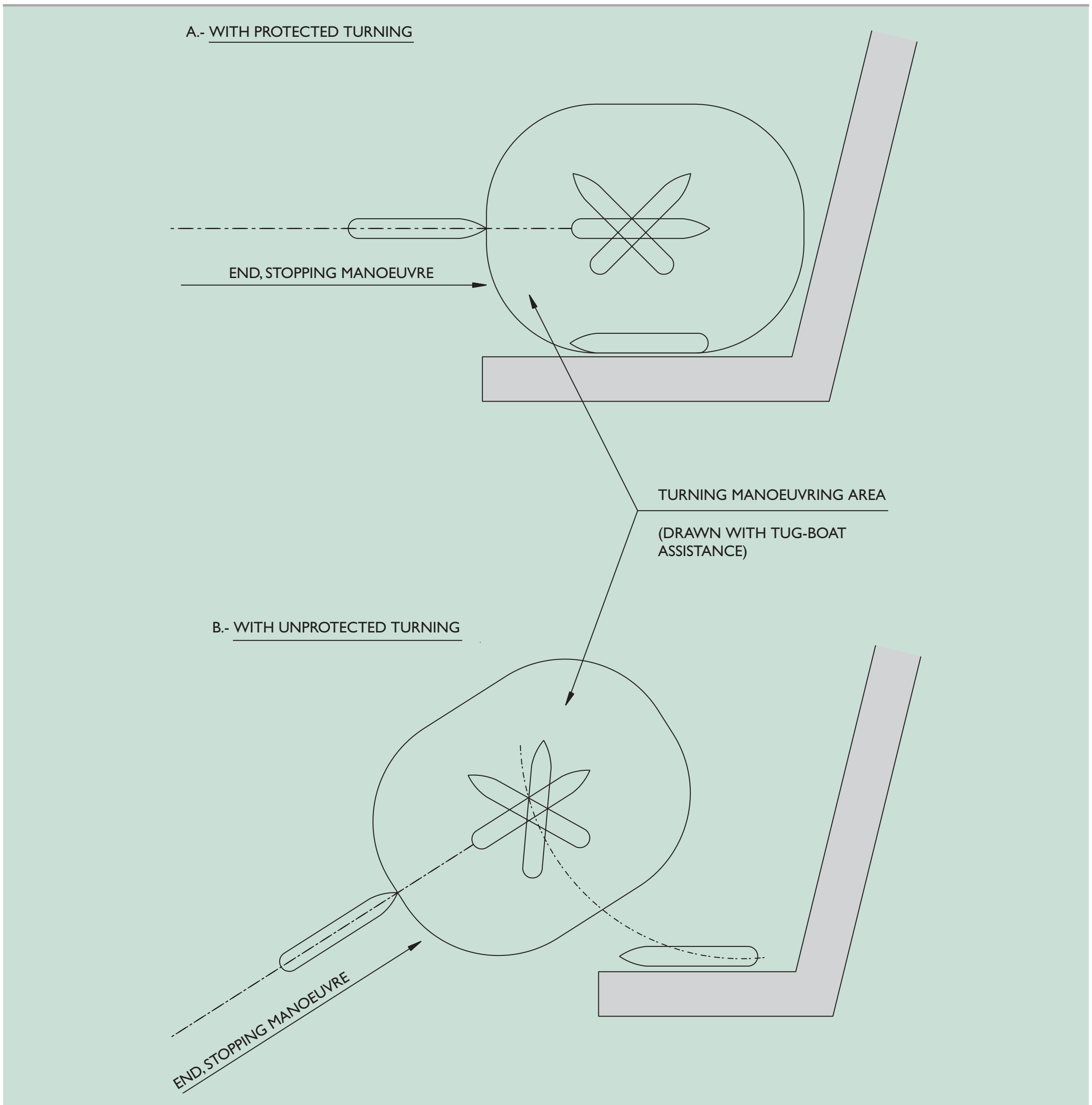
8.6.3.3. Stopping outside sheltered waters

Should the harbour's or site's configuration not allow the vessel's stopping manoeuvre to be carried out from its beginning until ending in a controlled manner, finishing in water suited to the turning and berthing manoeuvre (taking such to be that enabling the vessel to be subsequently navigated under control at low speed towards the quays or berths, whether under its own means or with tug-boat assistance), the vessel's stopping manoeuvre must be studied and positioned in areas outside the harbour or site under consideration so that the vessel may come to a stop before entering the harbour's or site's small area and proceeding to perform this final turning or approaching manoeuvre to the quays with tug-boat assistance (see fig. 8.31). In this case, it must be taken into account that, should they be the most unfavourable, the limit operating environmental conditions of this type of site may be caused by the limitations of the auxiliary vessels available for enabling the pilot to access the vessel, as well as because of the tug-boats, which must exit the shelterd waters to pick up the vessel and move it towards the quays. In the absence of more accurate studies suited to the particular characteristics of each case, these limit operating environmental conditions may be set at the following values:

- Absolute wind speed $V_{10.1\ min}$ $\leq$ 10.00 m/sec (20 knots)
- Absolute current speed $V_{c.1\ min}$ $\leq$ 1.00 m/sec (2 knots)
- Wave height H_s $\leq$ 2.00 m

these conditions are assumed non-directional in view of the manoeuvre's characteristics.

Figure 8.31. **Stopping outside areas suitable to turning and berthing**



8.6.4. Design of turning manoeuvre areas

8.6.4.1. Design by determinist methods

The dimensions of vessel turning manoeuvre areas calculated by determinist methods will be established as per the following criteria, depending on whether they are performed with or without the assistance of tug-boats.

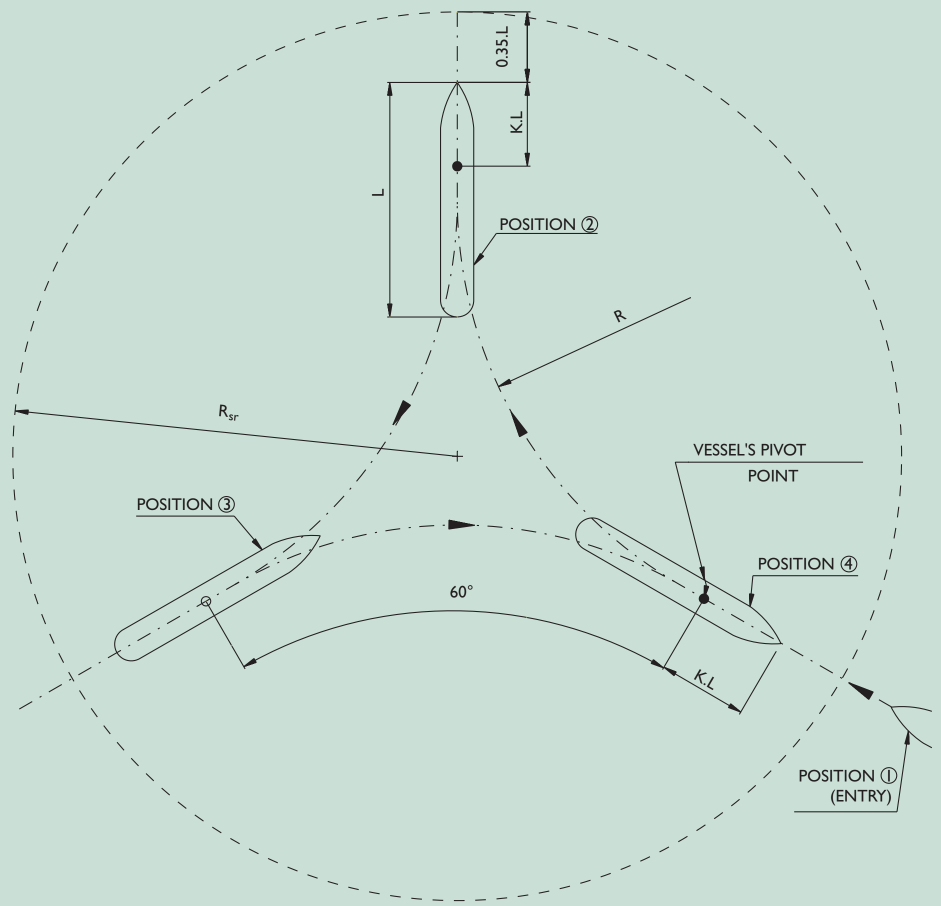
a) MANOEUVRES WITHOUT TUG-BOAT ASSISTANCE

The turning manoeuvre area or space a vessel needs to turn around reversing its direction of navigation, should it not use the aid of tug-boats, is a circle with a radius «R_{sr}», whose value will be determined with the following criteria, depending on whether the anchor is dropped or not.

- Without anchor dropped (see fig. 8.32)

$$R_{sr} = R \bullet \text{tang } 30° + K \bullet L + 0.35 \bullet L$$

Figure 8.32. Area for turning without tug-boat assistance or dropping anchors



R_{sr} = Manoeuvring circle´s radius.
R = Vessel´s path radius going ahead or astern.
L = Vessel´s length overall.
K = Distance from the pivot point to the vessel´s bow or stern (the most unfavourable) expressed as a fraction of L.
0.35. = Safety clearance.

where:

R_{sr} = Manoeuvring circle's radius without tug-boat assistance

L = Vessel's length overall

R = Minimum radius of the vessel's path in going ahead or astern for which, in the absence of more detailed studies, the following values will be taken as a function of the site's water depth.

Depth of water	Minimum radius
$\geq$ 5.0 D	3.0 L_{pp}
1.5 D	3.5 L_{pp}
$\leq$ 1.2 D	5.0 L_{pp}

where D is the vessel's draught and L_{pp} the length between perpendiculars.

These dimensions are for operating conditions not exceeding the following values:

- Absolute wind speed $V_{10.1\ min}$ — $\leq$ 10.00 m/sec (20 knots)
- Absolute current speed $V_{c.1\ min}$ — $\leq$ 0.50 m/sec (1 knot)
- Wave height H_s — $\leq$ 3.00 m

Should it be required to operate in more severe meteorological conditions, the modifications occurring in these vessel turning radii must be taken into account using the criteria expounded in section 8.6.3.1.b.

K = Distance from pivot point to the vessel's stern (or bow if greater), expressed as a fraction of the vessel's length overall (L).
K will take the value of 0.5 for larger displacement vessels with full underwater body forms (oil tankers, bulk carriers, etc.) which are usually critical for dimensioning Manoeuvring Areas, if the ratio between the at rest water depth (h) and the vessel's draught (D) is $h/D \leq 1.20$, whilst if this ratio $h/D \geq 1.50$, the value of $K = 2/3$. The value of $K = 1.0$ for high speed vessels (vessels with finer underwater body forms) and pleasure boats.

0.35 = Coefficient quantifying the clearance or Safety Margin (rh_{sd}) as a function of the vessel's length (L), which is determined by assuming that the vessel's longitudinal speed at the centre of the manoeuvring circle does not exceed 0.20 m/sec.

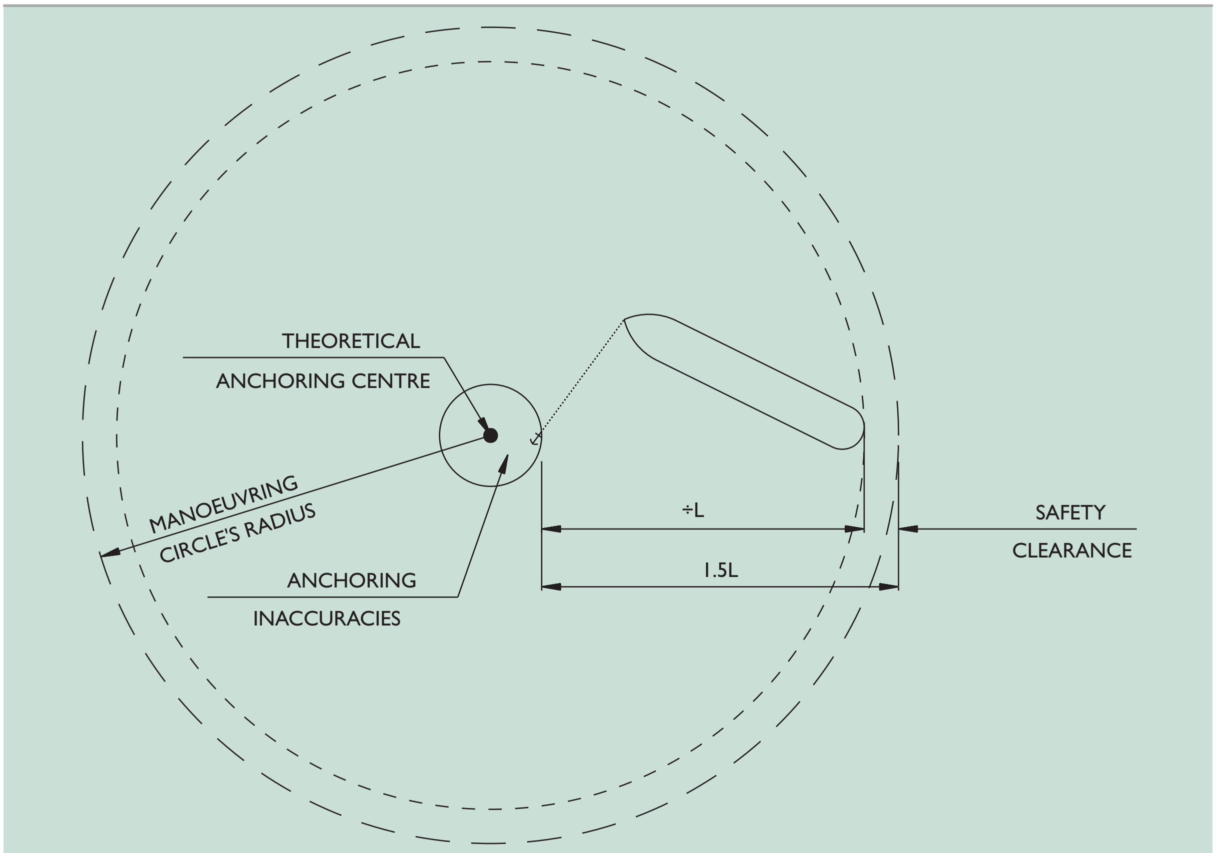
- With dropped anchor (see fig. 8.33)

If the vessel carries out the manoeuvre using the anchor, that of the side in whose direction the vessel is rotating has to be dropped and the engine given ahead, and a circle will be described whose centre is the anchor and whose radius approaches the vessel's length (L), as experience confirms, and a 1.5 L manoeuvring area radius is usually adopted, which takes this effect into account, and an additional clearance at the vessel's stern or Safety Margin (rh_{sd}) of 0.20 L.

The inaccuracies which may occur at the vessel's anchoring point would have to be considered on the value thus determined, deriving from the inaccuracy of the method used for positioning the vessel and those caused by the delay between the time when the order to drop anchor is given and the moment when the anchor holds in the seabed. Chart correctness and the skill of those at the Bridge of the ship also have an influence. All these factors may be assessed at between 25% and 50% of the length «*L*» of the vessel being considered, assuming it accesses the manoeuvre circle's centre with a longitudinal speed not greater than 0.20 m/sec and the limit operating conditions do not exceed the following values:

- Absolute wind speed $V_{10.1\ min}$ — $\leq$ 10.00 m/sec (20 knots)
- Absolute current speed $V_{c.1\ min}$ — $\leq$ 0.50 m/sec (1 knot)
- Wave height H_s — $\leq$ 2.00 m

Figure 8.33. **Area for turning without tug-boat assistance but with dropping anchors**



Anchoring inaccuracies ÷ (0.25 / 0.50) • L
L = Vessel´s length overall.

b) MANOEUVRES WITH TUG-BOAT ASSISTANCE

Should the vessel's turning manoeuvres be performed with tug-boat assistance, the resulting dimensions of the manoeuvre area are given schematically in fig. 8.34, where an area is defined from a central rectangle with width «$2B_g$» and length «$2L_G$» which is where the vessel's centre of gravity may be located when accessing the manoeuvre area with a longitudinal speed not greater than 0.20 m/sec in the centre of the rectangle. The dimensions appearing in the scheme are as follows:

$$B_G \geq 0.10\,L$$
$$L_G \geq 0.35\,L$$
$$R_{cr} \geq 0.80\,L$$

where «L» is the vessel's length overall.

These minimum dimensions of the Manoeuvring Area include a Safety Margin (rh_{sd}) of 0.10 . L over the whole perimeter and are determined on the assumption that the limit operating conditions do not exceed the following values:

- Absolute wind speed $V_{10.1\ min}$ ≤ 10.00 m/sec (20 knots)
- Absolute current speed $V_{c.1\ min}$ ≤ 0.10 m/sec (0.2 knots)
- Wave height H_s ≤ 1.50/2.00 m, according to the type of tug-boats available

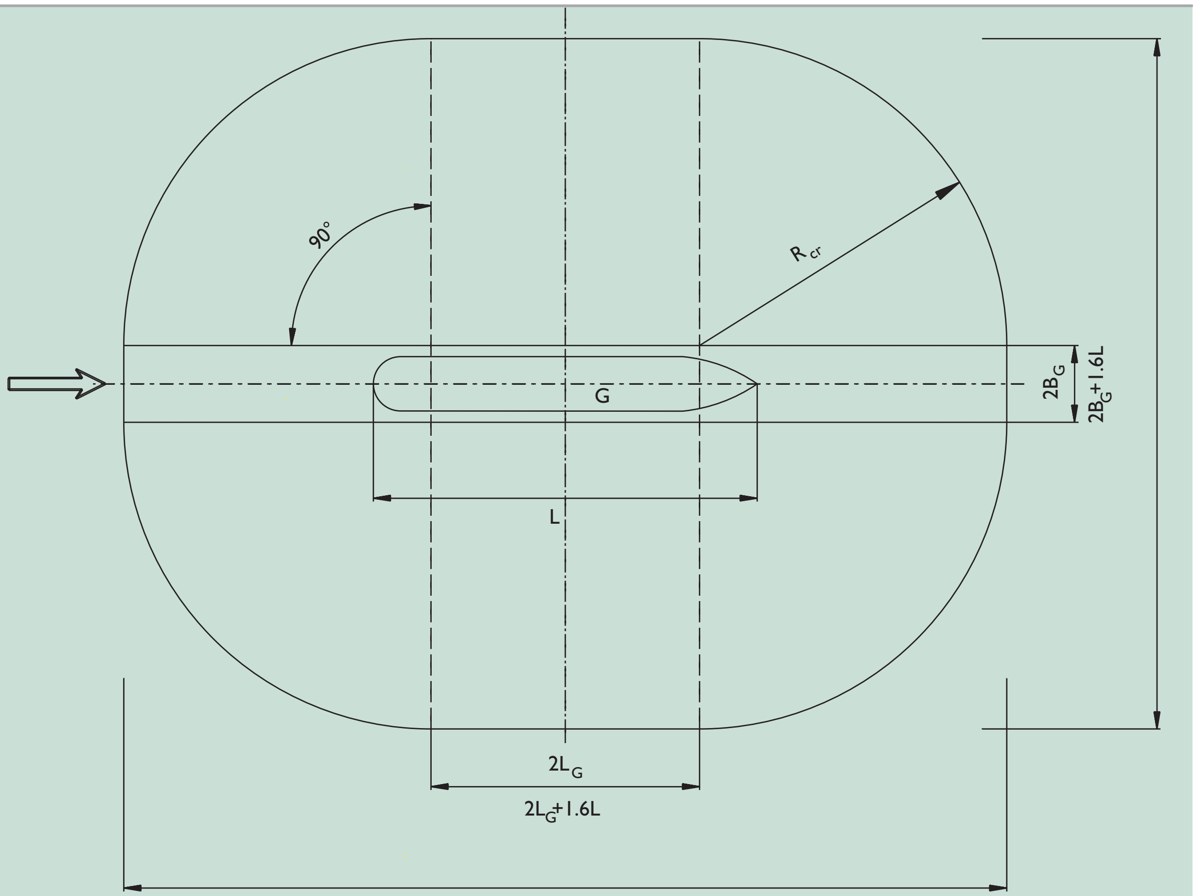
The tug-boat power required for adopting the manoeuvre area's minimum values will be calculated according to the criteria expounded in section 5.7. applied to the limit environmental condition values indicated (if compatible with the site's configuration and characteristics) assuming that the resulting forces act simultaneously. Should sufficient tug-boats not be available, the dimensions of the scheme recommended may be kept to, adopting lower Limit Operating Conditions which are compatible with the total tug power available whilst maintaining the safety factors as established in the said section 5.7.

If higher Operational Limits are wanted, two procedures may be followed:

- Increase the power of the tug-boats, which shall be dimensioned for the Operational Limits under consideration in that case, in which event the manoeuvring area's dimensions as defined in figure 8.34 would be kept.

- Increase the manoeuvre area's minimum dimensions without increasing the tug power, taking into account the increase in drift due to unbalanced forces caused by wind, wave and current. This drifting will be calculated using the following criteria, assuming that a 180° turn is made with an even angular speed in 30 minutes time.

Figure 8.34. ***Area for turning with tug-boat assistance***



L = Vessel´s length overall.
R_{cr} ≥ 0.80 L
R ≥ 0.35 L
K ≥ 0.10 L
⇨ = Direction of vessel´s entry.

Note: See text for a possible adjustment to these dimensions in operations performed with thruster fitted vessels.

- Drif due to wind
  - The limit drifting speed will be calculated by balancing the forces due to the wind on the vessel, in excess of those due to an absolute wind speed of 10.00 m/sec, with those generated by a current equal to the drifting speed acting like a resistant force on the vessel's hull, using in this respect the criteria established in section 4.7.
  - It will be assumed that this limit drifting speed acts from the very first moment, and, therefore, the acceleration period until this steady speed is reached will be ignored.
  - It will be assumed that the wind can blow in any direction unless restrictions are adopted as regards the operating conditions to be established. It will be assumed that the wind force direction stays constant during the whole turning manoeuvre.

- Drift due to waves
  - This will be determined by the same procedure as established for calculating drif caused by wind although the limit drifting speed will be calculated by balancing the forces caused by wave action on the vessel, in excess over those corresponding to a 1.50/2.00 m wave height, with those generated by a current equal to the drift speed acting as a resistant force on the vessel's hull.
  - It will be assumed that waves may act in all directions compatible with the geometry and protection conditions of the area being analysed, taking into account the pertinent wave transform factors. It will be assumed that the wave force direction will remain constant during the whole turning manoeuvre.

- Drif due to current
  - Will be determined using the foregoing procedure assuming that the limit drifting speed coincides with the excess of the current's speed over the absolute value of 0.10 m/sec.
  - It will be assumed that the current may act in any direction with values compatible with the configuration of the area being analysed. It will be considered that the direction in which the current acts will remain constant throughout the turning manoeuvre.

This resort to increasing the manoeuvre area's dimensions without increasing tug power cannot be adopted in the cross direction landward into the quay to which berthing will occur unless this quay is dimensioned for a berthing energy for operation without tug-boat assistance. However, it is a procedure normally used in the case of channels or estuaries with heavy longitudinal and very small cross currents, in which manoeuvre areas more elongated in directions parallel to the quays may be accepted, with no special difficulties and no need to unnecessarily increase the tug-boats' horsepower.

Should the manoeuvre be performed with vessels fitted with thrusters which fully undertake the functions of tug-boats, this Turning Area's dimensions may be reduced, adopting a value of $R_{cr} \geq 0.70.L$ which takes into account the reduction of spaces occurring when not having tug-boats involved in the manoeuvre inside the Turning Area. This reduction cannot be applied should the thrusters only be able to partially assist the manoeuvre and the vessel needs to be supplemented with tug-boats when working under Limit Operating Conditions. This will be the most common supposition if the thrusters are sized with the criteria given in section 3.6.

8.6.4.2. Design by semi-probabilistic methods

In this procedure, geometric design of vessel turning spaces is fundamentally based on a statistical analysis of the areas swept by vessels in the different manoeuvres being considered which enable the resulting dimensions to be associated to the risk preset in each case, should a sufficient number of manoeuvre repetitions be available.

This method may be applied in a practical manner on the basis of simulator studies, small scale tests, real time measurements or similar procedures which may reproduce the problem raised with greater or lesser accuracy. Part 9 of this ROM deals with the main aspects of Simulation Models, which are the tools most frequently used for this type of study.

Prior to using this method, the characteristics of the system used and its limitations must be accurately known, and those aspects of the situation which are not reproducible with the model used must be determined (e.g., navigation marking and associated inaccuracies), since all those conditions that cannot be modelled must be considered by other procedures. The scheme as followed in this ROM is that in all these aspects which simulation models do not consider, the same criteria will be used for assessing them as were defined for the determinist method. In particular, the Safety Margins (rh_{sd}) will be appraised exactly the same in both methods.

The analysis made with these procedures usually studies different vessel turning manoeuvres in which the characteristics of the vessels relative to this type of manoeuvre (number of propellers, thrusters, etc.), limit operating environmental conditions, tug-boat availability and characteristics, apart from other factors affecting the dimensions of these areas, are particularly considered.

The general design procedure will comprise the following phases:

1. Knowing the model to be used and its limitations, especially those aspects that cannot be reproduced in the study and which must be addressed by determinist procedures.

2. Knowing the characteristics of the Manoeuvring Area and its surroundings (geometric identification of the area, bathymetry and water levels, marine environment existing in the area, etc.). The definition level required in this respect may significantly vary depending on the simulation system used.

3. Defining the marking and beaconing systems which may be set up, as well as the manner in which they are incorporated into the simulator.

4. Defining the operational environmental limits according to vessel type and dimensions, the tug-boats available or any other particular condition that may be defined in each case.

5. Defining the tug-boats available and their participation in the manoeuvres taking into account the vessel type and dimensions, environmental conditions existing or any other condition that may be established.

6. Specifying the «scenarios» to be reproduced on the simulator. «Scenario» is taken to be the set of conditions defining a manoeuvre (which will be repeated several times for its statistical processing), comprising at least the following aspects:

   - The type of vessel representative of the fleet category to be studied and its characteristics for this type of manoeuvre.

   - The limit operating environmental conditions representative of the interval to be analysed.

   - The tug-boats and other aids to navigation which will be available in this operation.

7. Defining the number of simulator runs to be made, repeating the manoeuvre for every scenario. The study's accuracy will increase as a greater number of runs becomes available, with the counterpart of a rise in simulation costs. Between 12 and 15 runs are recommended for final designs.

8. Specifying the cross sections of the Manoeuvring Area where vessel occupied areas are to be evaluated. Obtaining an envelope or continuous record of all positions swept by the vessel in each of the manoeuvres is recommended. This facilitates the study of the occupied areas.

9. Statistically analysing the simulator results in keeping with the purpose of the study. If the target is only to determine the Manoeuvring Area's surface, interest will lie solely in the limit occupied area values. If, in addition, it is wished to optimise the fairway's track, the vessel's centre of gravity deviation from the preset reference track must be analysed. In all cases, the process will be to determine the functions of density and exceedance, adjusting different distribution functions (Normal, Gumbel, Weibull, etc.) for each of the study's cross sections, determining their correlation coefficients and selecting the functions that best fit in, which, in general, will be the symmetric type for studying the centre of gravity's position and those of an asymmetric type when analysing the occupied area on either of the two sides.

10. Selecting the distribution functions (preferably one type for the sides and another for the centre of gravity, if necessary). The mean values of the centre of gravity's deviation density function will be used in order to optimise the track's axis. The functions of the probability of exceedance will be used to analyse the Manoeuvring Area's width and, in addition, the most unfavourable confidence bands (those causing larger occupied area) corresponding to 95% will be determined. The probability of exceedance (p_{ij}) of that Navigation Area being exceeded in that section by a vessel of type (i) under the operating conditions of the interval (j) – the scenario being analysed –will be calculated on these confidence intervals– entering with the procedure as described in section 2.5 and, particularly, in sub-section 2.5.6.

The nominal width of each section studied in the Manoeuvring Area, determined by this semi-probabilistic method, will be:

B_n = [Width between bands statistically calculated as a function of the preset risk «E»] + [additional width due to effects not addressed on the simulator, which will be calculated with the criteria established by the determinist method] + [Safety Margin «rh_{sd}» evaluated with the criteria established by the determinist method].

8.6.5. Design of the vessel setting sail area

Whether by determinist or semi-probabilistic methods, the vessel setting sail area will be dimensioned with criteria similar to those for the stopping area, assuming that vessels, in this manoeuvre, move from zero speed to the admissible speed in fairways or approach routes. Since in this case the vessel will be improving its manoeuvring control capability as its speed increases, the singular aspects arise in the initial stretch of the manoeuvre and are usually covered by the provisions for space made in relation to the approach manoeuvres if both manoeuvres are carried out under the same Limit Operating Environmental Conditions and having the same tug-boat assistance. Should these circumstances not be fulfilled, the following aspects must be verified:

- The capacity of the towing elements and the vessel's other own resources (propeller, rudder, thrusters, etc.) to control the vessel's position, with the safety margins as specified in chapter 5.

- Uncontrolled vessel movements (rotations and displacements) which might occur in this initial phase of the manoeuvres and the effect they might have on the route and areas subsequently swept by the ship.

8.6.6. Manoeuvring area marking

Vessel stopping areas will be marked as per AISM criteria, using the usual navigation marks (cardinal, lateral, leading line, etc.) as established therein and paying prime attention to the definition of the navigation area's edges since the vessel will ly leave the fairway's axis and will need to accurately know where it is in relation to the available area's boundaries.

Marking manoeuvring areas will be basically directed to mark the boundaries of the areas available (which will normally be straight sided polygons enveloping the areas required), as well as the axes and fundamental points for the manoeuvre (approach routes to manoeuvring areas, centre area for dropping anchors, etc.). The proximity of these areas to existing infrastructures will allow fixed references to be used for this marking in a large number of cases.

8.7. ANCHORAGE AREA

8.7.1. Definition

Anchorage is defined as the area where vessels drop anchor, or anchor, awaiting their entry into that part of the harbour reserved for performing typical port type operations (loading, unloading, supplies, repairs, etc.), which does not exclude these operations frequently being undertaken at the anchorages.

Harbours are generally set up at the back of bays or natural, sufficiently wide roadsteads and, at least partially, sheltered from storms and sea swells by coastal protrusions or headlands, reefs, islets, shallow water or, in short, by the convenient form of bathymetric contours. Anchorages in these cases are usually located in the outer harbour or in outer water close to the port, although anchorages sheltered by artificial piers may also be set up. In other cases, harbours are located at the end of navigation channels and anchorages might also be placed in navigation channel widenings. As they are offshore facilities, anchorages would normally be sited in places with low protection.

8.7.2. Factors affecting design

The design of an anchorage mainly depends on the following factors:

- The size, dimensions and characteristics of the most unfavourable vessel it is expected to receive (which might not be the largest), which is why several types of vessel will usually need to be analysed.
- The type of operations expected to be undertaken, including typical characteristic port operations, as well as the nature of the cargo carried by the vessels which will use the anchorage and, should such be the case, those of the cargo to be handled there.
- The time the vessels which will remain or operate at the anchorage will stay at anchor.
- The site's general configuration and the availability of spaces for carrying out approach, verification, staying, operation and departure manoeuvres.
- The number of anchoring points to be provided at the site.
- The maritime environment in the area and the limit operating conditions established for the different functions.
- The site's physical characteristics and, in particular, the depth and decline of the seabed and quality of the latter to act as an anchor holding.
- Environmental conditions to be preserved at the site and the availability of pollution combating resources should cargo loading and unloading operations be undertaken.
- The availability of tug-boats and other elements for providing aid to navigation and to port operations, should such be the case.
- The proximity of landing stages or quays for small craft assiting in operations.

A study of all these factors is beyond the scope of this ROM but an analysis of those points affecting the design of these Areas is given below.

a) ANCHORAGE CAPACITY

An anchorage must be of a sufficient size to allow a vessel or vessels to move unhindered with a suitable safety margin depending on the anchoring system chosen, taking into account the vessel staying time, vessel lengths and the lengths of chain expected to be paid out and taking due clearance from hazards or vessels close by should anchors drag. Section 8.7.3 gives the dimensions recommended in accordance with the different anchoring systems and criteria for anchorage distribution.

b) DEPTH

The minimum depth of water required at the anchorage will be determined with the criteria defined in Chapter 7. The maximum desirable depth depends on the length and weight of chain available but, in general, it is not advisable to exceed triple the minimum depth required by the Design Vessel.

As far as the seabed topography or relief is concerned, it must not display steep declines since, if the chain works in the direction of the greatest depths, the anchor may slide down the slope and easily drag and may find difficulty in holding again.

c) QUALITY OF THE HOLDING GROUND

Sailing directions usually give the type of seabed and quality of the holding ground, which information is very important for assessing the suitability of an anchorage.

The best holding grounds are fine, hard sand, muddy sand and compact mud. Areas of sand and shell sand as well as loose stone, gravel and pebbles are acceptable. Clay bottoms are good but have the disadvantage that if the anchor drags, it finds difficulty in biting again since its arms and flukes become plugged up, enveloped in a mass of clay. This is why, in the event of drag, it is advisable to weigh anchor and wash it before making another attempt at anchoring.

Soft mud seabeds are relatively unsafe since, whilst biting in is not difficult, the anchor is likely to drag without the chain showing perceptible signs of flapping. If the anchor is buried too deep in the mud, it may be impossible to weigh it. If the stay at the site is to be prolonged, it is advisable to heave up and drop the anchor again from time to time.

Rock or coral and excessively hard holding grounds are bad, since the anchor flukes do not bite in and if they should embed in some seabed protuberance, it may happen that they come clear when the vessel swings or become tangled such that recovering the anchor is difficult or impossible.

The old fashioned stock anchors bit into very soft seabeds quite easily; more recent, improved models dig in satisfactorily in almost any type of bottom because they are buried deeper during the final phase of dragging before firmly settling in. This does not mean that the seabed quality factor is any the less important. Results of tests made with the most efficient anchors in use may be mentioned as a clarifying detail. According to such results, they withstand a pull 10 times their weight without dragging in good holding ground, they resist 12? times their weight with exceptional seabeds (a mixture of sand, pebbles and clay) and only 6 times their weight in poor quality seabeds (soft mud)

d) PROTECTION FROM WIND AND SEA

To design effects, the anchorage should be chosen in accordance with prevailing winds, seeking the greatest natural shelter possible, whilst also endeavouring to achieve sufficient protection from wave effects. The environmental conditions forecast must be heeded for the specific conditions of use of each specific case. It is advisable to anchor closer to the windward coast in order to avail of the greatest clear space possible in the event of dragging.

e) CURRENTS

Depending on its direction and intensity, the current may make the vessel drag anchor, particularly when it turns beam on to the wind because of its action or when the holding ground is bad. To the effects of application, special attention must be paid to changes in current and, in any case, the engines must always be «on attention» for emergencies.

f) LIMIT OPERATING CONDITIONS

The maritime environmental conditions usually set as anchorage operational limits are given below. They depend on the vessel, type of anchorage and the operation expected. Wind velocity is determined for general type vessels. Should they have large sail surfaces (methane carriers, container ships, in ballast oil tankers, etc.), the operational limit wind velocities will be 20% less than those given in the table.

	Absolute wind velocity $V_{10.1\ min}$	Absolute current velocity $V_{c.1\ min}$	Wave height H_s
◆ Approach and mooring manoeuvres	17.0 m/sec	2.0 m/sec	2.5 m
◆ Vessel staying at anchorage			
• With one anchor ahead	24.0 m/sec	2.0 m/sec	3.5 m
• With two anchor down	30.0 m/sec	2.0m/sec	4.5 m
• Anchoring against ebb and flood and anchoring with an anchor ahead and an anchor astern:			
Longitudinal forces	24.0 m/sec	2.0 m/sec	3.5 m
Transverse		Anchorage not operative	
◆ Loading & unloading operations		Depend on the characteristics of the equipment	

g) MARITIME TRAFFIC IN THE AREA

It shall be tried not to locate anchorages nor anchor near highly frequented routes, particularly when visibility is poor.

h) NAUTICAL FACILITIES FOR TAKING AND LEAVING THE ANCHORAGE

As far as possible, an easily day-time and night-time entered and departed anchorage should be chosen which has suitable natural or artificial navigation marking enabling the vessel to be accurately and safely positioned when approaching and whilst remaining at anchor.

8.7.3. Anchorage design

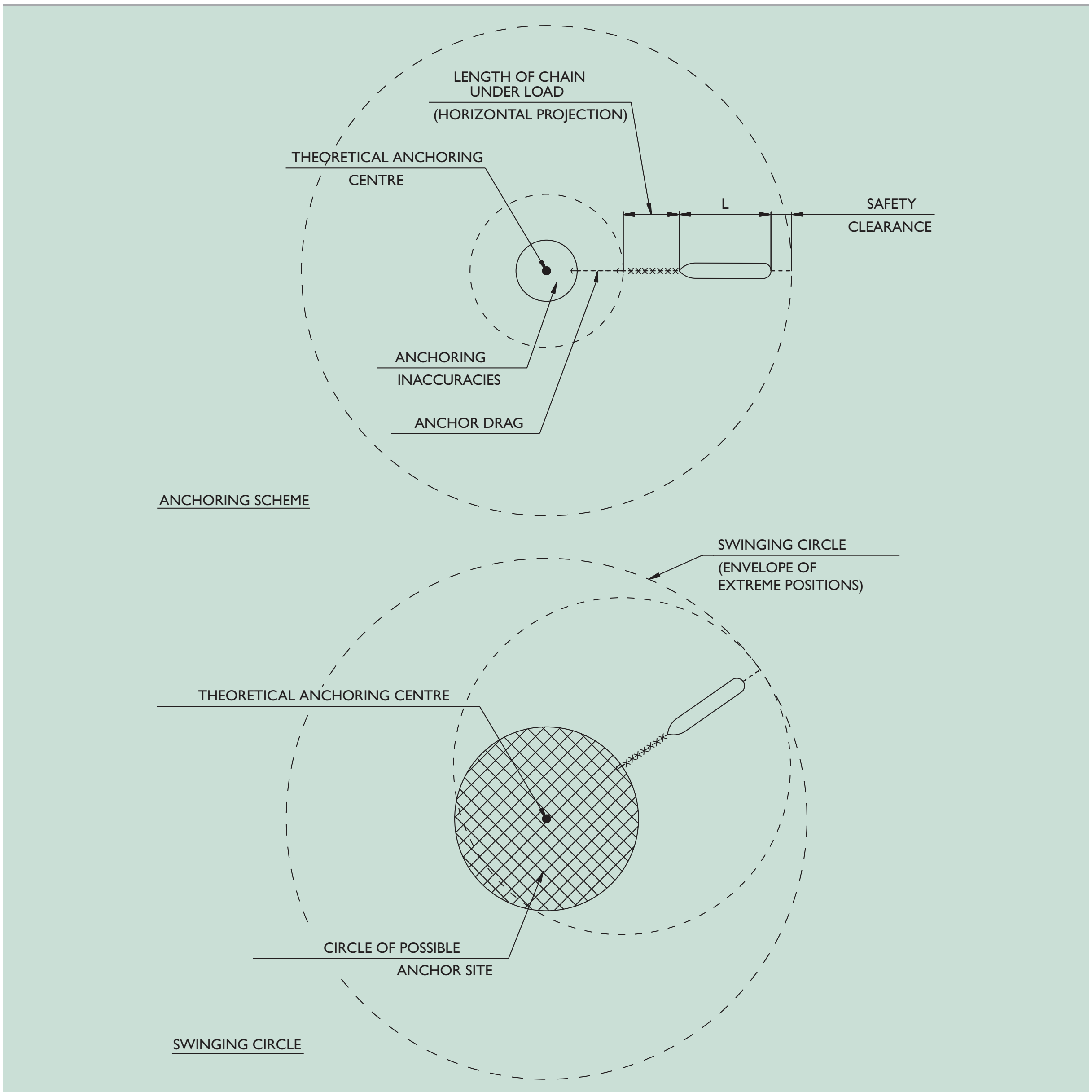
a) VESSEL WITH ONE ANCHOR AHEAD

A vessel is said to swing with one anchor ahead when it pays out the chain to which the anchor is connected through the hawse hole (an opening in the hull at the top of the bow), allowing the anchor to dig into the seabed and remain as the only securing element. The chain is windlassed in to lift the anchor, and the chain lifted out is stored in the chain locker and the anchor is lodged in the hawse pipe.

The swinging radius measured at the vessel's deck level can be calculated by the determinist method by adding together the following concepts (See fig. 8.35):

1. Vessel's length overall (*L*).
2. Length of chain it is expected to pay out at the anchorage. See section 8.7.3.e for analytically determining. It is wise to consider the total amount of chain available for the calculation to cover the possibility of having to pay it fully out because of heavy wind, waves or currents.
3. An additional safety distance to cover anchoring inaccuracies, intended for embracing errors such as those due to the inaccuracy of the method used for locating the position of the vessel to be anchored, or the vessel's run in the time elapsing between the moment the order to anchor is given and the time when the anchor holds in the seabed. Chart correctness and skill of the crew carrying out the operation are also influential. This safety distance depends on various factors, and a value between 25 and 50% of the length overall (*L*) of the vessel may be accepted.

Figure 8.35. **Swinging radius of a vessel with one anchor ahead**



4. A suitable prior notice margin for the event whereby the anchor drags, which may be evaluated with the following criteria, determined as a function of the wind velocity (similar criteria could be set for separate or combined wind, wave or current action, considering the resultant of the longitudinal forces acting on the ship):

   - Good anchoring resistance seabeds:
     - Anchoring with wind velocity ≤ 10 m/sec 0 m.
     - Anchoring with wind velocity of 20 m/sec 60 m.
     - Anchoring with wind velocity of 30 m/sec 120 m.
     - Anchoring with wind velocity ≥ 30 m/sec 180 m.

   - Sea bottoms with bad anchoring resistance
     - Anchoring with wind velocity ≤ 10 m/sec 30 m.
     - Anchoring with wind velocity of 20 m/sec 90 m.

- Anchoring with wind velocity of 30 m/sec 150 m.
- Anchoring with wind velocity ≥ 30 m/sec 210 m.

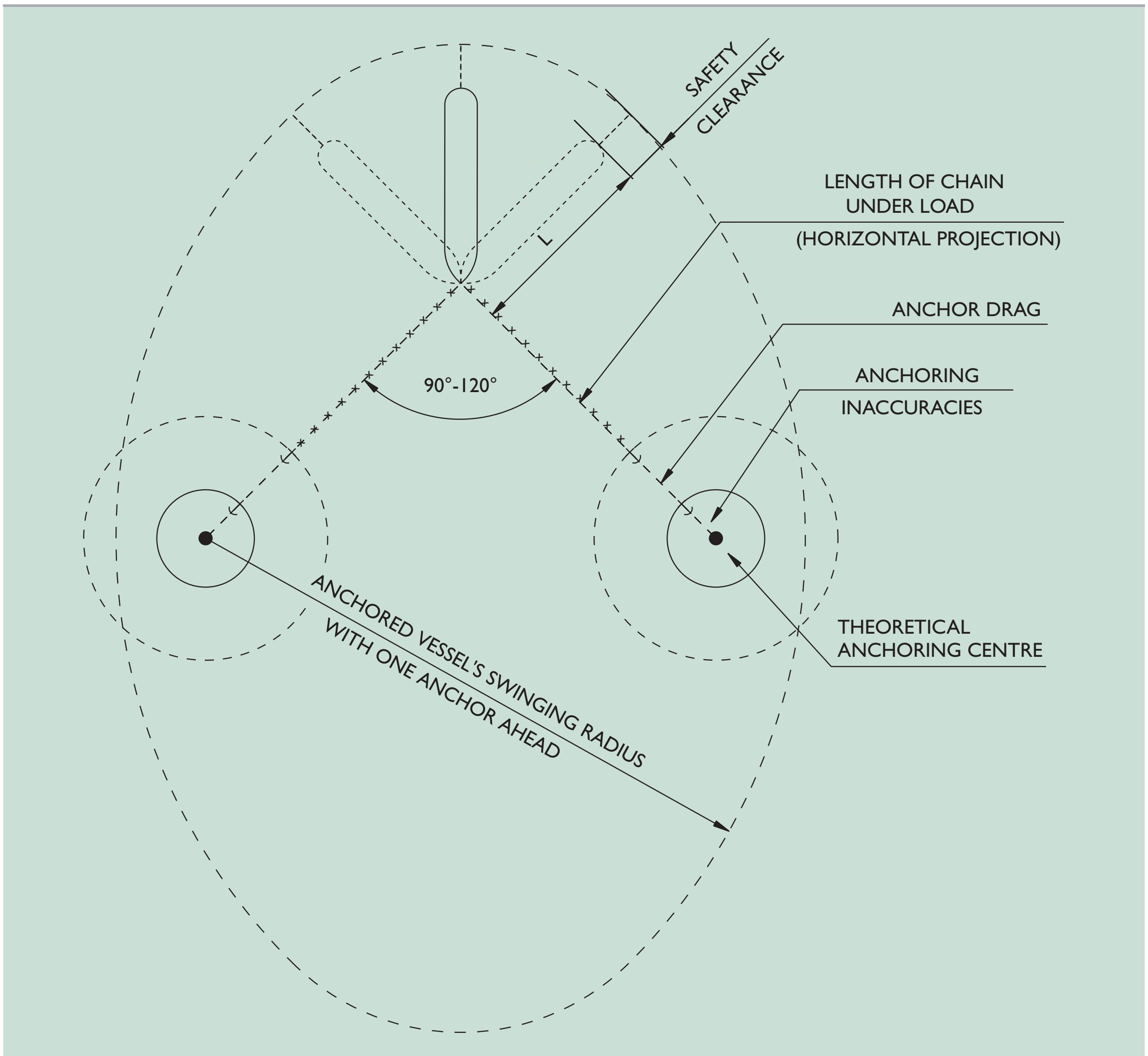
See sub-section «c» of section 8.7.2. dealing with holding ground quality to evaluate the anchoring resistance of seabeds in keeping with their nature.

5. A safety clearance which may be 10% of the length overall (*L*), with a minimum 20 m (except for fishing and pleasure craft which may be reduced to 5 m).
   Calculation by semi-probabilistic procedures is not recommended unless reliable information is available on anchor drag (point 4 of the foregoing list), applicable to the specific site under consideration.

b) VESSEL WITH TWO ANCHORS DOWN

The area swept by a vessel anchored with two bow anchors down is determined as a function of the compatibility of movements as imposed by each of the anchoring lines. The resultant scheme is given in fig. 8.36 in which all dimensions are defined in the foregoing section.

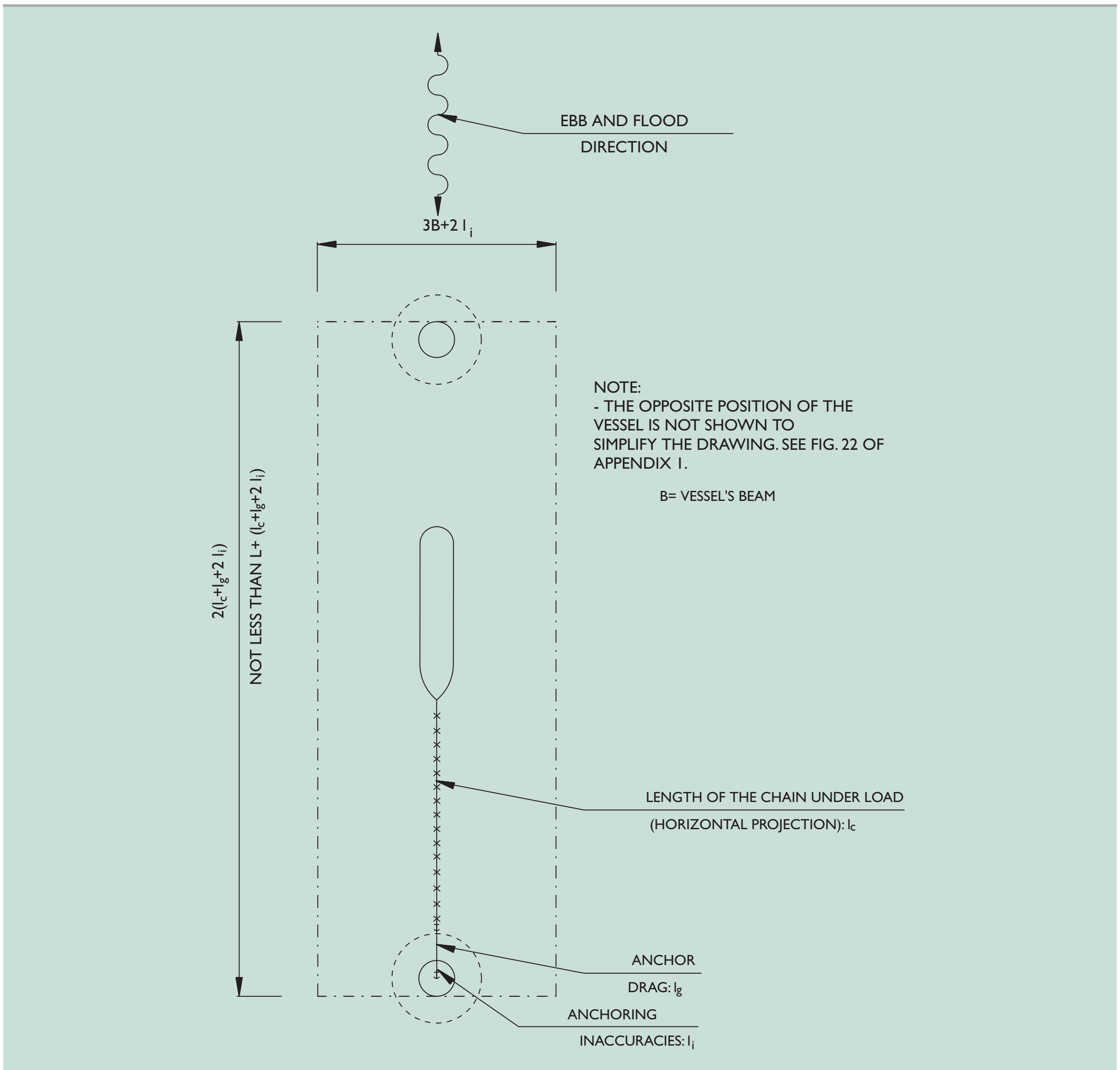
Figure 8.36. Area for anchoring with two anchors down



c) ANCHORING AT EBB AND FLOOD

The occupied area for this type of anchoring is also imposed by the conditioning factors of compatibility of movements. The resulting scheme is given in fig. 8.37, in which all dimensions of interest are defined in sub-section «a» of this section. It must be pointed out that this anchoring system has practically no vessel securing conditions for transverse forces which is why it cannot be used when forces are expected to act in this direction. Its use is limited in practice to cases where the force is tidal, with opposite action directions in ebb and flood of the tide.

Figure 8.37. ***Area for anchoring with two bow anchors at ebb and flood***

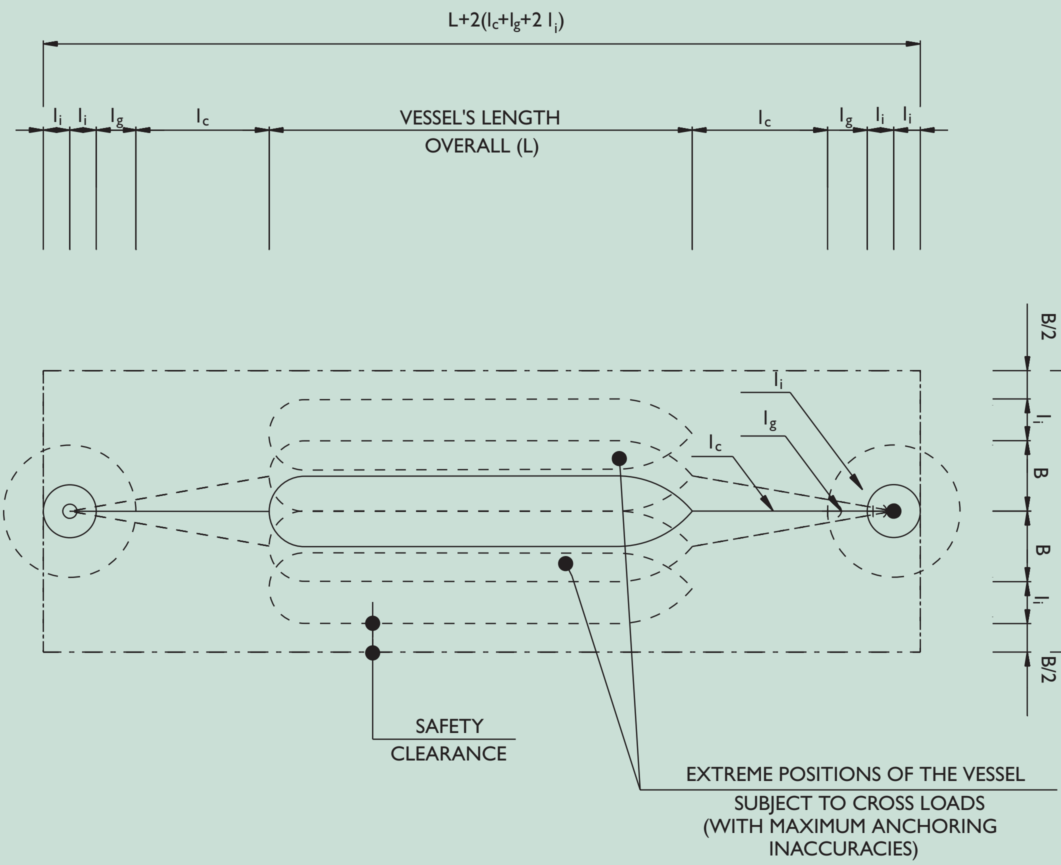


d) ANCHORING A VESSEL WITH ONE ANCHOR AHEAD AND ONE ASTERN

The occupied area for this type of anchoring is also imposed by the conditioning factors of compatibility of movements. The resulting scheme is given in fig. 8.38, in which all dimensions are defined in sub-section «a» of this section. This anchoring system has precarious vessel securing conditions in the transverse direction and, in any case, long runs of the vessel are needed to be effective from a resistance point of view. Its use is also limited to cases where the prevailing force is tidal, with opposite action directions in ebb and flood of tides.

This type of anchoring can only be undertaken in vessels fitted with a stern anchor, of which very few exist, or in very small boats having bow anchors and a grapnel (a small anchor which can be dropped and weighed by hand) which could be anchored by the stern, or two grapnels.

Figure 8.38. ***Area for anchoring with one anchor ahead and one astern***



l_c = Length of chain under load (horizontal projection).
l_g = Anchor drag.
l_i = Anchoring inaccuracies.
B = Vessel´s beam.

e) LENGTH OF CHAIN TO PAY OUT

The length of chain a certain vessel has to pay out depends on many factors, particularly on the quality of the holding ground, on the length of stay at the anchorage, on the swinging space available taking into account the proximity of fixed hazards or other vessels, on the protection the anchorage gives against wind, waves or currents, on the prevailing and forecast weather, on the intensity and direction of prevailing currents and, finally, to a very important extent, on the depth of the site.

Traditionally, most authors advise using a basic length of chain to pay out under normal average conditions in the order of 3 to 4 times the depth of high water for short stays and good protection, and 5 to 7 times for long stays and worse conditions of protection.

The fundamental point that must be underlined is that the anchor performs with maximum effectiveness when the chain is exerting a horizontal pull or a pull parallel to the seabed and the aim should be to pay out as much chain as necessary to ensure that such condition is fulfilled. If, because not enough length of chain is paid out, such aim is not achieved, the anchor will lose a large part of its holding power and will probably drag. As an indication, the following table is given showing how the anchor's holding power diminishes depending on the chain's slope to the seabed at the anchor ring.

Angle of slope	**0°**	**5°**	**10°**	**15°**
◆ % of maximum holding power	100%	80%	60%	40%

This means that it suffices for the chain to form a 15° angle to reduce the anchor's holding capacity by more than half, which is an important piece of evidence to bear in mind for the consequences of what may happen when, for some reason, it is not possible to pay out enough chain to work parallel to the seabed.

Assuming that the size of the anchor chain has been chosen to provide a working load exactly equal to the maximum anchor holding capacity, it may be accepted that the minimum of chain to be paid out for ensuring a horizontal pull on the anchor depends solely on the site's depth and type of chain.

There are currently different types of chain in use, such as wrought iron, mild steel, cast, forged or pressed steel and other steel alloys, nickel or manganese, the most usual being mild steel or wrought iron.

The ideal length of chain to be paid out for a certain depth is that of a catenary such that it ensures a horizontal pull on the anchor ring when the force the vessel exerts on the chain is equal to the former's working load. If that force becomes greater, the chain's tension increases, the catenary's curvature decreases and a vertical component is generated which tends to weigh the anchor, making it drag before the chain becomes subjected to undue abnormal forces. The chain's ideal length is given by the following formula:

$$l_c = \sqrt{\left(h+h_e\right)\left[\frac{T_c}{2w} - \left(h+h_e\right)\right]} = \sqrt{h_{ef}\left(\frac{T}{2w} - e_f\right)}$$

where:

l_c = length of chain to be paid out.

h = depth of water at site

h_e = height of hawse hole above water surface

T_c = chain's working load with a safety factor of 4 (1/4 of the corresponding breaking load and must not be confused with the test limit load which is usually 2/3 of the chain's strength).

w = weight of chain per unit of length (the value for a submerged chain will be considered).

If less length of chain is used, the vessel will tend to drag before the chain is supporting the safety load for which it is designed. If a longer length is used, the chain may be subjected to stresses above its working load due to its own weight, with the risk of becoming deformed or breaking in two.

The foregoing formula may also be used to determine the length of chain for any other working load and, in particular, for that which would correspond to the resulting forces on the vessel caused by the limit operating environmental conditions that may be established.

Should the space available not allow the length of chain determined by the foregoing formula to be paid out, shorter lengths for angles of chain on the seabed of up to 3° could be accepted, although it would be necessary, in this case, to take into account the reduction in the anchor's holding power which would result.

The horizontal projection of these chain lengths, which is the value for determining the horizontal geometric configuration of these Harbour Basins will be determined for the design conditions finally adopted, using the catenary equations.

f) DISTANCE BETWEEN ANCHORED VESSELS

The swinging radius and occupied area that have been calculated according to the foregoing criteria ensure that if a certain number of vessels of the same class anchor at a distance twice the values calculated, the following contingencies may occur, without causing risks or difficulties:

1. Two adjacent vessels may swing in opposite directions at maximum approach with their chains fully taut. This is unlikely to happen since, with appreciable winds and currents, they will bear in similar manner. There is the possibility they might tend to swing in the opposite direction through the current's action when broken or reversed whilst, at the same time, there are light winds, but in that case, chains will not be fully taut.

2. A vessel anchored in the leading line of other two nearby adjacent may weigh anchor and leave separately with no risk of collision.

3. A vessel may make its approach to take up anchorage between two vessels already anchored with no risk of the adjacent ships hindering its manoeuvre to sweep a station, when swinging.

If vessels of a different type or class, they must be separated by a distance equal to the sum of their respective swinging radii or occupied areas to ensure the the three conditions mentioned above are fulfilled.

In the particular case of a small sized harbour or area, it may happen that the space available will not allow vessels to be separated by that desirable distance equal to double or to the sum of the swinging radii (or occupied areas). Should it be necessary, this distance may be reduced until accepting at least the criterion of spacing adjacent anchorages by a separation equal to half the value desirable established for vessels of the same class. If they were different types, the greatest swinging radius will be adopted as the separation. In this case, only contingencies 2 and 3 specified above would be covered and it would be necessary to be on guard for approach swinging in contingency 1; but, under normal conditions and with good holding ground, the risk incurred is small and may even disappear by having a medium horsepower tug-boat or auxiliary craft available to aid vessels to bear up in the same position.

Even though acting in the manners just discussed, if the available space were to still prove insufficient, the separation between vessels may be reduced even further by calculating the minimum swinging radius as follows: vessel's length overall plus the length of chain it is really expected to use (see section 8.7.3.e.) plus the minimum safety margin to cover anchoring inaccuracies (for which the centre of the anchoring station should be suitably marked and the operating rules applicable in each case be defined), plus the safety clearance relative to the hazard. This criterion removes the risk of more chain than necessary being paid out under extreme environmental condition, as well as the risk of anchor drag. Therefore, it could only be applied if the fact that the vessel must leave the anchorage when the environmental conditions used to determine the length of chain are reached is established as a condition. It would also be necessary to check whether the separation between vessels allows approach and departure manoeuvres to be carried out without interference.

g) ANCHORAGE DISTRIBUTION AND SITES

Anchorage distribution and sites will be adapted to the area's physical features and to the use intended to be made of them. In particular, in the case of vessel traffic carrying hazardous cargoes, specific anchorages will be appointed in areas far from the port's usual traffic.

The wide space available and the smoothness of the seabed at certain sites, such as some open roads, enable a circular shaped anchorage to be arranged with the station zero or reference vessel in the centre and the other ships anchored in concentric circles. Those with the smallest diameter will be used by the smallest vessels.

In coastal areas where the seabed relief displays a gentle, even slope, anchorages are usually sited on different parallel marking lines practically coinciding with the isobaths. Those closest to land are assigned to the smaller vessels and the deepest to the larger.

In the more general case, when the conditions as expounded in the previous two paragraphs do not occur, anchorages must be accommodated in an irregular shape, adapting them to the site's features and dimensions.

8.7.4. Anchorage navigation marking

Anchorage marking in normal cases will be limited to the anchoring area perimeter definition by buoys and beacons, without providing for any type of anchoring point marking which, should such points be used, will be marked by the vessel's systems.

In the infrequent case of choosing to mark each of the possible anchoring points, each anchorage or anchoring station will be assigned an identifying number and its position will be determined by leading lines, markings and distances, whether with respect to notable points and maritime signals located on land or with reference to the station zero or another adjacent anchorage.

8.8. MOORING AREAS AND BUOY SYSTEMS

8.8.1. Definition

This section includes facilities where vessels remain moored to buoys or other fixed or floating elements other than quays and where typical port operations may be carried out. The differentiating element of this type of facility is the absence of conventional type quays or berths, which does not exclude auxiliary platforms being used in certain cases at which certain loading and unloading related operations are concentrated.

The use of this type of facility is generally imposed by an absence of fixed protection structures whether because they are sites located in outer harbour water or because there is no minimum port infrastructure which enables typical port operations to be performed there.

Facilities of this kind are usually of two main types:

- Single buoys or single dolphins
- Systems of buoys which in some cases are configured for using the vessel's anchors.

8.8.2. Factors affecting design

The fundamental factors affecting the design of mooring areas and buoy systems are as follows:

- The size, dimensions and characteristics of the Design Vessels.
- The type of port operations it is expected to undertake in them and the nature of the cargoes to be handled.
- The site's general configuration and space availability for approach, staying and departure manoeuvres.
- The number of mooring areas and buoy systems to be set up at the site.
- The area's maritime environment and the limit operational conditions established for the different port operations.

- The environmental conditions to be preserved at the site and the availability of pollution combating resources available in the case of certain cargoes.

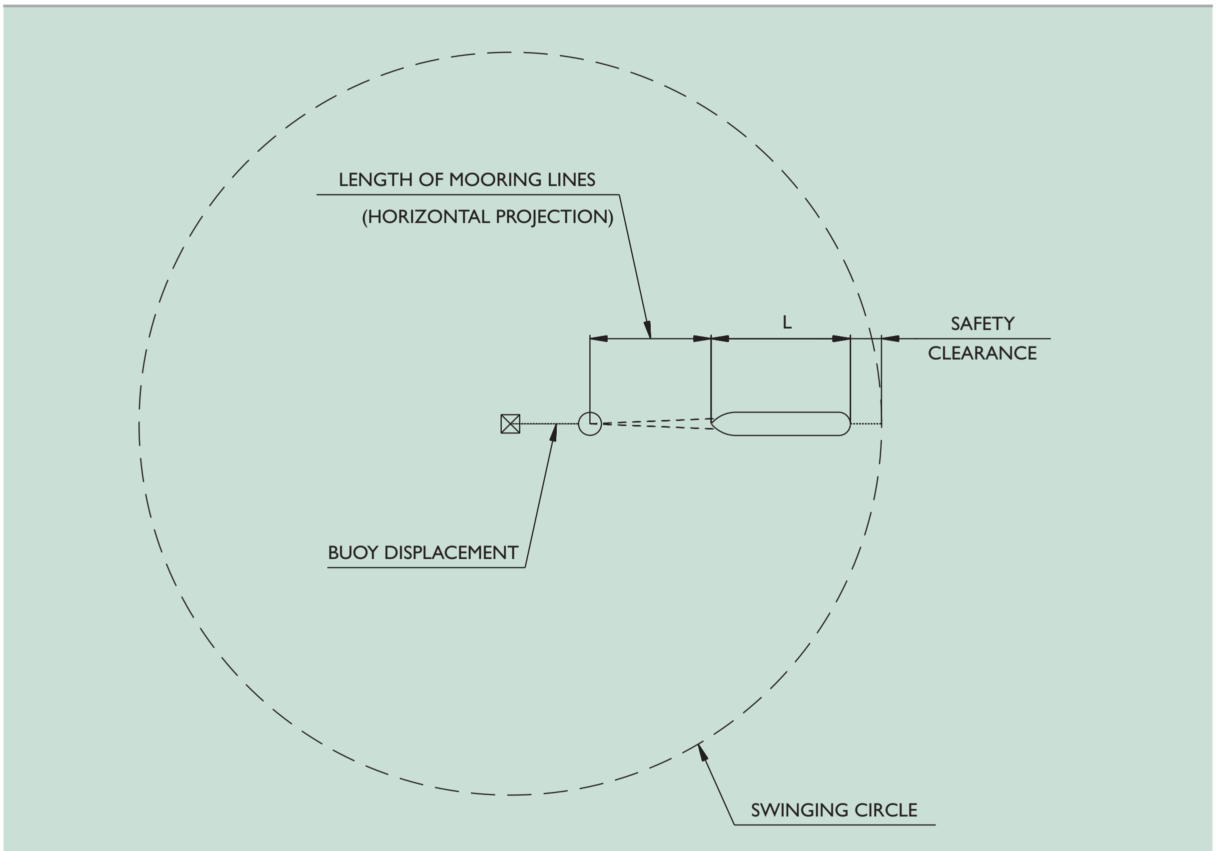
- The availability of tug-boats and elements of aid to navigation and to port operations.

8.8.3. Required harbour basin dimensions

a) SINGLE BUOYS OR SINGLE DOLPHINS

Should the vessel bow moor to a buoy or any other type of structure (single pile, tower, etc.), the mean swinging radius at the vessel's deck level may be calculated by the determinist method, by adding together the following concepts (Fig. 8.39):

Figure 8.39. ***Swinging radius of a vessel bow-moored to a buoy***



Note: The figure is showwn for a single buoy, in the case of a single dolphin, the displacement or deformation of the structure will normally be much less.

1. Vessel's length overall (*L*).

2. Length of the mooring lines under load, which will be determined as a function of the characteristics of the vessel, of the buoy and of the limit operating environmental conditions accepted.
   As a preliminary, it may be assumed for single buoys or flexible structures, which are the most usual, that the length of mooring lines is 35 m for large vessels up to 100,000 t displacement and 45 m for vessels over 200,000 t displacement. Linear interpolation can be used for intermediate vessels; for smaller boats (fishing and pleasure with lengths less than 20 m) a length of mooring lines of 30% of the boat's length overall (*L*) may be exceeded, also as a preliminary. These lengths must be increased by the elastic mooring

line elongation when coming under load which may be estimated at approximately 25 to 30% of the length, depending on the material of which they are made.

3. A safety clearance of 10% of the length overall (*L*) may be estimated, with a minimum of 20 m (except for fishing and pleasure boats which could be reduced to 5 m).

Calculation with the semi-probabilistic method is not advisable since the greatest uncertainties of this design originate in the structural behaviour of the mooring systems under limit operational conditions and their effect is not significant.

The dimensions resulting with these criteria lead to swinging radii much less than those determined for mooring with anchors since, in this case, some of the uncertainties addressed there are not present. Therefore, the dimensions generally obtained are not sufficient to keep them as safety distances to specific charted hazards since they would not leave sufficient room to guarantee vessel approach and departure manoeuvres to and from the single buoy or facility under consideration.

Likewise, should several anchoring points be addressed, if a separation between every two were to be kept, equal to the sum of their respective swinging radii, the risk of contact between adjacent anchored vessels would be eliminated, but, in general, the distance would also be insufficient to guarantee anchorage approach and departure navigation without interference with other vessels anchored in the area. Apart from limitations deriving from the anchored vessel's swinging radius, those originating in vessel approach and departure manoeuvres will therefore have to be considered and the most unfavourable vessels will have to be studied in this respect (which might not be those of the largest displacement which would operate in the different anchoring stations) so that these operations could be performed with suitable safety margins (see section 8.6).

As an indication and in the absence of more precise studies, the following safety distances from the centre of the buoy or anchoring point to the charted hazard being considered may be set:

- At exposed sites: 4 x Design Vessel's length overall
- At semi-sheltered sites: 3 x Design Vessel's length overall
- In sheltered estuaries:
  - With charted hazards in a sector less than 60° around the buoy's centre: 2 x Design Vessel's length overall
  - With charted hazards in a sector greater than 120° around the buoy's centre: 3 x Design Vessel's length overall

b) BUOY SYSTEMS

The dimensions required for setting up a buoy system depend on the configuration adopted overall and on the use of the vessel's anchors as vessel securing systems or not. From amongst the multiple schemes that may be developed, figures 8.40 to 8.44 show the most usual cases for the following assumptions:

- Mooring to two buoys, one at the bow and one at the stern

- Anchoring with two anchors at the bow and mooring to two buoys at the stern.

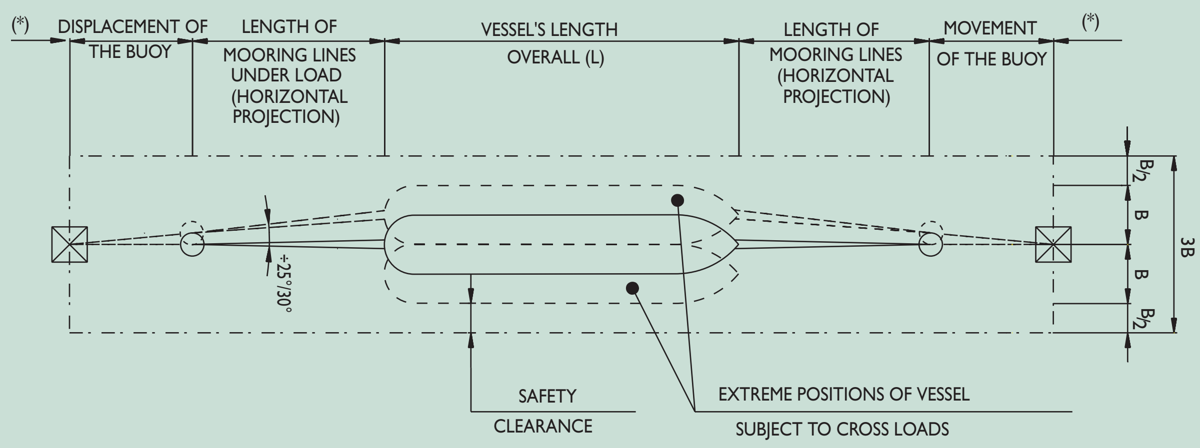
- Mooring to two buoys at the bow and two buoys at the stern.

- Anchoring with two anchors at the bow and mooring to three buoys at the stern

- Mooring in a buoy system

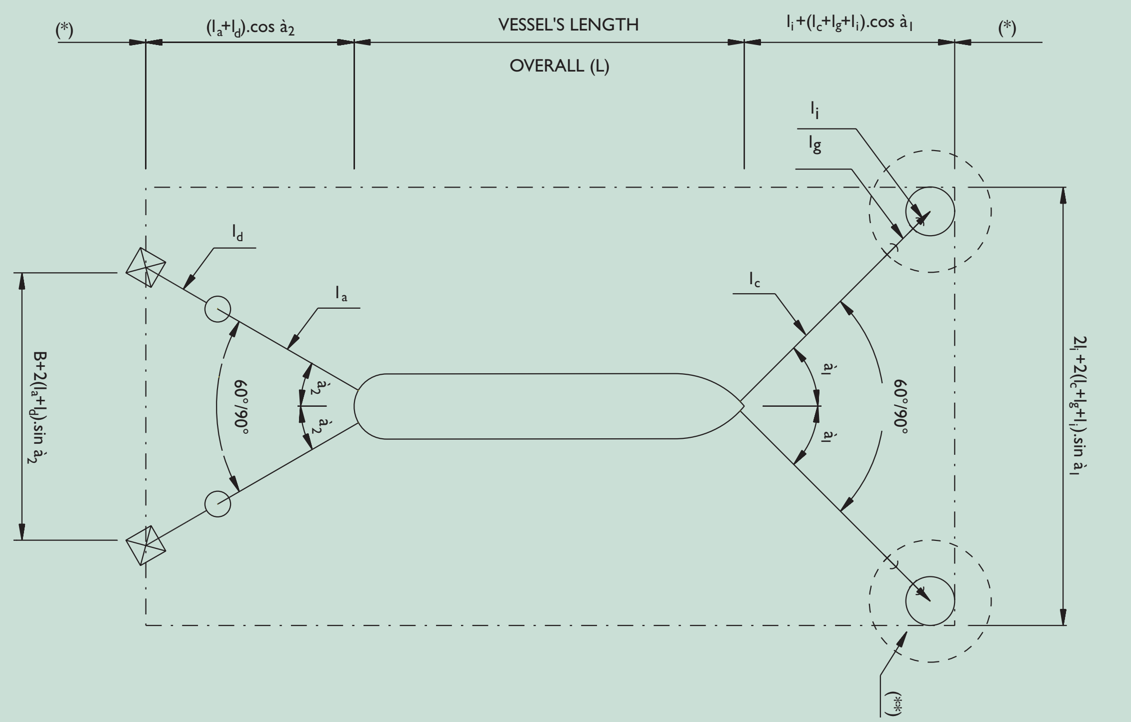
These figures give the dimensions necessary to keep the vessel moored under safe conditions with its pertinent clearances and will therefore need to be supplemented with the dimensions of the approach and departure navigation areas necessary for anchoring the vessel in the required position.

Figure 8.40. **Area for mooring with two buoys, one at the bow and one at the stern**



Note: The space necessary for setting up the buoy anchoring systems has not been considered, nor the possible movement of the buoys in the opposite direction when there is no vessel in the mooring area.

Figure 8.41. **Area for anchoring with two anchors at the bow and mooring to two buoys at the stern**



l_a = Length of mooring lines under load (horizontal projection).
l_d = Displacement of buoy under load.
l_c = Length of chain under load (horizontal projection).
l_g = Anchor drag.
l_i = Anchoring inaccuracies.
B = Vessel´s beam.

(*) The space necessary for setting up the buoy anchoring systems has not been considered, nor the possible displacement of the buoys in the opposite direction when there is no vessel in the mooring area.
(**) In practice, anchoring positions are not symmetrical. The second to anchor is further away. The area drawn is the most unfavorable envelope.

The calculation is based on the determinist method; the semi-probabilistic calculation procedure is not advisable, since the greatest uncertainties in this design originate in the structural behaviour if the mooring systems under limit operating conditions and their effect is not significant.

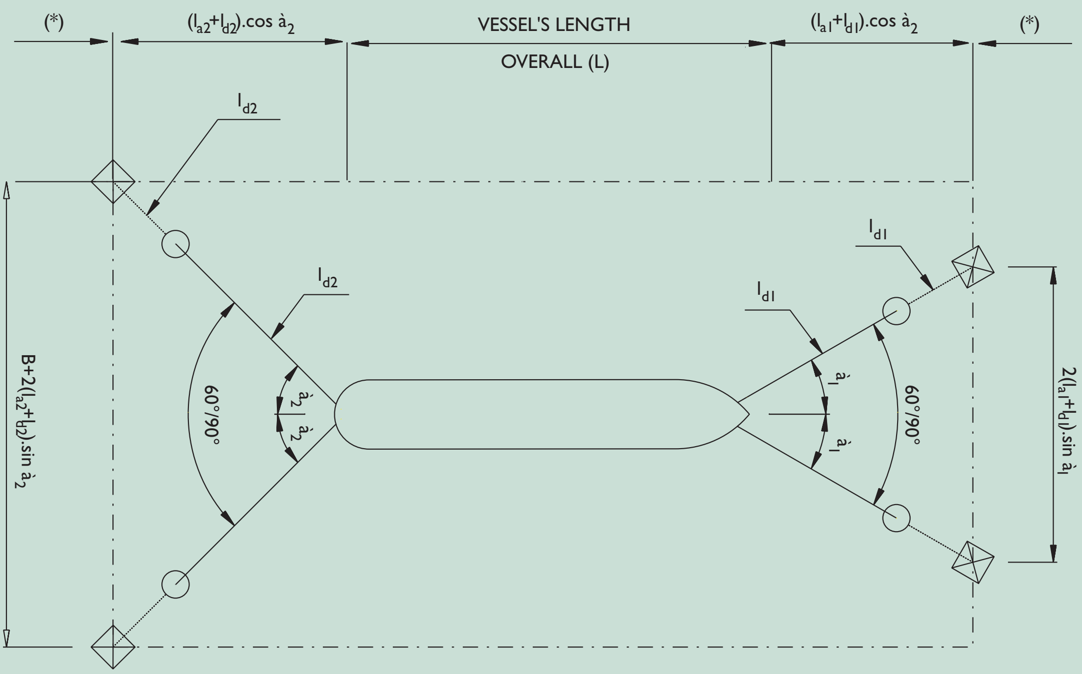
8.8.4. Operating conditions

The environmental conditions normally established as operational limits for mooring areas and buoy systems are shown below, depending on the vessel being able to freely orient itself to the minimum resistance position or the moored vessel's orientation being practically fixed.

	Mooring area with free orientation			Mooring areas with fised orientation (buoy systems, etc.)
	Mooring to single buoys	Mooring to mini single buoys (fishing and pleasure boats) (1)	Mooring to single dolphins	
Approach and mooring manoeuvre:				
• Absolute wind velocity $V_{10.1\ min}$	17 m/s	17 m/s	17 m/s	10 m/s
• Absolute current velocity $V_{c.1min}$	2.00 m	2.00 m	2.00 m	0.5 m
• Wave height H_s	2.50 m	2.00 m	2.50 m	2.00 m
Vessel staying at anchorage:				
• Absolute wind velocity $V_{10.1\ min}$	30 m/s	245 m/s	39 m/s	30 m/s-22 m/s(2)
• Absolute current velocity $V_{c.1min}$	2.00 m	2.00 m	2.00 m	2 m-1 m(2)
• Wave height H_s	4.50 m	2.00 m	3.50 m	3 m-2 m(2)

(1) Mooring to mini-single buoys or small buoys usually occurs with fishing and pleasure boats.
(2) The first figure is for forces longitudinal to the vessel and the second for forces transversal to the vessel.

Figure 8.42. ***Area for mooring to two buoys at the bow and to two buoys at the stern***



$l_{a1}\ l_{a2}$ = Length of mooring lines under load (horizontal projection).
$l_{d1}\ l_{d2}$ = Movement of buoy under load.

(*) The space necessary for setting up the buoy anchoring systems has not been considered, nor the possible movement of the buoys in the opposite direction when there is no vessel in the mooring area.

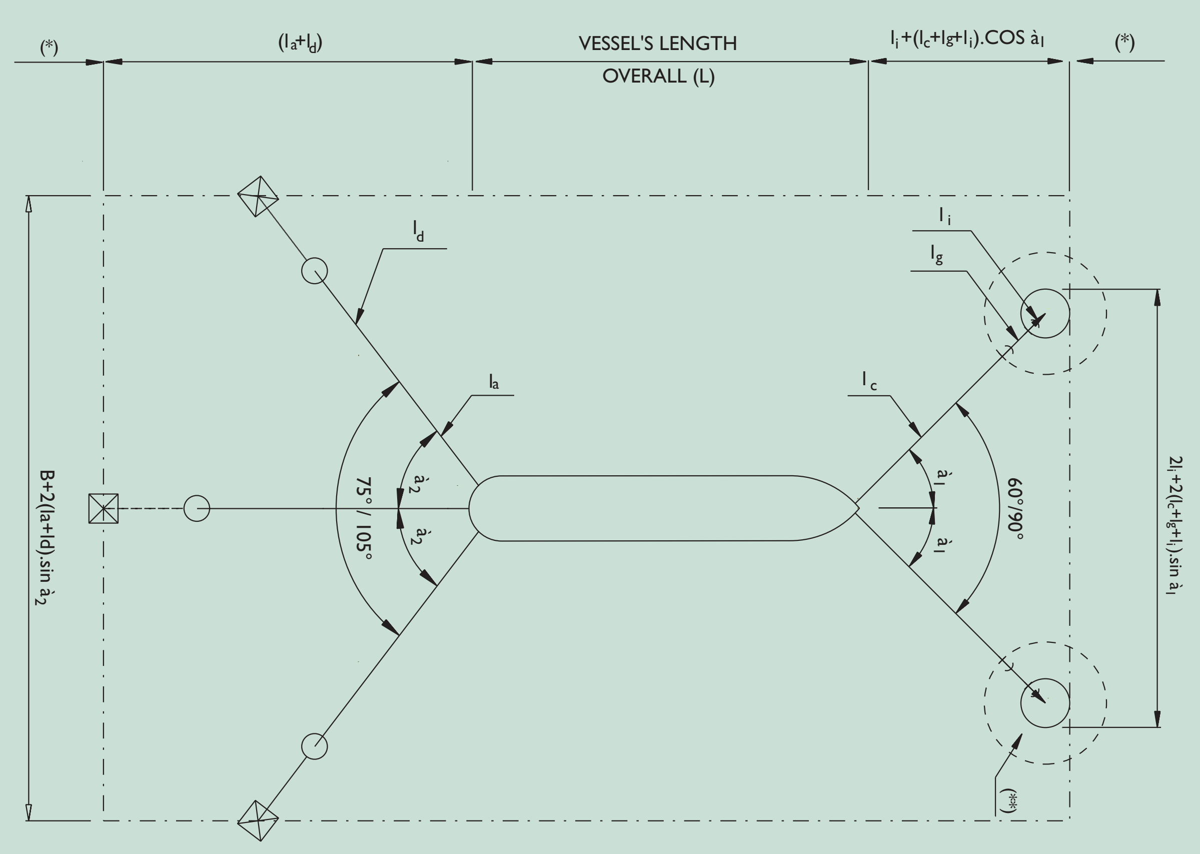
The limit loading and unloading operational conditions basically depend on the type of cargo to be handled and on the characteristics of the equipment provided, and they cannot be established in a generalized, simplified way.

8.8.5. Mooring area and buoy system navigation marking

Mooring area and buoy system navigation marking must be fundamentally directed to mark the following aspects:

- Floating and fixed elements costituting the anchorage (buoys, towers, platforms, hoses, etc.)
- Submerged items used in operating the facility (submerged hoses, undersea valves, etc.), taking into account the conditioning factors for their usage.
- Leading lines and marks necessary for navigation and dropping anchors at the places required.

Figure 8.43. Area for anchoring with two anchors at the bow and mooring to three buoys at the stern



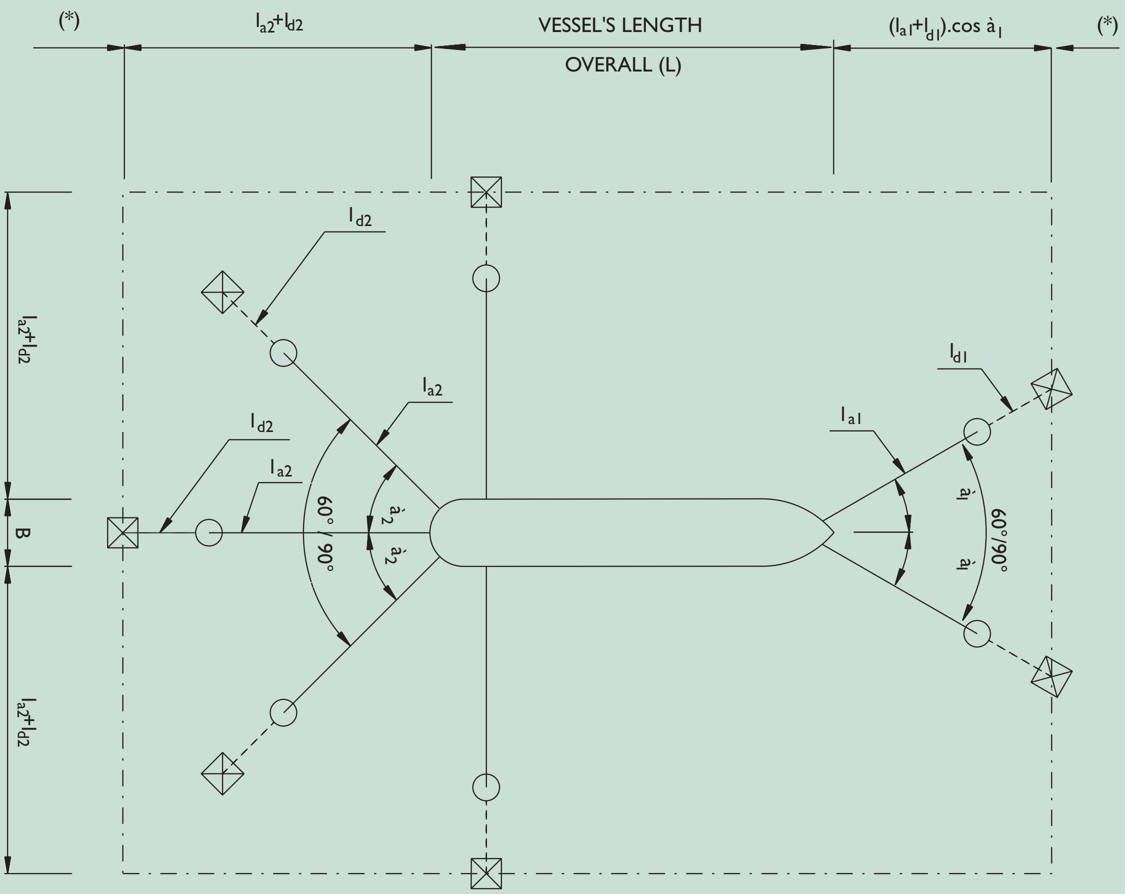
l_a = Length of mooring lines under load (horizontal projection).
l_d = Movement of buoy under load.
l_c = Length of chain under load (horizontal projection).
l_g = Anchor drag.
l_i = Anchoring inaccuracies.
B = Vessel´s beam.

(*) The space necessary for setting up the buoy anchoring systems has not been considered, nor the possible displacement of the buoys in the opposite direction when there is no vessel in the mooring area.
(**) In practice, anchoring positions are not symmetrical. The second to anchor is further away. The area drawn is the most unfavorable envelope.

8.9. COMMON CONDITIONS APPLICABLE TO FAIRWAYS, MANOEUVRING AREAS, ANCHORAGE AREAS, OUTER HARBOUR WATERS, MOORING AREAS AND BUOY SYSTEMS

Dimensions of all harbour basins, as recommended in the foregoing sections, are determined irrespective of the use to be made of the sides or areas adjacent to those under analysis. That is to say, they are net dimensions for the function being considered in each case.

Figure 8.44. ***Area for mooring to a buoy system***



l_{a1} l_{a2} = Length of mooring lines under load (horizontal projection).
l_{d1} l_{d2} = Displacement of buoy under load.

(*) The space necessary for setting up the buoy anchoring systems has not been considered, nor the possible movement of the buoys in the opposite direction when there is no vessel in the mooring area.

Should these adjacent areas be used for other purposes, the dimensions required for them will have to be considered. Thus, should there be quays along a fairway or in the boundary of a turning area, the width required by the largest vessels operating at those quays must be considered both at the moored positions and those necessary for operations prior to berthing or unberthing compatible with the use of the harbour basin being considered. An additional clearance beam for the largest beam vessel which may operate at the quay is usually considered for this space.

8.10. BASINS AND QUAYS

8.10.1. Factors affecting design

Basins will be dimensioned taking into account the following main conditioning factors:

- The harbour's general configuration, the integration of the basin into its harbour basins and the integration of its quays and land areas into the port's planning.

- Vessel basin approach and departure navigation, taking the largest design vessels expected to operate in them into account.

- The length of quays required in their different alignments as a function of the types and dimensions of the vessels expected to operate in them. The interchangeability of berthing places and equipment mobility as well as the convenience of having straight alignments and not having angles less than 50° between two adjacent quay alignments will be assessed in this respect. Special requirements for a certain type of quay (e.g. ramps or blocks for Ro-Ro vessels) will also be assessed.

- The levels of disturbance occurring for the different wave conditions which may arise at the site as a function of the maritime environment existing, as well as the percentages of exceedance of disturbance levels assumed to be the maximum admissible in keeping with the uses to be made of the basin.

- Long period wave resonance or amplification conditions.

- The nature of the facings configuring the basin, particularly in connection with their incident wave reflecting characteristics. The influence which the occupancy of quays has will be taken into account since it represents a significant modification to the reflecting conditions of some facings.

- The current regime existing in the basin, which should be minimal. Even in the case of basins located on fluvial currents, longitudinal currents are not recommended to be over 1.5 m/sec in the basin.

- Wind regimes at the site and their effect on the type of operations to be undertaken in the basin. In general, basins are recommended to be configured so that the main quays are oriented in the direction in which they least receive wind and waves crosswise to the vessel, which is usually the most favourable from the point of view of already berthed vessels. However, the effect of cross winds on loading and unloading equipment must be assessed, as in some cases it may be a determining factor and might lead to a quay orientation different to the previous one. The effect of winds and waves on berthing and deberthing operations must also be analysed, and, in the end, the quay orientation would prove to be a compromise solution.

- Sedimentation phenomena in the area and the risk of silting. And also, should such be the case, the possibility of ice floes.

- The site's geological and geotechnical characteristics and the consequent suitability of the ground to receive infrastructure works, perform dredging or serve for securing anchors.

- Environmental impacts that may occur in both the construction and service phases.

- Special safety requirements which may be imposed by the traffic of certain cargoes, with special attention to the case of hazardous cargoes for which vessels carrying such will be required to berth with the bow facing the exit.

- Foreseeable extensions to the basin and the port in general and the limitations which the configuration adopted for the basin might represent in this respect. The possibility of using water depths deeper than those required by the largest design vessels will be particularly analysed and a study of the design's sensitivity to water depths exceeding those required by 2 m is recommended.

In practice, taking all these conditioning factors into account will lead to compromise solutions where a balance will be achieved between requirements that at times will prove contrasting. This circumstance will generally be aggravated by the fact that a large number of basins will have been subjected to a process of historical evolution in which not all of these conditioning factors will have been taken into account from present day viewpoints.

Analysing all these factors exceeds the scope of this ROM and they will be analysed in detail in other Recommendations in this programme. This ROM 3.1 is restricted to solely analysing aspects related to vessel navigation and staying and operating conditions at quays, to which the first four points of the foregoing list refer and the effect other factors have on them (maritime environment, type of structures configuring the basin, etc.) will be taken into account.

Should a basin have any of its alignments undeveloped, which circumstance might reach the extreme case of there only being one alignment (riverside quays, jetties, etc.), the criteria here expounded will be followed with the simplifications arising in each case, without forgetting that this alignment might form part of another more complex basin or configuration in which some of the problems referred to here may occur.

8.10.2. Basin accessibility from seward side

A vessel's approach to basins and its berthing at the quays located in them is the final stage of its navigation (or the initial in the event of departure) and must therefore be analysed with the same basic principles as given in previous sections.

The case of a basin being sufficiently dimensioned to allow the arrival of vessels navigating by their own means until inside and there carrying out turning and berthing manoeuvres with or without tug-boats is not usual and, should it occur, would be resolved using the criteria already expounded till now.

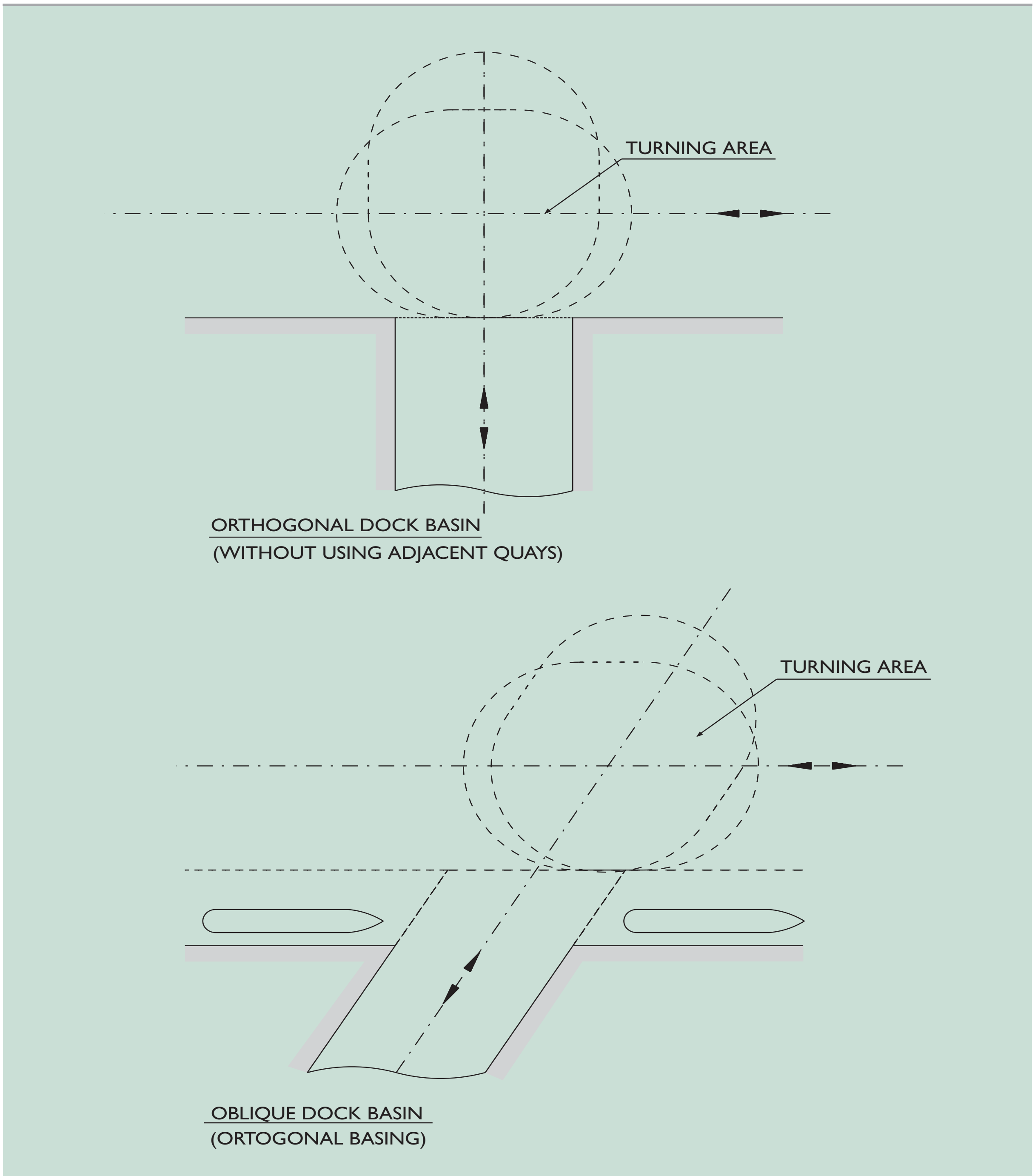
The most frequent case is that where the basin is not sufficiently dimensioned to perform turning manoeuvres inside and, therefore, a turning area must be provided for at its entrance. Three solutions may be adopted in this case:

- If feasible, the best option would be to arrange for a turning area at the basin entrance, with its centre located on its longitudinal axis. The dimensions of this turning centre would result from the envelope of the areas required for vessel entry and exit and from the obliqueness between the basin's longitudinal axis and the axis of the fairway through which it is approached, applying the criteria given in section 8.6.4. Figure 8.45 shows this scheme for the case of an orthogonal and an oblique basin which are developed for operating with tug-boats. It must be pointed out that should quays adjacent to the basin entrance be prepared for vessel operation, the spaces required for these uses must be kept to with their pertinent safety margins.

- If there were no actual space for developing the aforedefined turning area, two possibilities might be analysed:
  - Locating the centre of the turning area off the basin's longitudinal axis. In this case, the vessel's path on its approach to the basin must follow a curved section which, on arrival or departure, must be travelled over by the vessel going astern. Since this manoeuvre is complex, it will normally require tug-boat assistance and, therefore, the following limitations are established for the geometric conditions of this curved section of the path (see figure 8.46):

    Radius (R): $\geq 2.5\ L$ (Length)
    Length of curved section (l): $\leq 6\ L$

Figure 8.45. ***Area for turning at a basing entrance***



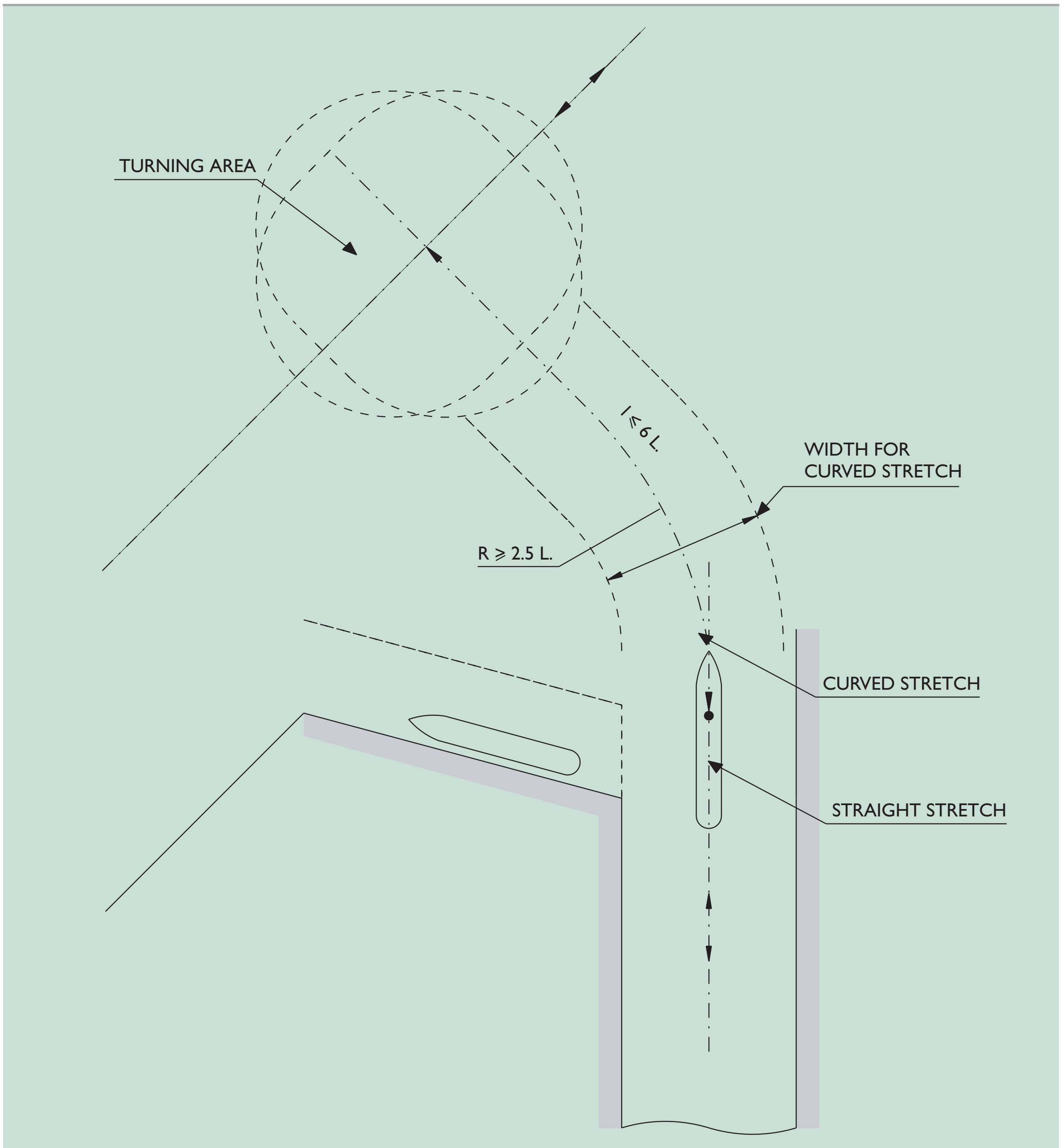
Drawn for Manoeuvring with tug-boat and without geometrical turning area changes.

- Width of fairway at curved section: Determined for the waterway's alignment conditions and the vessel's navigability conditions (which will be assumed as bad since it will be going astern).

◆ Using the dock water to carry out part of the turning manoeuvres as shown schematically in figure 8.47. This operation will also require the use of tug-boats and a free area for manoeuvres which will allow a semi-circumference of radius 1.5 L (Length) to be inscribed in it. These dimensions could be reduced if other physical elements were to be used to facilitate turning, such as the vessel revolving supported on a berthing structure specially designed to these effects or with some fixed point by means of mooring lines. However, these cases are not usual and specifying them is beyond the boundaries of this Recommendation.

Should a basin not have all its alignments configured, other vessel quay approach and departure manoeuvres could be looked at and will be solved with the general criteria given in the pertinent sections. Should the site and configuration of these quays be determined in keeping with certain vessel approach and departure manoeuvres, the due reserves of harbour basin area will be established to prevent these spaces being occupied by the development of future quays and infrastructures.

Figure 8.46. ***Area for turning moved from the basin axis***

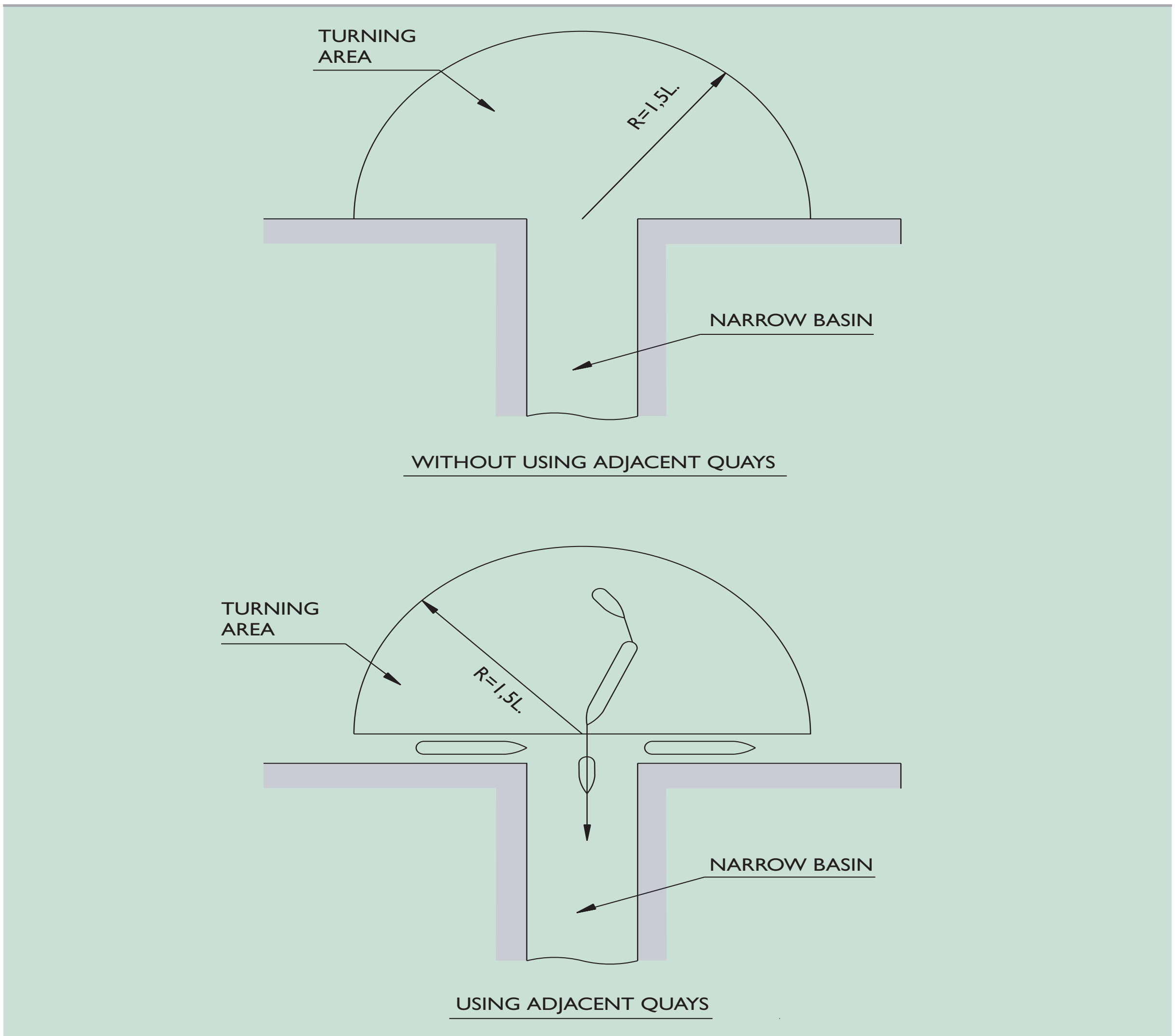


Drawn for Manoeuvring with tug-boat and without geometrical turning area changes.

8.10.3. Basin dimensions

Minimum basin dimensions will be defined by the length of its quays and width of the basin area, which will be determined by the determinist method with the criteria as given in the following sub-sections a) and b) except for the specific recommendations made in section 8.10.4 for marinas. Semi-probabilistic design could be used if a sufficiently broad statistical analysis of all the manoeuvres that might be performed were to be available. This recourse is basically used at present for studying the possibilities of specific vessel operation in pre-existing basins and quays.

Figure 8.47. ***Area for turning interconnected to a basin***



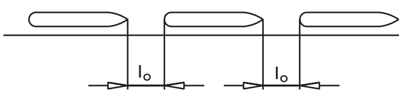
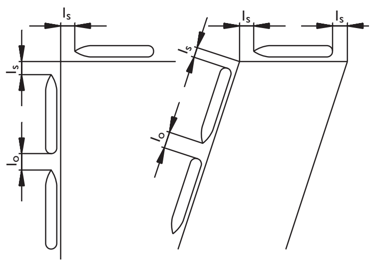
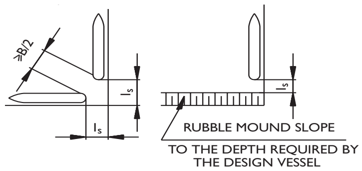
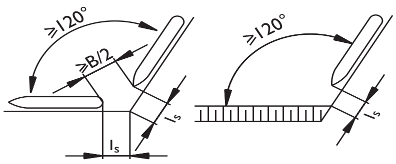
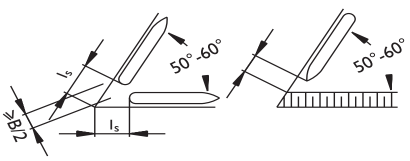
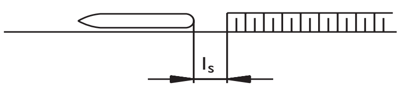
Drawn for Manoeuvring with tug-boat and without geometrical turning area changes.

All dimensions given in this article need tug-boats, which does not prevent operations being carried out without their assistance under certain maritime environmental conditions and by vessels fitted with suitable means (thrusters, twin screw, etc.) or by smaller vessels which can safely manoeuvre in the spaces available without tug-boat assistance. In any case, at least the dimensions here recommended will be kept to unless basins and quays are designed for the exclusive use of special vessels provided with the best manoeuvrability conditions, in which case this condition must be shown in the pertinent Operating Rules. The optimised design which may be obtained in these cases is recommended to be made by means of simulator studies.

a) QUAY LENGTH

Quay lengths will be determined as a function of the maximum dimensions of the vessels expected to operate at the different berths, of the basin's configuration and of the type of structure of the quays adjacent to the berths, whether they are vertical facings, have rubble mound armour or other elements placed on a slope. The criteria as given in fig. 8.48 will be used to determine these lengths, taking the vessel's length to be the length

Figure 8.48. Berhing line clearances

Representative scheme of the quay	Values of the variables as a function of the length overall (L in m) fo the largest vessel affecting the calculation of the dimension being analysed				
	Over 300	300-201	200-151	150-100	Less 100(1)
1. Distance «l_O» between vessels berthed in the same alignment (m) 	30	25	20	15	10
2. Separation «l_S» between vessels and changes in alignment or type of structure (m) a) 	30	25	20	10	5
b) 	45/40	30	25	20	15
c) 	30/25	20	15	15	10
d) 	–/60	50	40	30	20
e) 	20	15	15	10	10

(1) 20% of «L» will be taken as the value of «l_O» for vessels with length overall less than 12 m and the remaining values will be proportionately adjusted.
(B) Beam of the largest vessel affecting the calculation off the dimension being analysed.

overall (L) of the Design Vessel which affects the calculation of the dimension being analysed. These dimensions are determined assuming that the longitudinal currents in the basin have a velocity not over 1.5 m/sec (for higher velocities a simulator study for analysing berthing and deberthing manoeuvres and the pertinent space requirements is recommended). Moreover, the dimensions in Table 8.48 are based on the usual assumption that all vessels berthed may launch head and stern lines whereas they could be less if the mooring scheme were to be modified.

Should the quay be defined by its depth and not by its use, or when it is expected that such use may be changed in subsequent quay usage phases, the Length overall of the maximum vessel of any type compatible with the depth available will be taken.

Should the basin be subjected to highly exposed environmental conditions, it might be necessary to provide longer lengths of quay to increase the distance between vessels or allow longer bow and stern mooring lines to be used, which circumstance could arise also in the case of jetties located outside sheltered water. In these cases, the quay length and their ideal configuration must be determined according not only to the conditioning factors of the Floating Areas but also to the vessel's behaviour once berthed and moored.

Moreover, the pertinent additional space requirements must be considered should the use of blocks be provided for landing Ro-Ro type vessel ramps.

b) BASIN WIDTHS

Basin widths will be determined by taking the longest dimension resulting from considering the following cases:

1. Should the cross alignment closing off the dock be used as a quay for berthing vessels parallel to it, this alignment (and the width resulting as a consequence according to its obliqueness) will have at least the length required by the quays, determined with the criteria given in the foregoing sub-section a). See fig. 8.49.

2. Should any of the basin's longitudinal alignments allow more than 4 berthing places, the basin must allow for a vessel turning manoeuvre area sized with the criteria given in section 8.6.4. This turning area could be located at the back of the basin either in intermediate areas which do not leave basin backs with more than 4 berthing places in any of their longitudinal alignments or providing for all the basin being sufficiently wide so that vessels can turn in any position. The spaces necessary for berthed vessels and clearances which may be established in this respect must be taken into account in whatever solution is adopted. Likewise, should traffic density be greater than 1 vessel/hour, the fairway inside the dock is recommended to be sized to allow vessels to pass each other with their pertinent clearances from berthed ships.
   These recommendations will be followed for fishing boat docks and marinas irrespective of the number of berthing places in each alignment.

3. Should any of the basin's longitudinal alignments allow for 3 or 4 berths and the solution as described in sub-section 2) above not be chosen, the basin width must allow a vessel to go astern (therefore assuming bad vessel manoeuvrability), taking the spaces necessary for berthed vessels and clearances established in this respect into account.

4. In the case of commercial basins with quays at both sides, where the dock's longitudinal dimensions allow for 2 berths per quay in the longitudinal direction and vessels are not allowed alongside each other at the berths (see fig. 8.50), the minimum width of the basin will be the greatest of the following values, which are determined on the assumption that the entry or exit manoeuvre of two or more vessels simultaneously is not allowed.

$$B_{nd} = 3 \cdot B_{max} + L_r + 20 \text{ m}$$
$$B_{nd} = 5 \cdot B_{max} + L_r$$

where:

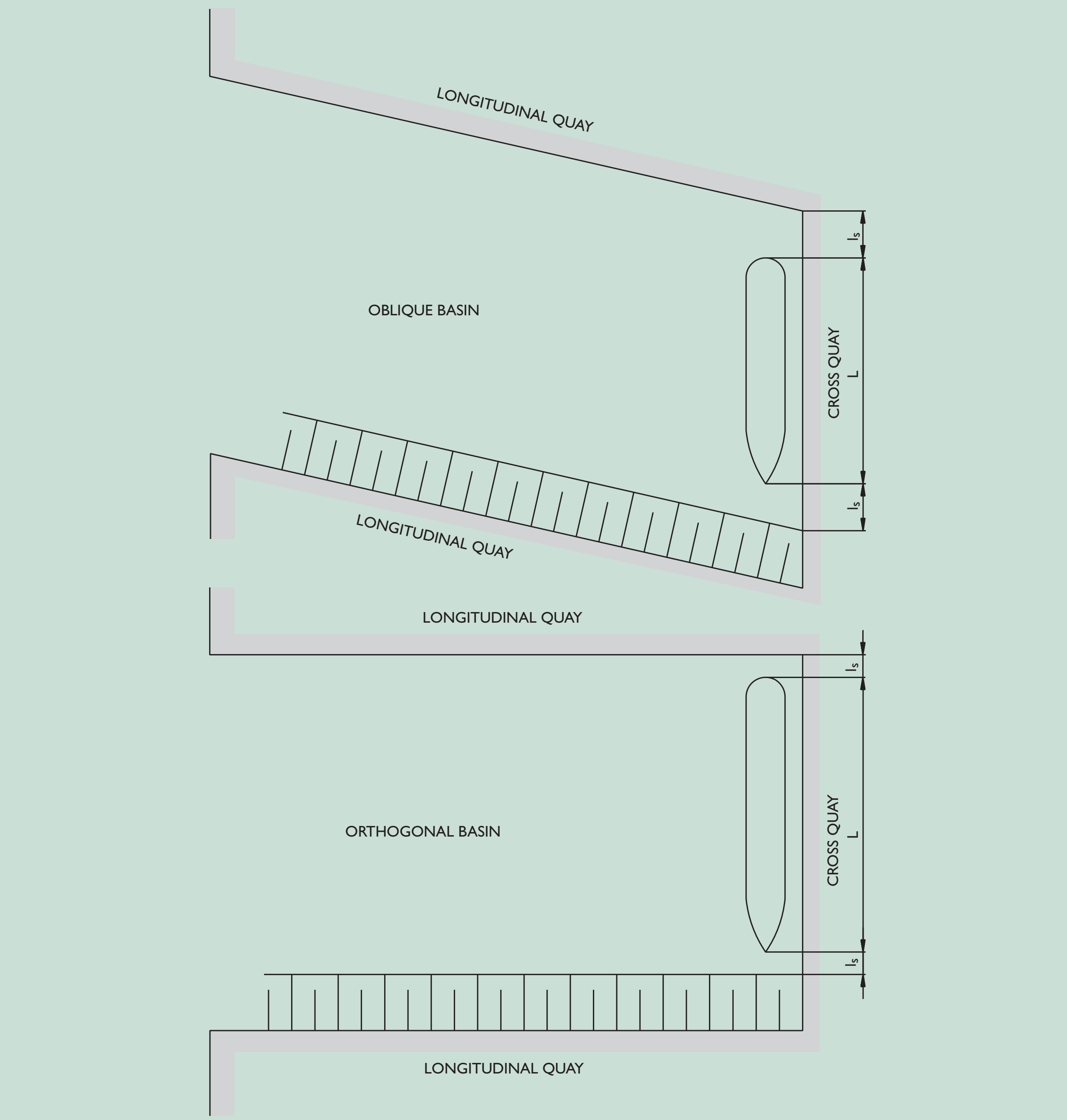
B_{nd} = Nominal basin width measured between planes of the outside longitudinal quay fender faces.

B_{max} = Maximum beam of the largest Design Vessel that can operate at any of the basin's quays.

L_r = Sum of the tug-boat's length overall and the horizontal projection of the towing line for the tug-boat necessary for the largest Design Vessels that can operate at any of the basin berths.

Should this information not be available, the L_r value may be determined as a function of the vessel's displacement, as per the following criteria:

Figure 8.49. ***Basin widths. Conditioning factors due to use of a cross quay***

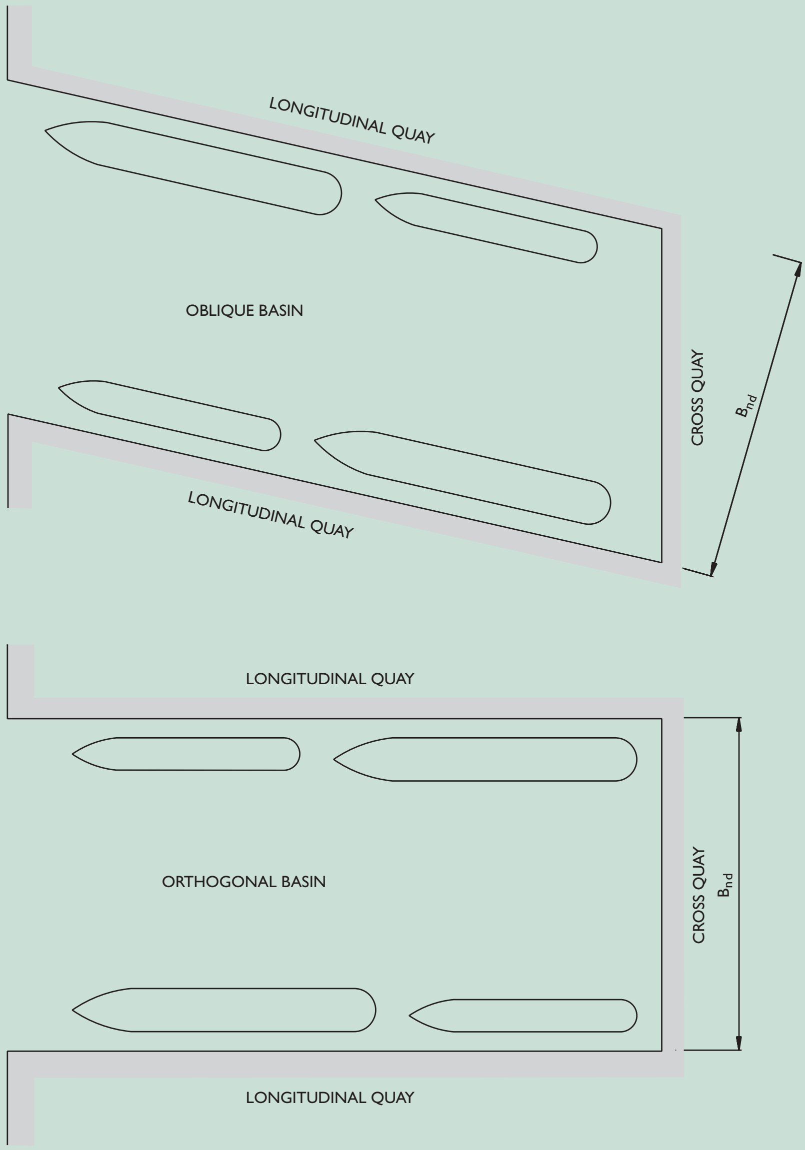


L = Vessel´s length overall.

l_s = According to criteria, section 8.10.3.a (see figure 8.48).

Vessel´s displacement (t)	Lr (m)
Up to 5.000	45
More than 5.000 up to 10.000	46-50
More than 10.000 up to 20.000	51-60
More than 30.000 up to 60.000	61-70
Over 60.000	71-85

Figure 8.50. ***Basin widths. Longitudinal alignments with two quays***



B_{nd} = Nominal width of the dock basin measured between planes of the outside fender faces of the longitudinal quays. See section 8.10.3.b.5.

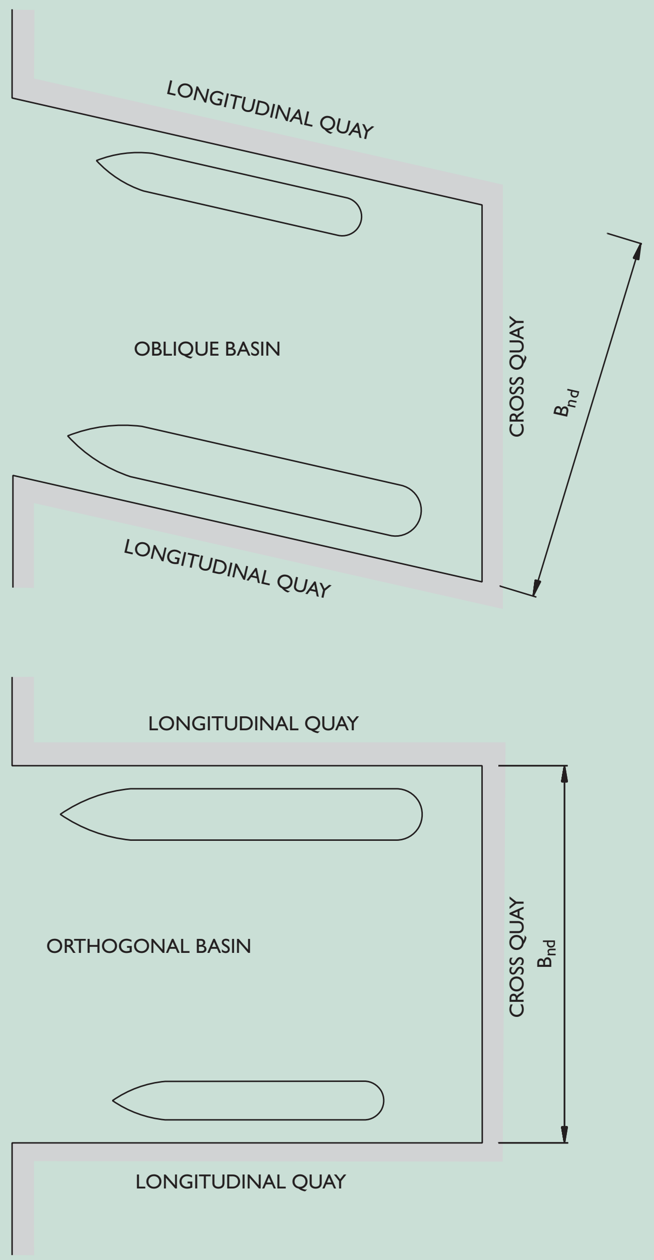
The term «L_r» cannot be discarded even though the manoeuvre is carried out as an exception without tug-boats. It must be recalled that these basin design criteria are based on using tug-boats and for those cases where operations are expected to be always performed without their assistance, simulator studies must be used for space optimisation (except for fishing and pleasure craft where point 2 of this section should be followed).

Should the basin only have one quay on one of the sides, the foregoing «B_{nd}» dimensions may be reduced by one beam «B_{max}».

4. In the case of commercial docks with quays on both sides where the basin's longitudinal alignments allow for a single berth per quay in a longitudinal direction and vessels berthing alongside in the berthing lines (see fig. 8.51), the basin's minimum width will be the greatest of the following values:

$$B_{nd} = 2 \cdot B_{max} + L_r + 20 \text{ m}$$
$$B_{nd} = 3 \cdot B_{max} + L_r$$

Figure 8.51. **Basin widths, longitudinal alignments with one quay**



B_{nd} = Nominal width of the dock basin measured between planes of the outside fender faces of the longitudinal quays. See section 8.10.3.b.6.

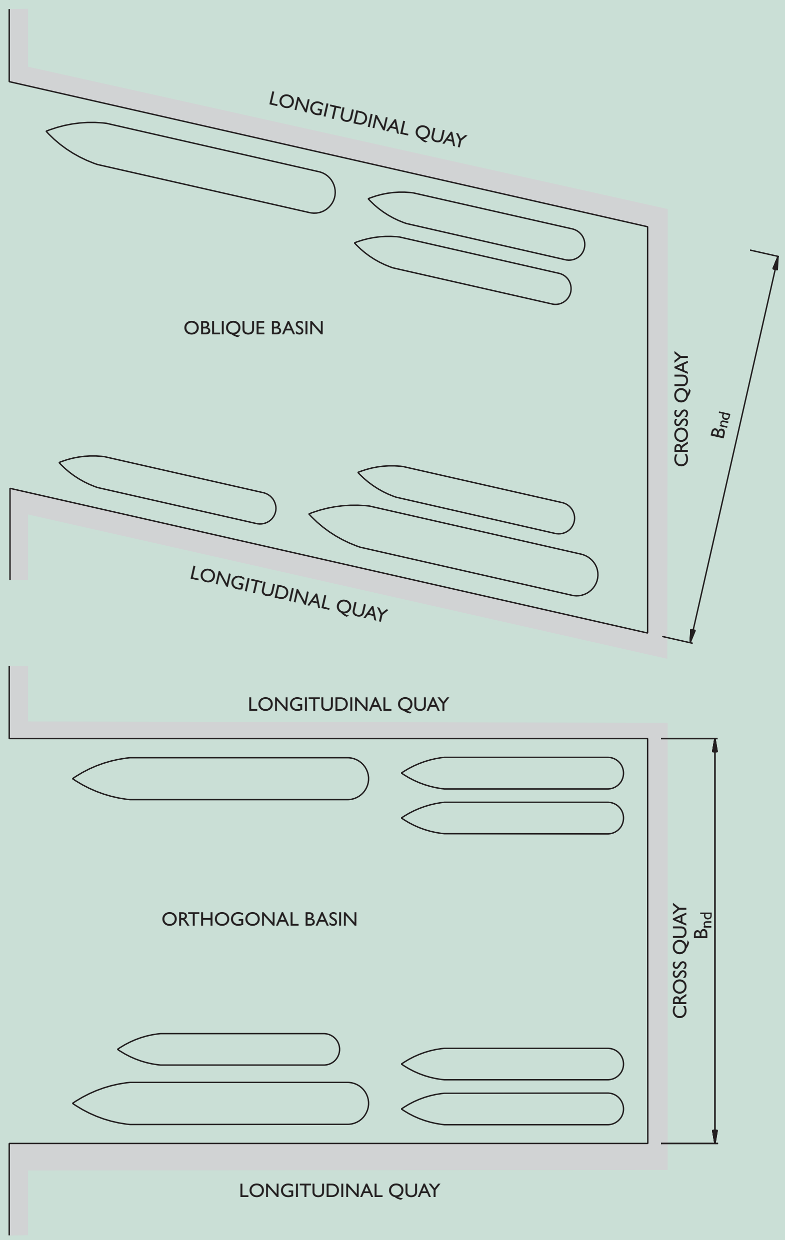
where the symbols have the same meaning as given in the foregoing paragraph.

Should the basin only have a quay on one of the sides, the foregoing «B_n» dimensions may be reduced by a beam «B_{max}».

6. Should vessel mooring alongside each other be provided for at any of the longitudinal quays (see figure 8.52), the aforedefined widths will be increased by

$$B_{ndp} = n_b \cdot (B_{max} + 2)$$

Figure 8.52. ***Basin width with vessels moored alongside each other at longitudinal quays***



B_{nd} = Nominal width of the dock basin measured between planes of the outside fender faces of the longitudinal quays. See section 8.10.3.b.5.

where:

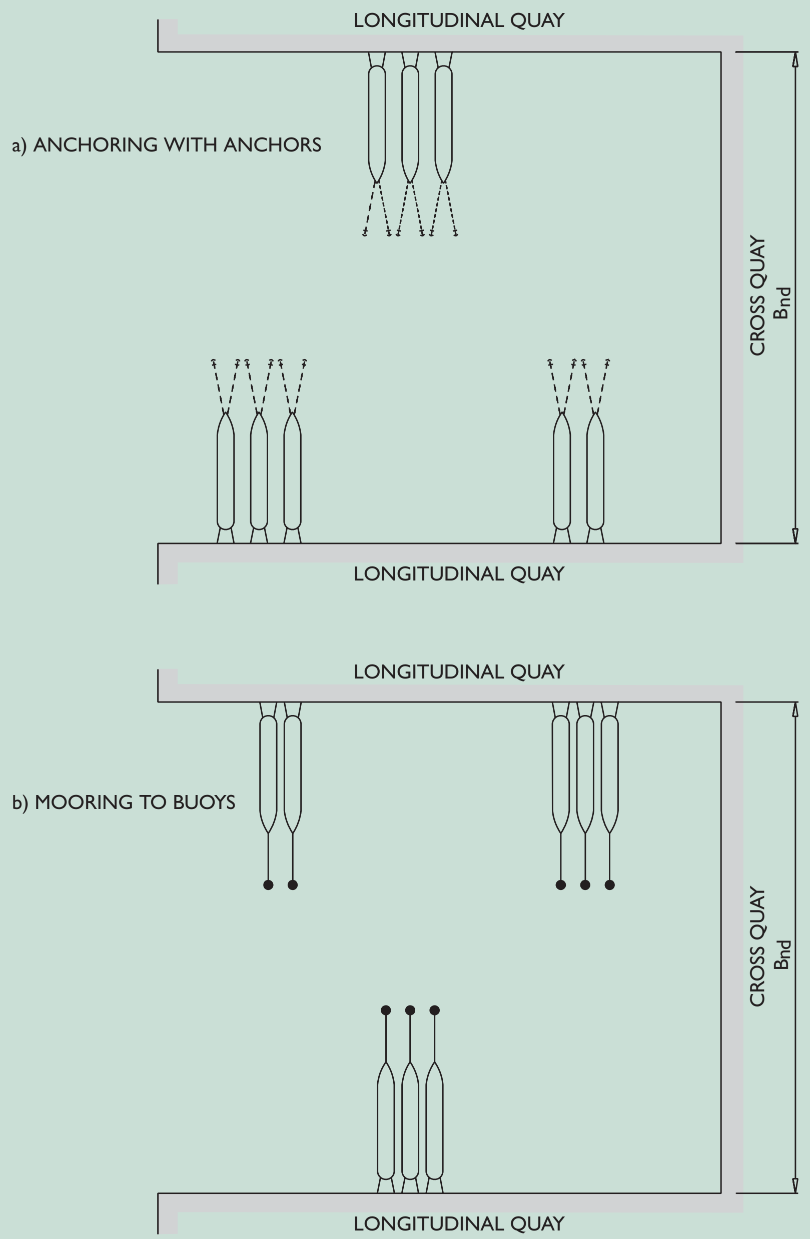
B_{ndp} = Increase in the basin's nominal width

n_p = Maximum number of vessels moored alongside measured in any alignment crosswise to the basin, without counting those directly moored to the quay. Should vessels be moored alongside each other at the quays of both longitudinal alignments, «n» will be the sum of those alongside on both sides.

2 = Space in metres required for fenders between vessels alongside each other.

7. Should end on vessel berthing be provided for at the both the basin's longitudinal alignments (see fig. 8.53), the dock's width will be the greatest of those obtained from the following expressions:

Figure 8.53. **Basin widths with vessels berthed by bow or stern (Mediterranean manner) at a longitudinal quay**



B_{nd} = Nominal width of the dock basin measured between planes of the outside fender faces of the longitudinal quays. See section 8.10.3.b.7.

$$B_{nd} = 2L + K_{mr} \cdot L$$
$$B_{nd} = 2L + 2(l_a + l_d) + K_{mf} \cdot L \text{ (for mooring to buoys)}$$
$$B_{nd} = 2L + 2 \cdot \zeta \cdot h + K_{mf} \cdot L \text{ (for anchoring with anchors)}$$

where:

- B_{nd} = Nominal width of the basin measured between planes of the longitudinal quay's outside fender faces.
- L = Length overall of the largest design vessel that can operate at any of the basin's quays.
- K_{mr} = Factor quantifying the vessel manoeuvring area between the two vessel alignments on one and the other side. This factor will take at least the value of 1.75 for smaller boat docks ($L \leq 12$ m) and 2.00 for the remaining ships ($L \leq 12$ m). It may be more accurately adjusted if turning area requirements are analysed with the criteria given in section 8.6.4.
- K_{mf} = A factor quantifying the vessel manoeuvre area between the two alignments of buoys or anchors anchored on either side. This factor will take at least the value of 1.50 for smaller boat docks ($L \leq 12$ m) and 1.60 for the remaining ships ($L \leq 12$ m). It may be more accurately adjusted if turning area requirements are analysed with the criteria given in section 8.6.4.
- l_a = Length of vessel bow mooring lines, determined with the criteria as specified in section 8.8.
- l_d = Swinging of the mooring buoys subjected to maximum design loads, determined with the criteria as specified in section 8.8.
- ζ = Factor quantifying the distance from the anchor's anchoring point to the vessel's bow as a function of the water depth «h» in the basin, determined with criteria as specified in section 8.7.
- h = Depth of water in the basin. The most unfavourable within those possible will be taken.

Should this type of berth only occur in one only of the longitudinal alignments, or the uses be combined in both alignments, the criteria here expounded become general for the characteristics of each specific case.

8. Should the vessel berth be provided Mediterranean manner at the cross alignment (see fig. 8.54), the longitudinal space required to implement this type of mooring according to the bow securing system provided for (buoys or anchors) must be taken into account.

9. Should floating elements be provided for (floating docks, ramps, etc.) which may need to be seabed anchored or buoy moored, the space requirement for these facilities will be taken into account.

8.10.4. Specific recommendations for marinas

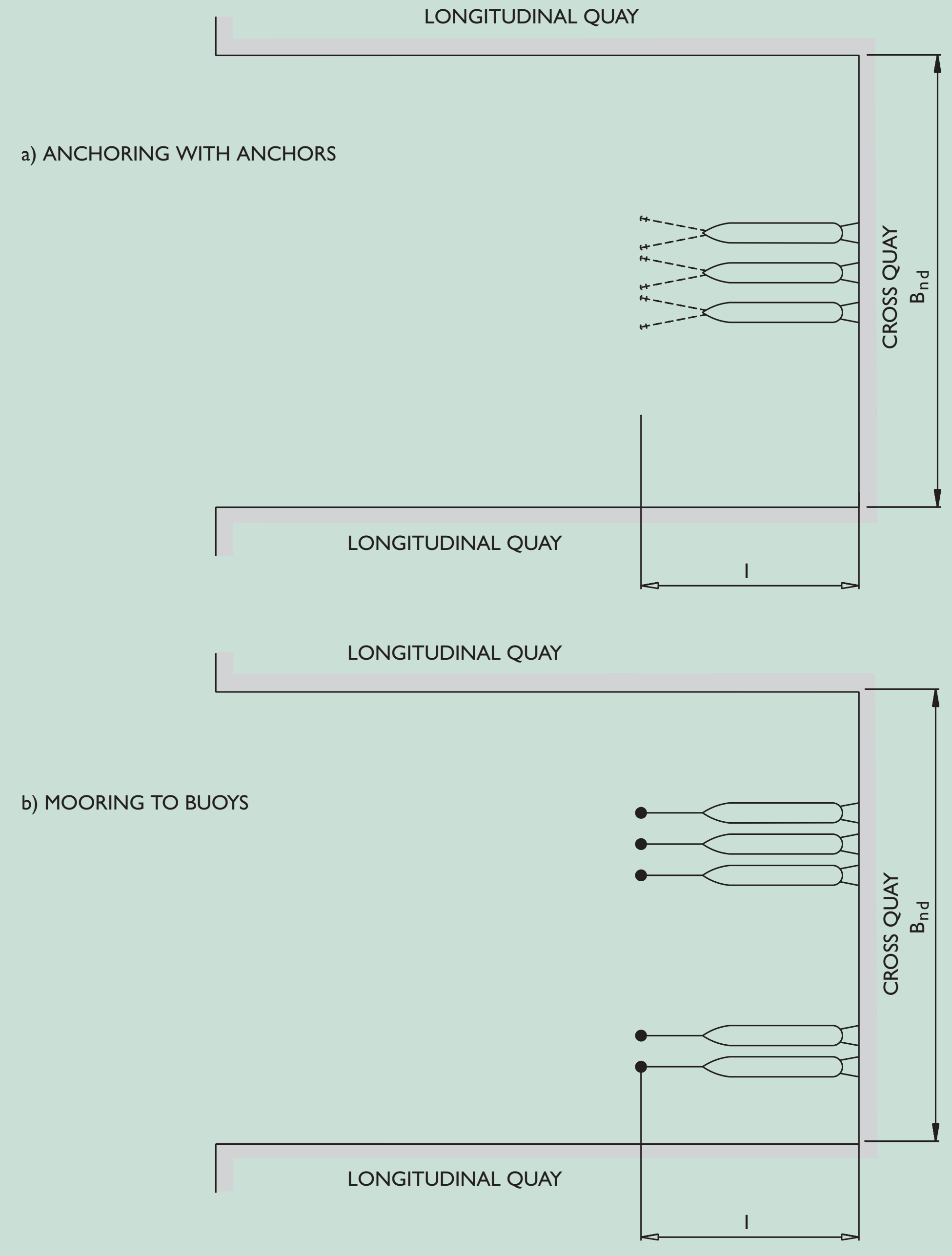
In the general case where marinas incorporate jetties, the following recommendations providing for spaces for boat berthing and departure berthing and manoeuvres will be followed (see fig. 8.55.).

a) MAIN JETTIES

- Distance between jetties
  The minimum distance between main jetties, measured between ends of the berthing jetties (or of the vessels moored there, if more unfavourable), i.e., the width of the navigation and manoeuvring area, will be at least 1.75 *L* for design vessels with a length overall (*L*) not greater than 12.00 m and 2.00 *L* for design vessels with a length overall (*L*) of more than 12.00 m.
  Should major vessel drift be foreseen due to the environmental conditions existing, these spaces will be increased as per the criteria given in section 8.6.4.

- Jetty widths
  The recommended width of the main jetties, in the case where they do not accept vehicle traffic, will be between 1.20 m and 2.00 m depending on vessel size and the number of berthing jetties available at each main jetty. If any kind of light vehicle traffic is expected, a width suitable to the vehicle characteristics will be adopted, with a minimum of 2.50 m.

Figure 8.54. **Basin width vessels berthed by bow or stern (Meditettanean manner) at a cross quay**



l = The space necessary to moor with buoys or with anchors is deterined with the criteria as given in section 8.8.

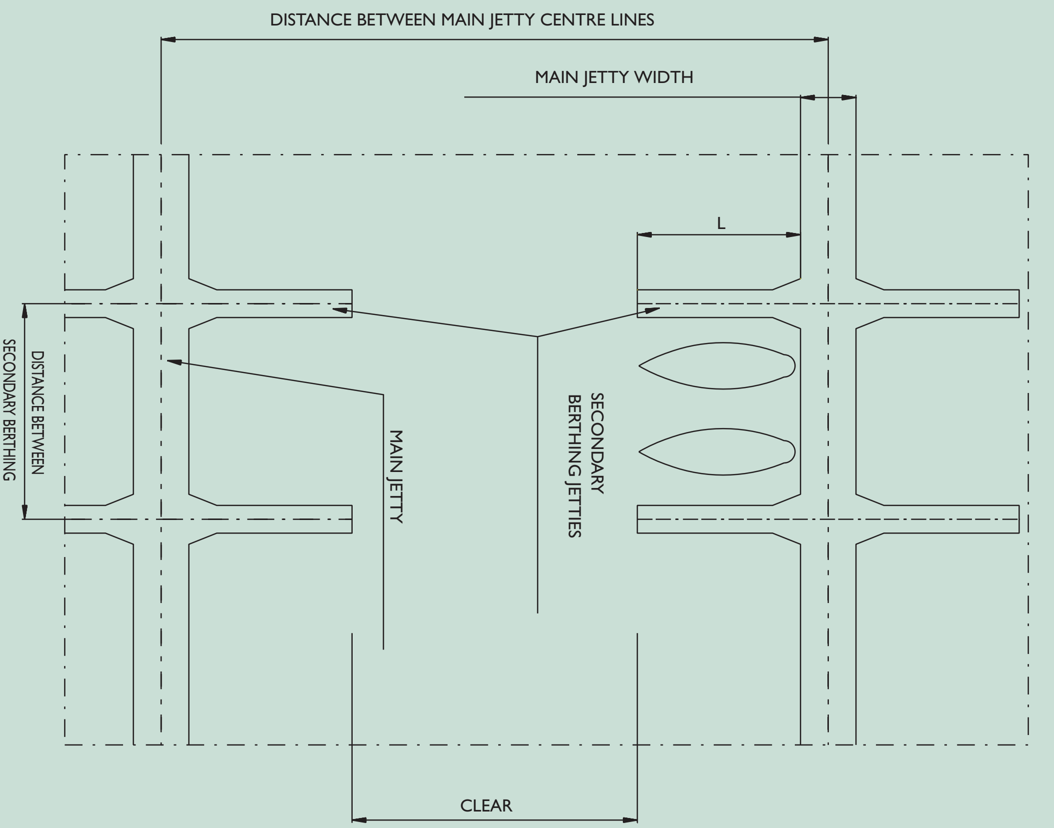
b) SECONDARY BERTHING JETTIES

- Distance between jetties
  - Single berths

    The distance between jetty centre lines will be at least equal to the sum of the maximum design vessel's beam plus a clearance of 0.30 - 0.50 m on each side of the boat plus the jetty's width.

- Double berths
  The distance between jetty centre lines will be at least equal to the sum of twice the maximum design vessel's beam plus a clearance of 0.30 - 0.50 m with respect to each of the quays, plus a clearance of 1.00 m between both boats.

Figure 8.55. **Layout configuration for pleasure boats**



L = Boat´s length overall.

These distances are determined assuming that the boats are a maximum 12 m long. Should larger boats be expected, clearances must be increased as a function of the berthing and departure manoeuvres expected to be performed according to the marina's configuration.

- Jetty lengths
  Berthing jetty lengths will be equal to the maximum design vessel's length (*L*). As an exception, shorter lengths may be accepted (70 or 80% of *L*) if a suitable boat mooring system is developed, which does not affect the dimensions of vessel Navigation and Manoeuvring Areas as defined in the foregoing section.

- Jetty widths
  The berthing jetty width recommended will be between 0.80 and 1.50 m as a function of the vessel size.

8.10.5. Limit operating conditions

The limit operating conditions usually adopted for vessel navigation and manoeuvring (stopping, turning) when performed inside basins are the same as established for these manoeuvres when being undertaken in other harbour areas irrespective of the fact that the more sheltered location of basins will usually cause a lower percentage of downtime in such areas due to adverse environmental conditions.

Three circumstances must be addressed as specific quay conditions:

- Vessel berthing
- Loading and unloading operation stoppage.
- Vessel staying at quays.

The limit conditions established for these three circumstances depend on other factors besides the boat. Thus, vessel berthing will depend on the tug-boats available and the quay fender systems. Stoppage of loading and unloading operations will mainly depend on the characteristics of the equipment used for such work; and vessel staying at quays on the structures' design criteria, on the availability of towing media for bringing boats out of the berths under these conditions and on the possibility of the boat being able to navigate in a controlled manner to other quays, anchorages or outer navigating areas. Other factors will intervene in certain particular cases, such as the limits of a pleasure boat's habitability under wave action.

The limit operating environmental conditions given in Table 8.1 are those usually being used for these manoeuvres but, obviously, others may be used to the extent whereby the downtime percentages resulting for different cases are evaluated as a function of the investments necessary to be able to guarantee operability under the limit conditions which may be adopted.

Table 8.1. Limit operating conditions at quays and jetties

	Absolute wind velocity $V_{10.1\ min}$	Absolute current velocity $V_{c.1\ min}$	Wave height H_s
1. *Vessel berthing*			
• Forces longitudinal to the quay	17.0 m/s	1.0 m/s	2.0 m
• Forces transversel to the quay	10.0 m/s	0.1 m/s	1.5 m
2. *Loading and unloading operation stoppage (for conventional equipment)*			
• Forces longitudinal to the quay			
– Oil tankers			
<30,000 DWT	22 m/s	1.5 m/s	1.5 m
30,000-200,000 DWT	22 m/s	1.5 m/s	2.0 m
>200,000 DWT	22 m/s	1.5 m/s	2.5 m
– Bulk carriers			
Loading	22 m/s	1.5 m/s	1.5 m
Unloading	22 m/s	1.5 m/s	1.0 m
– Liquid Gas Carriers			
<60,000m³	22 m/s	1.5 m/s	1.2 m/s
>60,000m³	22 m/s	1.5 m/s	1.5 m/s
– General cargo merchant ships, Deep sea fishing boats and refrigerated vessels.	22 m/s	1.5 m/s	1.0 m
– Container ships, Ro-Ros and Ferries	22 m/s	1.5 m/s	0.5 m
– Liners and Cruise vessels (1)	22 m/s	1.5 m/s	0.5 m
– Fresh fish fishing boats	22 m/s	1.5 m/s	0.6 m
• Forces transversal to the quay			
– Oil tankers			
<30,000 DWT	20 m/s	0.7 m/s	1.0 m
30,000-200,000 DWT	20 m/s	0.7 m/s	1.2 m
>200,000 DWT	20 m/s	0.7 m/s	1.5 m
– Bulk carriers			
Loading	22 m/s	0.7 m/s	1.0 m
Unloading	22 m/s	0.7 m/s	0.8 m

Table 8.1. ***Vessel limit operating conditions at quays and jetties (continuation)***

	Absolute wind velocity $V_{10.1\ min}$	Absolute current velocity $V_{c.1\ min}$	Wave height H_s
• Forces transversal to the quay			
– Liquid Gas Carriers			
<60,000m³	16 m/s	0.5 m/s	0.8 m/s
>60,000m³	16 m/s	0.5 m/s	1.0 m/s
– General cargo merchant ships, Deep sea fishing boats and refrigerated vessels.	22 m/s	0.7 m/s	0.8 m
– Container ships, Ro-Ros and Ferries	22 m/s	0.5 m/s	0.3 m
– Liners and Cruise vessels (1)	22 m/s	0.5 m/s	0.3 m
– Fresh fish fishing boats	22 m/s	0.7 m/s	0.4 m
3. *Vessel staying at quay*			
• Oil tankers and Liquid Gas Carriers			
– Actions longitudinal to the quay	30 m/s	2.0 m/s	3.0
– Actions transversal to the quay	25 m/s	1.0 m/s	2.0 m
• Liners and Cruise vessels (2)			
– Actions longitudinal to the quay	22 m/s	1.5 m/s	1.0 m
– Actions transversal to the quay	22 m/s	0.7 m/s	0.7 m
• Recreational boats (2)	22 m/s	1.5 m/s	0.4 m
– Actions longitudinal to the quay	22 m/s	1.5 m/s	0.4 m
– Actions transversal to the quay	22 m/s	07 m/s	0.2 m
• Other types of vessel	Limitations imposed by the quay design loads		

NOTES:
$V_{10.1\ min}$ = Mean wind velocity at 10 m high and 1 minute gust
$V_{c.1\ min}$ = Mean current velocity at a depth of 50% of the vessel's draught in a 1 minute interval.
H_s = Significant wave height (the period's influence will be taken into account for more precise studies).
Longitudinal = The wind, current or waves will be taken as acting longitudinally when their direction lies in the sector of ± 45° with the vessel's longitudinal axis.
Transversal = The wind, current or waves will be taken as acting transversally when their direction lies in the sector of ± 45° with the vessel's transversal axis.
(1) = Conditions refer to passenger embarking and disembarking.
(2) = Conditions refer to the limits for maintaining acceptable habitableness with passengers on board.

8.10.6. Basin and quay navigation marking

Basin and quay marking must be mainly directed to marking the following aspects:

- The definition of the basin access entrance and the definition of the most advanced infrastructure ends.
- The identification of berths.
- The leading lines necessary for vessel approach and departure routes to and from the basin when manoeuvres have to be performed in a preset direction.
- The delimitation of areas available for navigation when not defined by the basin's configuration (e.g., a berthable alignment is lacking or one of them is built with a slope and it is necessary to mark the level of the nominal water depth, etc.).
- The delimitation of the outer vessel turning areas when not included in other wider areas which are suitably marked for navigation.

8.11. SPECIAL FACILITIES

8.11.1. Locks

Locks are water level regulating structures used in fairways, harbours, operatings and other harbour areas with the purpose of removing tidal effects and other causes of water level variation, whilst allowing maritime and port operations to be run in a controlled manner.

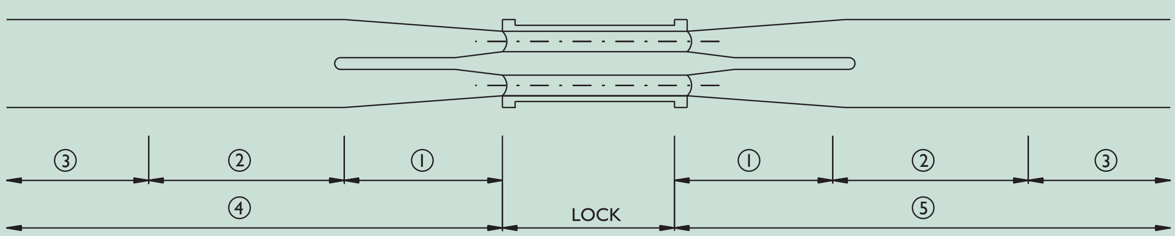
The site of locks as far as navigation is concerned must fulfil the following main requisites:

- Good accessibility for Design Vessels (which may possibly not be a single vessel but a string of vessels).
- Site located outside the flow of floating objects or ice floes, as well as possible silting up areas.
- Good visibility for carrying out all lock passing through operations.
- Possibility of making lateral extensions to implement new passing fairways or another type of construction which will take advantage of the differences in water level.

Fig. 8.56 shows the general configuration of a double fairway lock which is schematically represented for one fairway and the different elements can be observed there:

- Lock
  This is the central body of the system where the change in water levels will be performed to match navigation to the levels existing upstream and downstream. Its main dimensions will be determined with the following criteria, which are evaluated for the case of towing tug-boats, which is the case calling for the greatest development:
- Useful length: $L + L_r + 10$ m.
  where:
  L = Design vessel's length overall
  L_r = Sum of the tug-boat length and of the horizontal projection of the towing cable for the tug-boat required by the largest design vessel.
  Should this information not be available, L_r may be determined with the criteria as defined in section 8.10.4.b.

Figure 8.56. **Layout configuration for locks**



Legend
① Entrances. ② Waiting areas. ③ Transitions. ④ Upstream. ⑤ Downstream.

- Useful beam: 1.20.*B*.
  where *B* is the design vessel's beam.
- Waiting area
  These are areas located upstream and downstream of the lock where vessels wait before passing through. Their longitudinal dimensions depend on traffic forecasts and the lock's transit capacity, whilst their width depends on the system chosen to set the position of waiting vessels (berths, buoys, etc.).

A minimum safety clearance between vessels in transit and vessels waiting must be calculated for siting these areas. The clearance will be determined in each case as a function of the site's characteristics and of the towing and aid to navigation means.

- Entrances
  These are the areas arranged between the waiting areas and the lock. The transition will be carried out with a continuous profile, with no angles protruding outwards. The opening angle of each of the sides will be at least 1:6 and preferably 1:10.

- Transitions
  These are areas connecting the lock with the ordinary upstream and downstream fairway stretches. They will be dimensioned with the criteria used for defining transitions in fairways.

8.11.2. Dry docks and special quays

Implementing dry docks, slipways and certain special quays (Ro-Ros, Ferries, etc.) will call for configurations highly suited to the specific characteristics of this type of facility to be developed. Even though such configurations will define basin area limits, their materialization fundamentally depends on the operating conditions of these quays and facilities and, therefore, determining them goes beyond the content of these Recommendations and will be dealt with in those specifically drawn up for dry docks and quays.

8.11.3. Emergency grounding areas

Should it be legally mandatory, emergency grounding areas to which vessels will run in exceptional cases will be located in areas outside harbours close to their entrances, which fulfil the following conditions:

- Easy accessibility from port approach routes, with alignments which involve a minimum of manoeuvring and dimensioned for vessels with poor manoeuvrability characteristics.

- Clear separation between the routes and navigation and basin areas of the port so that its normal operations may continue with the vessel grounded, as well as during manoeuvres for refloating, salvage and recovery of the grounded vessel. The fact that the grounded vessel might be an oil tanker, chemical carrier, liquified gas carrier or other hazardous cargo vessel will be taken into account.

- Ample ground plan dimensions so that the vessel may be grounded in any position depending on the environmental conditions at the time. The minimum grounding area width is recommended in this respect to be 1.5 times the port's design vessel length, measured on either side of the fairway providing access to the grounding area.

- Ground of a suitable nature to allow vessels to be grounded without causing them greater damage than that it is intended to avoid (mud, sand, silt or similar). The suitability of such ground as regards refloating should also be taken into account.

- Acceptable sheltering conditions, particularly as to wave action and storms, so that the sea pounding onto a boat which will be in a precarious condition is prevented to the greatest extent possible.

- Acceptable morphological and maritime environmental conditions to prevent environmental damage that might occur through the loss of the vessel's cargo, fuel or stores.

- A non rough coast facilitating salvage operations under emergency conditions.

- Far from urban areas, particularly in the case of hazardous cargo traffic.

Emergency grounding areas will be shown on nautical charts but will not usually be marked for navigation regardless of the appropriate navigation marking should they be used.

8.12. LIMIT OPERATING CONDITIONS

The analysis of the different navigation and basin areas as defined in the foregoing sections has shown the limit operating environmental conditions normally used for nautical operations performed in each one. Different Harbour Basin dimensions, different tug-boat and other aids to navigation requirements and different port or manoeuvring downtime considered through adverse environmental conditions will result, depending on what such conditions are. Defining them is therefore an important item in determining Harbour Basins and in the Port's resulting configuration and, therefore, the criteria and values finally adopted must be clearly shown in the Operating Rules established accordingly.

Unless specific Operational Conditions for each case are available, the Limit Operating Conditions given in these Recommendations will be used and applied as follows:

- To the effects of design and dimensioning, it will be assumed that the different variables act simultaneously with their most requiring values, unless specific compatibility studies are carried out proving that these values cannot occur simultaneously at the site, in which case those compatible with each other will be taken. This condition may lead to considering different calculation hypotheses, taking each of the environmental variables as predominant and the remainder with the maximum values compatible therewith.

- To the effects of Operability, manoeuvres affected will be suspended at the time when any of the variables reaches the most unfavourable limits established irrespective of what the value the remaining variables have at any given moment is. The possibility of operating with values exceeding a variable associated to values not exceeding others is limited to cases where a detailed study has been carried out for the specific site.

The Downtime of the Area under consideration in relation to the total time available is recommended to be verified as an item of evaluation regarding the Limit Operating Conditions finally adopted being suitable at the normal service level in each case, in the absence of specific economic studies in this respect, i.e., the time in which the Area will be inoperative for certain operations because of any kind of limitation (ground plan, cross section, tug-boats, aids to navigation, etc.) caused through adverse environmental conditions higher than those established as Limit Operating Conditions.

In order to facilitate this analysis, Table 8.2. gives the mean downtimes usually accepted in the Areas targeted by this ROM, calculated for Design Vessel Limit Operational Conditions, whether caused by randomly occurring environmental variables not predictable in advance (winds, waves, currents, meteorological tides, poor visibility, etc.) or by other variables predictable in advance (astronomical tides, etc.). Should the Area be closed at night-time, it must be borne in mind that this circumstance reduces the useful time available and increases the percentage of area usage, whilst demanding stricter requirements on downtime admissible, such as is shown in Table 8.2 irrespective of any other economic or social evaluation which may be made with reference to night-time operation stoppage.

Table 8.2. Mean acceptable area downtimes due to adverse environmental conditions (higher than those established as operating limit for design vessels)

Area characteristics	Downtimes in hours for all concepts (1) (2)
A. Transit vessel areas (approaches, fairways, channels, entrances, manoeuvring areas, etc.).	
1. Ports of a general interest	
• Areas open to all kinds of vessels	200 h. year / 20 h. month
• Areas open to fishing and pleasure boats (3)	20 h. year / 4 h. month
2. Ports of refuge	
• Areas open to all kinds of vessels	300 h. year / 30 h. month
• Areas open to fishing and pleasure boats (3)	20 h. year / 4 h. month
3. Other ports	400 h. year / 40 h. month
4. Specialized terminals	
• Passenger, Container, Ferry and other terminals operating with regular lines	200 h. year / 20 h. month
• Bulk cargoes of any type and other terminals not operating regular lines	600 h. year / 60 h. month
B. Staying vessel areas (Anchorages, mooring areas, basins, quays, berths, terminals, etc.)	
1. Ports of any type	40 h. year / 20 h. month
2. Specialized terminals	
• Passenger, Container, Ferry and other terminals operating with regular lines.	200 h. year / 20 h. month
• Bulk cargoes of any type and other terminals not operating regular lines	500 h. year / 50 h. month

(1) The downtimes shown in this table refer to Area Closure for any concept, whether an environmental variable not predictable in advance (winds, waves, currents, meteorological tides, poor visibility, etc), or predictable in advance (astronomical tides, etc.). Area closure for night-time will not be considered to these effects and will only be evaluated as stated in the text.

(2) The minimum requirements shown in this Table are based on a 30% Area use by Design Vessels, calculated on the total useful time available (having therefore deducted the Area's downtime for whatever reason: not sufficient water level, maritime environment, night-time, etc.). Should this percentage of use be equal to or less than 20%, double the value of those shown in the Table may be used. Likewise, if the percentage of area use were equal to or higher than 40%, half the values as shown in the Table must be used; linear interpolation may be used for intermediate values.

(3) Downtime will be calculated for fishing and pleasure Design Vessel Limit Operating Conditions.

Part IX

Ship manoeuvring, numerical models and simulators

SHIP MANOEUVRING, NUMERICAL MODELS AND SIMULATORS

Part IX

9.1. OBJECTIVES

Numerical ship navigation and manoeuvring models and simulators are a powerful means for studying maritime and port projects. Their application is centred on the design and operation of port facilities, approach channels and harbour basins with the purpose of providing the designer with guidance as regards a ship's possibilities and restrictions in relation to the infrastructure and environmental conditions existing.

They are intended to reproduce the behaviour of a vessel subjected to the action of environmental factors during manoeuvring (wind, waves, currents, etc.) and assisted by tug-boats. Consequently, the use of these tools enables the feasibility of a certain manoeuvring strategy under various environmental conditions to be evaluated, whilst also incorporating the actions of man, should he be involved. Guidance is therefore obtained on the most suitable way for performing the manoeuvring, as well as its safety margins and even with respect to the need and power of the auxiliary manoeuvring resources to be used.

Different kinds of navigation and manoeuvring models and simulators exist, which are able to respond to different problems. The following applications may be highlighted in their most advanced versions:

a) DESIGNING MARITIME AND PORT STRUCTURES

A manoeuvring model is a major aid for detailed, integral evaluation of the different alternatives for building or extending maritime and port structures (interference of a breakwater's extension or a new quay in approach manoeuvring, possibility of access for a certain type and size of vessel, influence of various storms in the area (winds and waves) on the feasibility of a manoeuvring, degree of safety resulting, economic and safe routing of entrance channels, etc.).

b) ANALYSING OPERATING CONDITIONS

Drawing up port approach rules ((type and size of vessels, meteorological and tidal conditions, manoeuvring strategy, etc.), estimating the need for tug-boats (number and horsepower) in manoeuvring, safety margins for approaching berths under bad weather conditions, modification to the use of berths (conversion of terminals, etc.).

c) PERSONNEL TRAINING

An advanced simulator is an efficient means for personnel training (Captains, officers, pilots, etc.) both in a basic stage and in advanced or refresher courses. On board instrumentation and equipment handling, understanding of the system's physical response to external forces, practising preset communication procedures with tug-boats or traffic control systems, familiarization with new, different or larger sized vessels, prior exercises in entrance manoeuvring in new ports or ports whose facilities have been modified, the definition of action methods in emergencies or under extreme environmental conditions, etc. are all simulator application fields.

d) INVESTIGATION ON PORT TRAFFIC

Design and optimisation of aids to navigation systems, development of vessel control during berthing, establishing standardized communication procedures, determining approach times to different quays, determining tidal port entrance and departure periods (concurrence of tides, winds and waves for ships of different types and sizes), *a posteriori* analysis of maritime accidents, etc.

e) INVESTIGATION ON THE VESSEL

Mathematical modelling of the vessel's physical response under different conditions of draught, in channels and confined areas. Development of the most effective propulsion and steering systems. Development of new types of tug-boats. Development of new strategies for tug-boat application. Studying and assessing new navigation systems, means of communications and on board instrumentation, etc.

9.2. TYPES OF MODEL

There are two basic elements constituting these models:

- The mathematical formulation on which they are based which, in any case, should include simplifications in view of the multiple, complex nature of interacting phenomena.

- The equipment around the mathematical model, which involves man's relation with the modelled situation. This element determines the type of simulator and increases the degree of quality in reproducing the real situation.

The ultimate goal is to obtain a reproduction of both the vessel's physical response and the performance of the personnel operating on it, taking into account the importance of the human factor in undertaking manoeuvring. This is why it is fundamental in any event to have a complete, strict mathematical model which takes factors predominating in the manoeuvring into account. But, on occasions, acting on control elements similar to the real ones with a realistic perception of the surroundings is decisive. Specifically:

- On board instruments and gauges (gyro compass, rudder angle, log, main engine rpm, etc.).

- Control elements (rudder tiller, main engine telegraph, etc.).

- Radar image (vessel's position and course).

- Image of vessel's surroundings (reference marks and navigation marking, perception of position and movement).

- Means of communication with tug-boats and other ships.

To this effect, depending on the wealth of elements offered to the operator and similarity with the actual situation, four different levels within a broad range can be distinguished:

1. Models with autopilot.

2. Micro-simulators.

3. Mini-simulators.

4. Advanced simulators

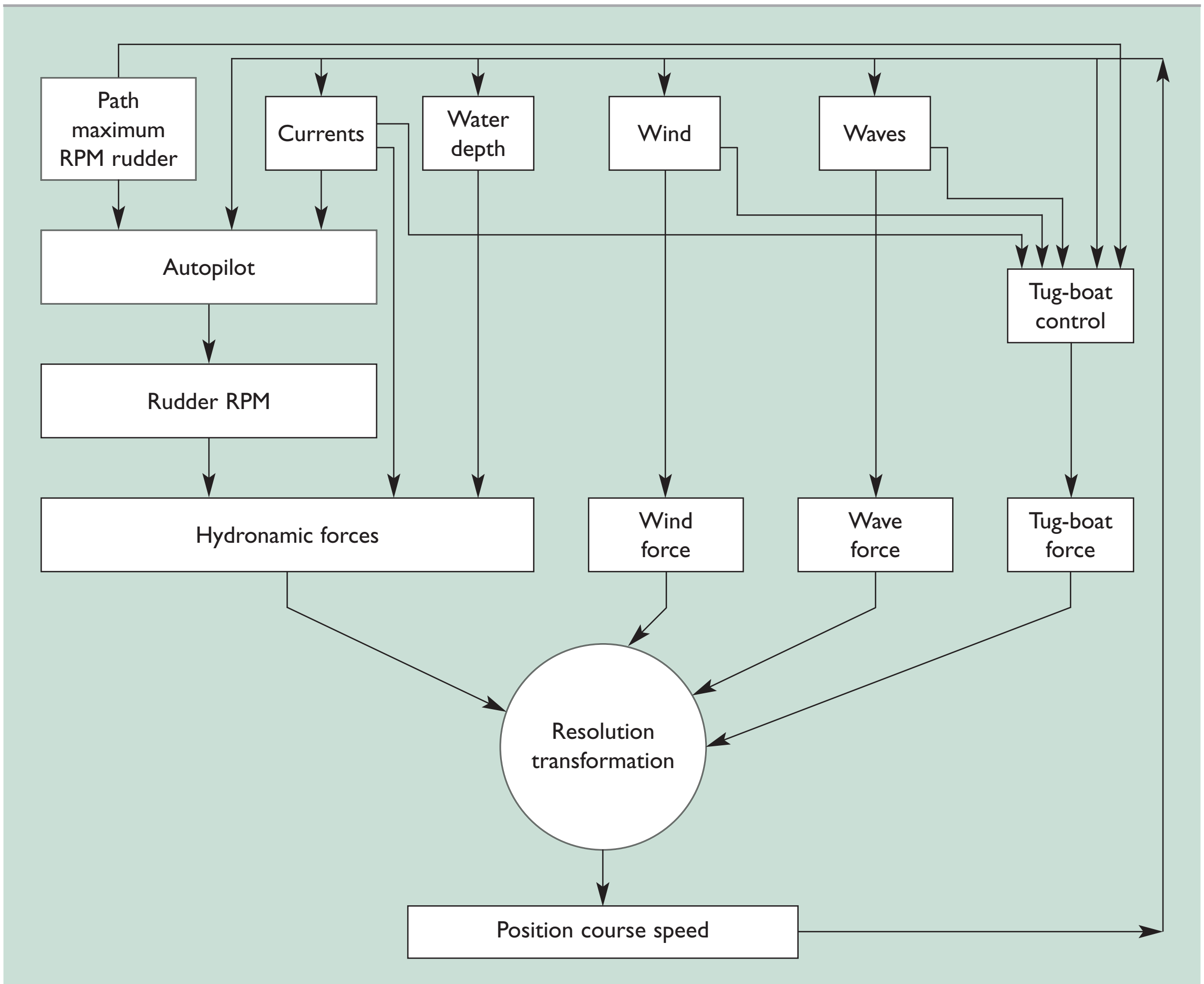
Each of the types of simulator listed are briefly described below.

9.2.1. Autopilot models

There is no man/system interactivity in this type of model. They are based on modelling both the vessel's performance and the physical conditions (wind, current and wave force, etc.) and the actions of the pilot, who is replaced by a mathematical algorithm.

A programme of the type shown in figure 9.01 is run in these models. The programme acts on the propulsion and rudder by means of an autopilot system, endeavouring to follow a preset path under preset environmental conditions. There is also a simplified tug-boat operating model in some versions. Thus, it is possible that such may assist the vessel in its turning, particularly in the case of following a path. The manoeuvring is simulated in a very short time which depends solely on the computer's calculation speed. This is why these models are also known as fast-time or accelerated.

Figure 9.01. ***Block diagram of a model with autopilot***



9.2.2. Micro-simulators

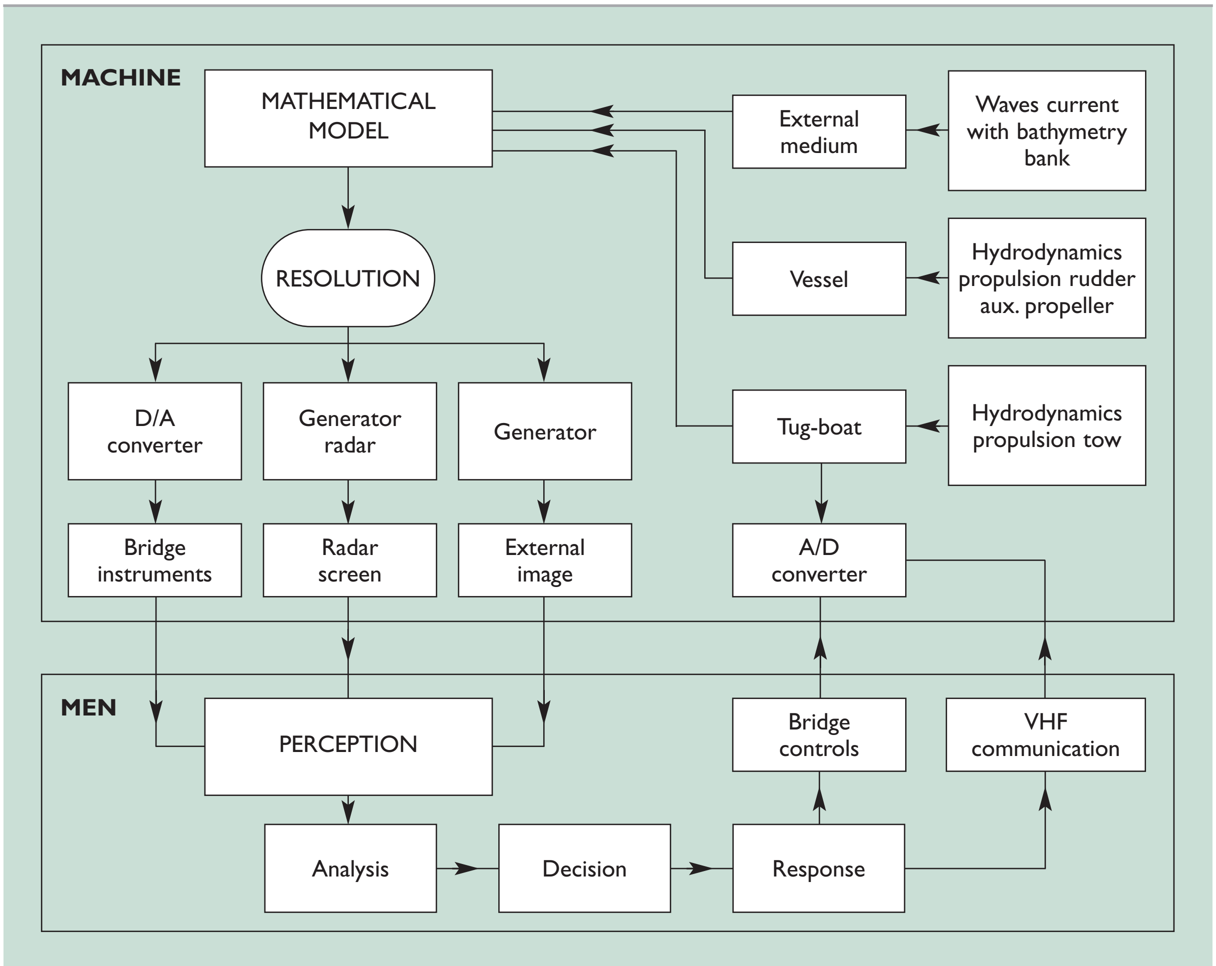
The main contribution of this second level is the man/system interactivity, which is a major qualitative change. The simulated manoeuvring last as long as in actual reality and the user can make decisions whilst they are being performed in the light of the information he is receiving. The resulting actions are orders to the engine, rudder or tug-boats.

The mathematical formulation which reproduces a vessel's behaviour to the action of various external forces may be exactly the same as in an autopilot model. The difference in the system's operation, however, is significant, as are the results.

Despite everything, the information received is limited and it is not intended to reproduce the usual on board instrumentation. The micro-simulator consists in a computer with its basic peripherals (printer and plotter). A radar type image is usually available (birds eye view) with the vessel's position in relation to its surroundings. At the same time, the screen displays a simplified indication of course, speed, rudder angle and engine rpm. Engine, rudder and tug-boat orders are given by means of a mouse or combinations of keys on a standard keyboard.

As was stated, interactivity represents a major contribution in manoeuvring performance analysis. Difficult to reproduce with a formulation like the autopilot's, the human factor is present as such and introduces a certain amount of dispersion into the results of the successive simulations of the same manoeuvring. This random component will have to be considered in the design criteria.

Figure 9.02. **Block diagram of an interactive simulators**



Real time action calls for more powerful IT equipment provided with more sophisticated operating systems. Only thus can orders be received from the user and be immediately incorporated into the model, whilst at once calculating the forces and solving the movement equations with sufficient accuracy and speed. The block diagram of an interactive simulator is given in figure 9.02.

9.2.3. Mini-simulators

This type of facility represents an intermediate state towards more complex simulators. There are two main differences with the foregoing stage:

- The incorporation of an external image of a vessel's manoeuvring area, as would be seen from the bridge.
- A reproduction of the bridge with all or part of its controls and gauges (engine and rudder telegraphs, speed, course, depth, wind speed and direction gauges, etc.).

Therefore, the references the user avails of are both the radar display and the external image, together with the usual on board gauges. However, all the foregoing is brought together in a limited space with a reduced capacity. The bridge premises may be far smaller than actual ones, and the steering console may be small sized. At the same time, the external image is displayed either on a graphic screen with some 45° horizontal amplitude or on larger sized projection systems, reaching up to 90 or 100 degrees vision.

Naturally, this type of simulator calls for a location specific to this function as well as costlier IT and communications equipment.

9.2.4. Advanced simulators

These represent the highest stage currently in use, with a very high degree of fidelity under constant improvement. This growth goes hand in hand with the development of higher capacity IT equipment, particularly as far as graphic processing is concerned.

One of the elements defining this type of system is the reproduction of a vessel's bridge and its instrumentation, all in a room provided to the effect. The instruments may even be twins of those found on actual bridges. The equipping level may even include control consoles (engine(s), rudder(s), bow and stern thruster(s)), various navigation systems (GPS, Decca, Loran C, direction finding –radio goniometry–), special synthetic or real radar equipment, communications systems (real VHF), various gauges (wind speed and direction, fathometer, gyro compass, logs, etc.), alarm consoles and navigation marking, etc.

A second notable element is the presentation of the vessel's external image projected onto a large size, generally circular screen which may reach 360° horizontal amplitude and between 25° and 35° vertical amplitude. This image displays breakwaters, quays, buoys, lights and lighthouses, reference marks, other ships either berthed or navigating, the visible part of the vessel and, in general, all objects relevant in reproducing the manoeuvring through being an obstacle or outstanding reference, in a relatively simplified manner. The manoeuvring can be performed under different conditions of light (day, dusk, night) and visibility (mist, fog, rain, etc.).

The main functional characteristics to be evaluated as regards the external image are: horizontal and vertical amplitude, number of graphic objects that can be controlled, image refreshing speed, resolution, image quality (number of colours, shading methods, possibility of texture presentation), presence of moving elements pre-programmed or controllable from an outside station (tug-boats, other nearby ships, etc.) illumination methods, presentation of the sea (waves, currents), presentation of the sky (cloudiness, showers, wind), presentation of vertical vessel motions, etc. Most depend on the graphic capability of the computer system to which is combined the number and quality of the projection system.

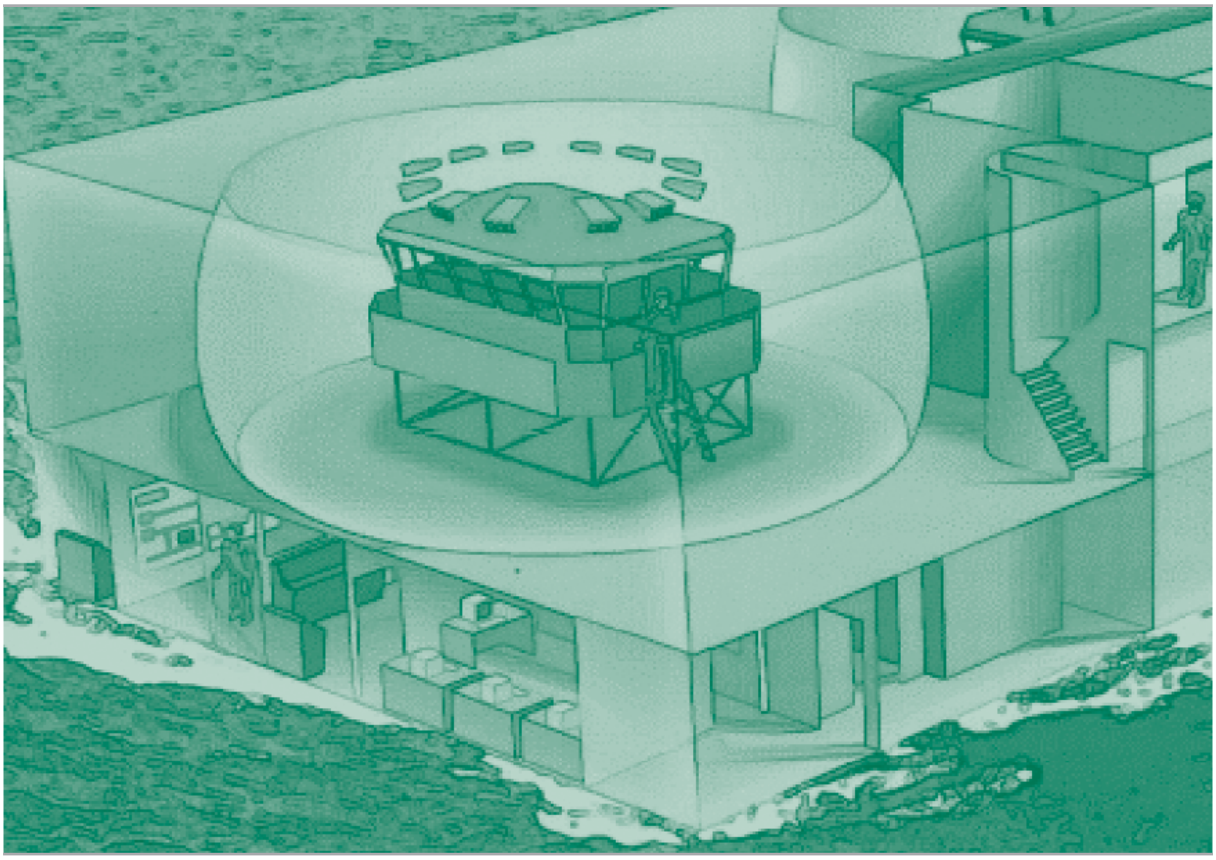
It is also frequent to avail of sound generation systems, fundamentally orientated to engine noise and vibration reproduction, own or external signals (horns, whistles) and other environmental noises (wind, rain). In some cases the simulator is mobile, and heaving, pitching and rolling oscillations due to the waves may be generated by means of hydraulic or electric actuators which support the bridge.

The most advanced simulators usually have an instructor's or controller's station provided with radar image and external display repeaters as well as the main bridge instruments (engine rpm, rudder position, bow and stern thruster rpm, log and sounder) combined in a control console, closed circuit television and sound, etc. The manoeuvring being simulated is monitored from this station and certain aspects external to the ship are controlled (communications receiver, environmental surroundings control, maritime traffic in the vicinity, tug-boat actions, break-down management or malfunctions of own control elements, etc.).

Certain designs allow several simulators to be interconnected so that complex manoeuvring conditions under which several different vessels interact can be reproduced (analysis of intense traffic situations - passing, overtaking -, tug-boat(s)/towed vessel interrelation, etc.).

A highly realistic atmosphere can thus be recreated, but it must not be forgotten that, under this appearance, there always exists a mathematical formulation which governs the vessel's performance, evaluating the external forces and calculating the pertinent response. Normally, as the cost of the facility increases, the underlying mathematical model is also improved, with external effects being more precisely incorporated. Nevertheless, limitations in this field are still extensive, as are the possibilities of progress. Figure 9.03 gives the basic scheme of a large simulator.

Figure 9.03. ***Basic scheme of a large simulator (bridge, projection system, screen, auxiliary facilities)***



9.3. BASIS OF THE MODEL

The mathematical model calculates the path of the vessel's centre of gravity and course throughout time, subjected to the action of external forces, propulsion (propeller) and steering (rudder). In the case of an autopilot model, a mathematical algorithm decides on rudder, engine and tug-boat operations. On the contrary, the model's operator gives real time orders in interactive simulators.

The main forces to be considered during the vessel's turning, which must be included in the mathematical model, are:

- Hydrodynamic forces on the hull (lift and friction).
- Propulsion (single propeller, two propellers, special devices), taking into account the dynamic response of the propulsion machinery (diesel engine, steam turbine, etc.).
- Forces due to steering equipment (one, two or more rudders), including interaction with the hull and propeller, as well as the steering engine's dynamic characteristics.
- Bow and/or stern auxiliary propellers, taking into account the relation of their efficiency with the vessel's speed.
- Modification of the flow round the hull in shallow water and varying bathymetry.
- Bank suction and rejection effects.

- Uneven spatially distributed currents, with special attention to the longitudinal gradient.
- Uneven spatially distributed and gusting wind.
- First and second order forces due to waves.
- Action of different types of tug-boat, including the time lag in the tug-boat's response to orders, as well as reduction in their efficiency with the vessel's speed.
- Vessel-to-vessel interaction (passing and overtaking).
- Auxiliary manoeuvring elements: mooring lines, anchors, etc.).
- Other forces: collision, grounding, etc.

The mathematical vessel motion models used display special characteristics, since they have to reproduce the usual conditions in port areas. Specifically, they must be able to reproduce low speed motions, with high drift angles in many cases, and almost always in shallow water.

The equations governing a vessel's motion are established with respect to a reference system fixed to the vessel's centre of gravity. The most usual is to analyse motions in the horizontal plane (surge, drift, yaw) since the influence of vertical motions (heaving, pitching, rolling) under manoeuvring conditions will only be relevant in high speed vessels. In any case, continuous developments in the hydrodynamic field allow the vessel's performance to be gradually incorporated with six degrees of freedom, including wave action, squat, etc.

The basic variables to be analyzed are the vessel's position (*x, y*), its course (ψ), the different speed components (*u, v, r*), the propeller's revolutions (*n*) and the rudder angle (α_T).

The vessel's response is governed by Newton's Second Law (Force = mass x acceleration) which is broken down into the three axes to be considered:

$$X = M_x \times x''$$
$$Y = M_y \times y''$$
$$N = I_p \times y''$$

where:

X	=	Component *x* of the extrenal force
Y	=	Component *y* of the external force
N	=	Moment resulting from the outside force with respect to the ship's centre of gravity.
M_x	=	Hydrodynamic mass (vessel plus added water) of the vessel in motion along the *x* axis.
M_y	=	Hydrodynamic mass (vessel plus added water) of the vessel in motion along the *y* axis.
I_p	=	The vessel's hydrodynamic moment of inertia with respect to the c.o.g (The upper index ´´ indicates second derivative with respect to time).

The foregoing equation is referred to the system of coordinates fixed to the ship, but is more frequently expressed in a fixed reference system:

$$X = M_x \times (u' - v \times r - x_G \times r^2)$$
$$Y = M_y \times (v' + u \times r + x_g \times r')$$
$$N = I_p \times r' + M_x \times x_G (v' + u \times r)$$

where:

u	=	Speed in direction *x*.
v	=	Speed in direction *y*
r	=	Rotation speed
x_G	=	Longitudinal coordinate of the vessel's c.o.g. referred to the system of coordinates fixed to it (the upper index ´ indicates first derivative with respect to time).

The typical equations of a simple, basic manoeuvring model are given hereafter as a description. This reference does not pretend to be exhaustive, since there are a multitude of variants, more or less complex as regards the number of terms considered and their formulation which is more complex, in general, than that described in this ROM's section 4.

9.3.1. Hydrodynamic forces

$$X_{hidr} = X_{u'} u' + X_{uu}uu + X_{vr}vr$$
$$Y_{hidr} = Y_{v'} v' + Y_{r'} r' + Y_{uv}uv + Y_{vv}v|v| + Y_{ur}ur + Y_{rr}r|r|$$
$$N_{hidr} = N_{v'} v' + N_{r'} r' + N_{uv}uv + N_{vv}v|v| + N_{ur}ur + N_{rr}r|r|$$

where:

X_{hidr} = Component *x* of the hydrodynamic force
Y_{hidr} = Component *y* of the hydrodynamic force
N_{hidr} = Moment of the hydrodynamic force

(The terms in italics are the vessel's coefficients –hydrodynamic derivates– which determine the hull's behaviour under a specific condition). These terms in italics are not shown in Table 1.1 of Notations.

The term X_{hidr} relates to the resistance to the vessel's advance under specific navigation conditions, whilst Y_{hidr} and N_{hidr} relate to the drifting force and yawing moment. Manoeuvrability characteristics are therefore expressed by a set of specific hydrodynamic coefficients for each vessel or type of vessel. These coefficients are usually determined by physical model testing (tests in a channel, in a manoeuvring or free model tank), and are a particular feature for each type and size of ship under a given load condition.

9.3.2. Propulsion forces

$$X_{prop} = X_{nn}n^2 + X_{un}un$$
$$Y_{prop} = Y_{nn}n^2$$
$$N_{prop} = Y_{prop} \times x_{prop}$$

where:

X_{prop} = Component *x* of the propulsion force.
Y_{prop} = Component *y* of the propulsion force.
N_{prop} = Moment of the propulsion force.
n = Propeller revolutions.
x_{prop} = Longitudinal position of the propeller referred to the system of axes fixed to the vessel.

(The terms in italics are typical of the vessel's propulsion and its interaction with the underwater hull). These terms in italics are not shown in Table 1.1 of Notations.

The term X_{prop} relates to the propeller supplied thrust. The other terms represent the lateral forces due to the propeller's action and explain, for instance, the phenomenon of the vessel's side veering when going astern. In any case, the dynamic performance of the overall propulsion machinery (minimum and maximum rpm, characteristic torque-rpm curve, etc.) must be considered.

9.3.3. Steering forces (Rudder)

$$X_{rudder} = X_{dduu}\alpha_T\alpha_T uu + X_{ddnu}\alpha_T\alpha_T nu$$
$$Y_{rudder} = Y_{duu}\alpha_T u|u| + Y_{dnu}\alpha_T nu + Y_{dnn}\alpha_T nn$$
$$N_{rudder} = Y_{rudder} \times x_{rudder}$$

where:

X_{timon} = Component *x* of the steering force.
Y_{timon} = Component *y* of the steering force.

N_{timon} = Moment of the steering force.
α_T = Rudder angle.
x_{timon} = Longitudinal position of the rudder referred to the system of axes linked to the vessel

(The terms in italics are typical coefficients of the vessel's rudder and its interaction with the underwater hull). These terms in italics are not shown in Table 1.1 of Notations.

The term X_{timon} relates to the increase in resistance when setting a certain rudder angle. The terms Y_{timon} and N_{timon} express the drift and rotating torque induced by the rudder. The steerin engine's dynamic characteristics (maximum rudder angle, rate of rotation, etc.) must also be considered.

9.3.4. Manoeuvring thrusters (Bow and/or stern)

$$Y_{helaux} = (\gamma_w/2g) \times A_{helaux} V^2 f_1 (u/V_F)$$
$$N_{helaux} = Y_{helaux} f_2 (u/V_F)$$

where:
Y_{helaux} = Transverse component of the force induced by the thruster.
N_{helaux} = Moment induced by the thruster.
x_{helaux} = Longitudinal position of the thruster referred to the system of coordinates fixed to the vessel.
γ_w = Specific weight of sea water.
g = Acceleration of gravity.
A_{helaux} = Area of the thruter's nozzle.
V_F = Rate of flow in the nozzle.

The thruster induced forces generally take the form of the product of fluid density times the area and times the flow velocity squared, which corresponds to dynamic fluid pressure phenomena. The terms f_1 and f_2 represent factors of thrust reduction because of the interaction of the flow and the hull at different navigation speeds.

9.3.5. Shallow water

A deep water condition is considered when the ratio $h/D > 5$ (h = depth, D = vessel's draught). In this case, the influence of the seabed on the vessel's manoeuvring capacity is negligible. On the other hand, in limited water depth ($h/D < 2$), the water flowing around the hull in motion is altered by the restriction of the flow passage cross section and vessel manoeuvrability characteristics are modified. This effect becomes very important in very reduced underkeel clearance situations (10% or even 5% depth) which are not infrequent in many channels and port basins.

The manoeuvring models most used incorporate this phenomenon by means of two or more sets of hydrodynamic coefficients obtained through scale model tests under various depth conditions. The vessel response coefficients most suited to the local depth at all times are chosen during a model's application, or interpolation between the available coefficients is carried out, normally as a function of $D/h\text{-}D$.

9.3.6. Bank suction and rejection

$$X_{bank} = X_1 u^3/hB_T + X_2 uvB/B_T$$
$$Y_{bank} = Y_1 uvx_b + Y_2 a_e u^2 + Y_3 a^2_e uv$$
$$N_{bank} = N_1 uvx_b + N_2 a_e u^2 + N_3 a^2_e uv$$

where:
X_{bank} = Longitudinal component of the suction/ rejection force.
Y_{bank} = Transverse component of the suction/ rejection force.
N_{bank} = Moment of suction/rejection.
h = Depth of water in the channel.

B_T = Width of navigation channel
B = Vessel's beam
x_b = Blockage coefficient B_T/B.
a_e = Coefficient of eccentricity.

(The terms in italics are coefficients of the vessel's hull). These terms in italics are not shown in Table 1.1 of Notations.

The term X_{bank} relates to the increase in resistance when navigating in confined water. The terms Y_{bank} and N_{bank} express the lateral force and rotating moment due to suction towards the channel's bank caused by the asymmetry of the flow round the hull.

9.3.7. Currents

It is usual to reproduce the influence of the current on the vessel by applying the principle of relative motion. That is to say, since the vessel's hydrodynamic coefficients reproduce the forces and moments on the hull subjected to a water flow around it, it is valid to consider that such flow is made up of the speed of the vessel vectorially added to the velocity of the local current. The composition of accelerations will also have to be taken into account. The resultant equations are:

$$u_r = u - u_c \qquad u'_r = u' - u'_c$$
$$v_r = v - v_c \qquad v'_r = v' - v'_c$$
$$r_r = r - r_c \qquad r'_r = r' - r'_c$$

where
u, v, r = The vessel's absolute speed
u_r, v_r, r_r = The vessel's relative speed
u_c, v_c, r_c = The current's absolute speed

(The upper index ´ indicates a derivative with respect to time).

It is important in the model to consider the existence of longitudinal current gradients (variations in intensity or direction along the length of the vessel) which may produce rise to highly relevant rotating moments. This is why it is not sufficient to consider the current's point value but to integrate its variations through at least three points along the vessel's length.

9.3.8. Wind

$$X_{wind} = (\rho/2g) \times C_X\,(\alpha_{vr}) \times AM_{frontal} \times V^2_{vr}$$
$$Y_{wind} = (\rho/2g) \times C_y\,(\alpha_{vr}) \times AM_{lateral} \times V^2_{vr}$$
$$N_{wind} = (\rho/2g) \times C_N\,(\alpha_{vr}) \times AM_{lateral} \times L \times V^2_{vr}$$

where:
X_{wind} = Longitudinal force of the wind.
Y_{wind} = Transverse force of the wind.
N_{wind} = Moment of forces produced by the wind.
$C_X(\alpha_{Vr})$ = Longitudinal form coefficient.
$C_Y(\alpha_{Vr})$ = Transverse form coefficient.
$C_N(\alpha_{Vr})$ = Moment's form coefficient.
α_{vr} = Angle of wind incidence relative to the vessel.
ρ = Specific weight of air.
g = Acceleration of gravity.
AM_{front} = Front area of the vessel's upper work.
$AM_{lateral}$ = Lateral area of the vessel's upper work.
V_{vr} = Relative wind velocity.

(The terms in italics are the coefficients of the vessel). These terms in italics are not shown in Table 1.1 of Notations.

Once again, wind induced forces take the form of a product of density times an area times the flow velocity squared which corresponds to dynamic fluid pressure phenomena.

The term X_{wind} relates to the increase in resistance to advance due to the wind. The terms Y_{wind} and N_{wind} express the lateral force and rotating moment due to wind action. All the foregoing values depend both on the dimensions of the vessel and on the forms of upper work (volume and longitudinal position of superstructures, deck cargo, hatch covers and masts, etc.) and on the wind's angle of incidence relative to the vessel. Coefficients C_X, C_Y and C_N show these aspects.

9.3.9. Waves

First order forces produce vertical vessel movements (heaving, pitching, rolling) and instant yawing which not all models can calculate with accuracy and sufficient speed. Second order forces have greater influence on the manoeuvring and are usually formulated as follows:

$$X_{wave} = (\gamma_w/2g) \times C_X(T_w, \alpha_w) \times AV_{front} \times H^2_s$$
$$Y_{wave} = (\gamma_w/2g) \times C_Y(T_w, \alpha_w) \times AV_{lateral} \times H^2_s$$
$$N_{wave} = (\gamma_w/2g) \times C_N(T_w, \alpha_w) \times AV_{lateral} \times L \times H^2_s$$

where:

X_{wave} = Longitudinal wave force.
Y_{wave} = Transverse wave force.
N_{wave} = Moment of forces produced by waves.
$C_X(T_W, \alpha_W)$ = Longitudinal form coefficient.
$C_Y(T_W, \alpha_W)$ = Transverse form coefficient.
$C_N(T_W, \alpha_W)$ = Moment's form coefficient.
T_W = Wave period.
α_W = Angle of wave incidence.
γ_W = Specific weight of sea water.
g = Acceleration of gravity.
AV_{front} = Front area of the underwater body.
$AV_{lateral}$ = Lateral area of the underwater body.
L = Vessel's length overall.
H_s = Significant wave height.

(The terms in italics are coefficients of the vessel). These terms in italics are not shown in Table 1.1 of Notations.

The term X_{wave} relates to the increase in resistance to advance due to waves. The terms Y_{wave} and N_{wave} express the lateral force and rotating moment due to wave action. All the foregoing values depend both on the dimensions of the vessel and on the forms of the underwater body and on the angle of incidence of the waves to the vessel. Coefficients C_X, C_Y and C_N show these aspects, as in the foregoing case.

9.3.10. Autopilot

There are various formulations although autopilots based on PID algorithms (proportional-integral-differential) are the most used. A target path to which the vessel must hold as far as possible whilst suffering deviations from the effect of environmental agents or from the actual manoeuvring limitations is assumed as a start. The desired position and course is checked at all times on the path with a certain anticipation distance. Thus, errors in position and course are calculated as differences between the actual values and those required. From these values, actions involving the rudder (increase in deflection) and engine (increase of rpm) are decided upon according to the following formula:

$$A_{P_a} \times \alpha_T + B_{P_a} \times \alpha'_T = C_{P_a} \times \Delta\psi + D_{P_a} \times \Delta y + E_{P_a} \times r + F_{P_a} \times r + F_{P_a} \times r' + G_{P_a}$$

Where:

α_T	=	Rudder deflection angle.
$\Delta\psi$	=	Course error.
Δ_y	=	Position error.
r	=	Vessel's rate of turn.
A_{P_a}, B_{P_a}, C_{P_a}, D_{P_a}, E_{P_a}, F_{P_a}, G_{P_a}	=	Autopilot coefficients.

(The upper index ´ indicates the derivate with respect to time).

The rudder deflection angle is limited to a maximum value (normally 35 degrees) and its rate of deflection is likewise limited by the servomotor's power. The engine's rpm are increased if the rudder angle required to correct the vessel's position exceeds a preset value (in the order of double the maximum angle) so that the usual action of turning ahead for a few seconds in order to increase steering is reproduced.

9.3.11. Tug-Boats

A simulator must be able to reproduce tug-boat operation with sufficient realism, even when provided with a simplified model. To this effect, the number of tug-boats, their horsepower and bollard pull and their position with respect to the towed vessel are relevant parameters to be considered. The working method (pulling tow, pushing ahead, holding, etc.) and the type of tug-boat (conventional propulsion, ducted propeller, cycloidal propulsion, Schottel propulsion, etc.) will determine the effective pull it is able to give in each situation. The loss of efficiency in the tow with speed must necessarily be included in the model. Likewise, the time lag in executing orders and the time to increase or reduce the pull must also be addressed, as well as the time required to move the tug-boat from one position to another, if necessary.

To this effect, several degrees of quality are available in tug-boat simulation which range from the most simplified vector model (force defined by its magnitude and direction, without considering the majority of the aspects mentioned), through advanced models (which consider parameters mentioned in a more or less simplified manner and automatically calculate the force available at all times), simplified interactive simulation (tug-boat captains on simple models with a bird's eye view of the manoeuvring area) up to complete interactive simulation (each tug-boat has its bridge with instruments and an outside display and operates a dynamic model (propulsion, steering, navigation and tow) which interacts with the towed vessel). Naturally, the aim of the study will determine the relevance of the tow at all times and the need to use a more or less advanced model.

9.4. PREPARING A STUDY

A programme addressing the selection of «manoeuvring scenarios» to be analysed should be drawn up before taking on a study. Such scenarios are taken to be a combination of vessel, port or navigable channel layout and environmental condition (wind, waves, current, tide level, etc.). Planning this prior process is extremely important, especially if a real time simulator is used, because of several factors:

- The cost of the facility is very high.
- Personnel costs are also major, as the coordinated action of a team of engineers, pilots or captains and IT specialists is required.
- Several repetitions of the manoeuvring should be made for each environment, vessel and type of manoeuvring with the purpose of obtaining a statistically acceptable sample.
- Use of a simulator takes up long periods of time due to working in real time mode.

Drawing up a manoeuvring study calls for first building a mathematical and graphic model of the area to be studied, in which the following starting information is determined:

Propulsion, steering and manoeuvrability characteristics of the vessel or vessels.

- Bathymetry and water levels.
- Definition of the navigation channel.
- Current field.
- Wind field.
- Wave field.
- Definition of tug-boats.
- Definition (should such be the case) of the autopilot parameters.
- Definition (should such be the case) of the tug-boat controllers.
- Target path (for the autopilot).
- Radar boundary (coast, port, buoys, etc.).
- Graphic information on the port (coast, breakwaters, quays, light-houses, buoys, vessels berthed, etc.) based on drawings, charts, photographs, etc.

Vessel manoeuvrability characteristics expressed by means of a set of hydrodynamic coefficients are determined by testing with a physical channel model and are incorporated as a specific file for each ship. Results are compared with the usual manoeuvrability tests (turning circle, zig-zag manoeuvring, etc.) so that correct reproduction of the vessel's performance is ensured.

9.5. DEVELOPING OF SIMULATED MANOEUVRES

As was stated before, a target path, assumed optimum, is first defined in autopilot models. The deviation (position and course) from this path is assessed whilst the programme is running and the control algorithm selects the suitable engine and rudder orders to correct the error. Some models allow engine and rudder orders to be preselected in sub-stretches or specific points of the path. Once this prior definition has been made, the process is carried out automatically, with no human intervention, in a manner repeated in time. This is why the manoeuvring's duration solely depends on the computer's calculation power. As an indication, a manoeuvre in the order of one hour's real time duration may be performed in a few seconds on a personal computer. Hence the name of accelerated (fast-time) models.

On the other hand, two fundamental characteristics occur in advanced simulators:

- Man-machine interactivity.
- Real time performance

That is to say, man is included in the perception-decision making - communication - execution- verification cycle:

- *Perception* of visual information (vessel's position and speed through the outside image of the port and the radar screen) and instrument information (indicators of engine rpm, rudder angle, course, log, depth finder, wind velocity and direction, etc.).

- *Decision making* from instant information and its comparison with the predefined strategy, which crystalizes into actions on the engine, rudder, auxiliary manoeuvring propeller and tug-boats.

- *Communication* of orders to the rudder and tug-boats, a process which should be performed with the maximum clarity and checking the correct understanding of such orders.

- *Execution* of the orders on the control elements available at the bridge (levers, buttons, etc.) or at the tug-boat panel located in the control room.

- *Verification* of the orders by the oral response of the tug-boat helmsman and/or captain and the physical response of the vessel.

The use of a simulator takes up long periods of time because of real time working. That is to say, the simulated manoeuvring lasts exactly the same as under actual conditions. This is how the perception-evaluation-decision making process takes place under normal conditions.

This cycle is repeated continuously during simulation until the manoeuvring ends. The end of simulation is determined either by the vessel arriving at the quay or area planned under controlled speed, by confirming that the manoeuvring being analysed is impossible to perform or by a collision or grounding with serious consequences. In the event of a minor accident, the manoeuvring continues in most cases, with the purpose of obtaining information on the pilot's action limits.

There are usually at least two people at the bridge during simulation. Each of them plays a preset role in performing the manoeuvring:

- *Pilot:* Handles the vessel during the manoeuvring. He has previously decided on the action strategy and carries it out, giving orders to the helmsman on the use of the engine (ahead-stop-astern and speed), the rudder and the bow thruster. Likewise, communication is established by VHF radio with the tug-boats, laying down how many and in what positions they are to operate and requesting their action during the course of the manoeuvring.

- *Helmsman:* He is purely an executor of the pilot's orders as regards use of the engine and rudder. He is obliged to repeat his orders out loud with the purpose of guaranteeing that they have been correctly understood.

The instructor or controller located off the bridge is added to them. He verifies the operation of the simulator system and performs an auxiliary role in tug-boat operation, communication from a VTS centre, control of other vessels simulated, etc.

Usually between 8 and 15 simulations are carried out under each manoeuvring condition with the purpose of incorporating the randomness of human behaviour into the simulation. This ROM recommends between 12 and 15 simulations for final designs.

The results of each simulation, whether interactive or with an autopilot, are stored in a summary file on the computer disk, where the main variables are sequentially listed: vessel's position, course and speed at each moment in time, actions on the engine and rudder, use of tug-boats, environmental forces, etc. This information allows a detailed analysis of the manoeuvring's performance to be subsequently carried out.

9.6. ANALYSING RESULTS

Simulator operators usually have IT tools available enabling several representations of the simulation results to be obtained.

- *Path display*, on a two dimensional drawing which shows the port's boundary and the vessel's position at preset time intervals. See figure 9.04.

- *Tables of instant values* of different variables (time elapsed, distance travelled, rudder deflection angle and speed, engine rpm, vessel speed components, tug-boat forces, etc.) throughout simulation.

- *Time series displays* of the foregoing variables. Several series for different simulations may be superimposed. See figure 9.05.

- *Statistical displays of variables*. Grouping together different simulations of one given condition, the mean values and standard deviations of each variable at each point of the vessel's run are drawn. Indications can thus be obtained on the action trends in each area (engine use, vessel speed, etc.).

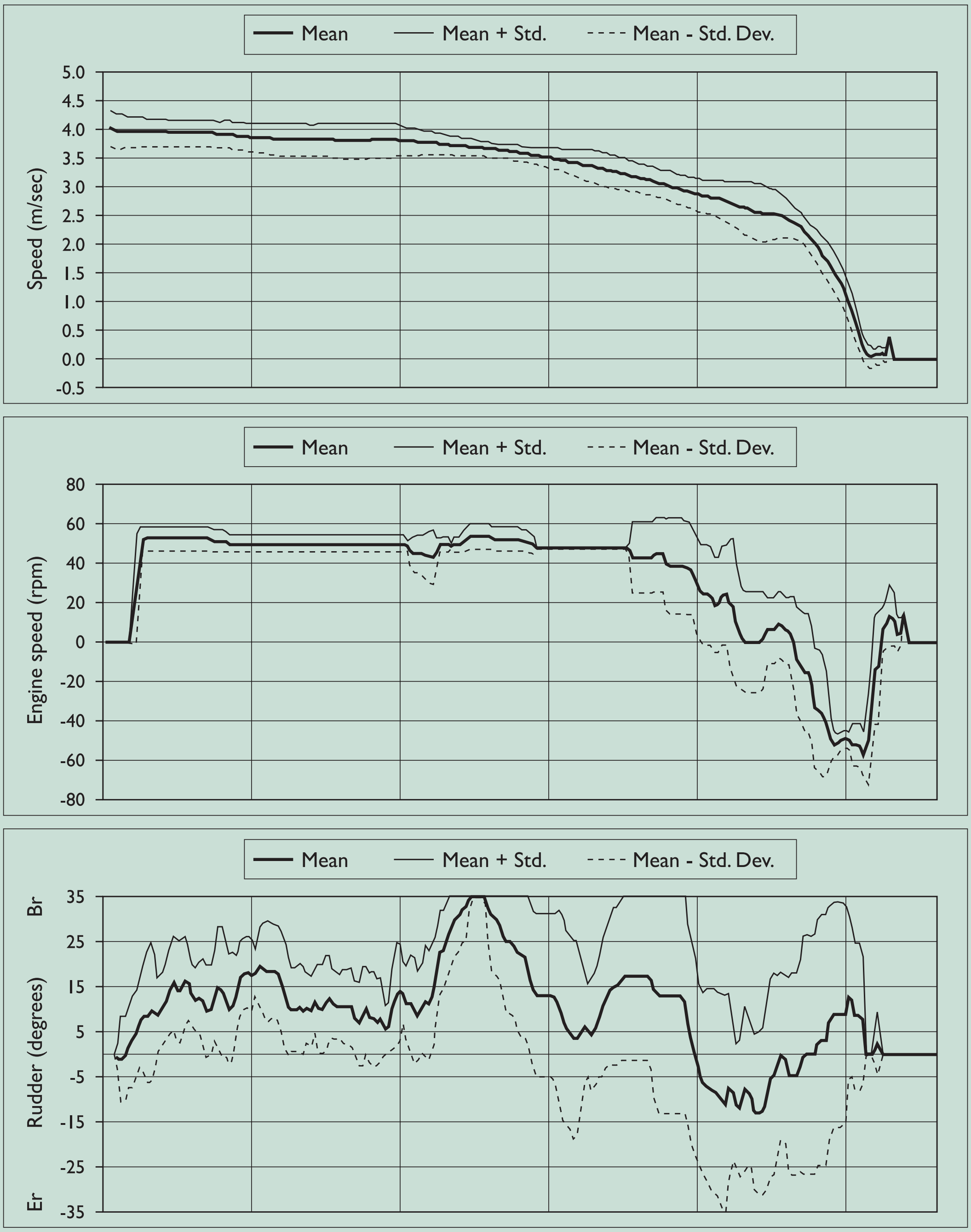
- *Display of the area occupied* by the vessel. A two-dimensional drawing shows the port's boundary and the swept path occupied by the vessel during navigation. There are several variants and the area occupied in a particular simulation and the envelope of several performances of the same condition or even a probabilistic interpretation of the area occupied can be drawn, associating a certain distribution to the borders.

Two types of analysis can be carried out using this information: the first, called «expert rating», refers to each execution in particular, is based on the experience of engineers, captains and pilots and is specified in the rating of specific aspects of the manoeuvring: speed at certain reference points, distances to channel limits, level of use of manoeuvring devices (propulsion and rudder), tug-boat requirements, etc. The appraisal of the pilot handling the manoeuvring obviously has fundamental weight in this rating process.

The manoeuvring's difficulty and the influence of each of the factors involved can be evaluated by examining these variables, and valuable, useful information can be obtained for improving the action strategy. This rating system is generally the only one applicable to autopilot models which do not avail of instructions allowing the human factor to be predefined.

Figure 9.04. **Simulated path display**

Figure 9.05. **Time series graphs (speed, engine rpm, rudder angle)**



It is also possible to carry out a more detailed statistical analysis of the different phases of the manoeuvring should there be a sufficient number of repetitions on an interactive simulator. Both control actions executed during simulation (use of engine, rudder, manoeuvring propellers and/or tug-boats) and the vessel's response (positions and speed, route, obstacle passing distances, etc.) are addressed here.

From the point of view of the semi-probabilistic design method as recommended in this ROM, a study of the vessel occupied area during its run and its interference with the navigable area's limits is very important. Thus, the following aspects can be qualitatively and quantitatively rated:

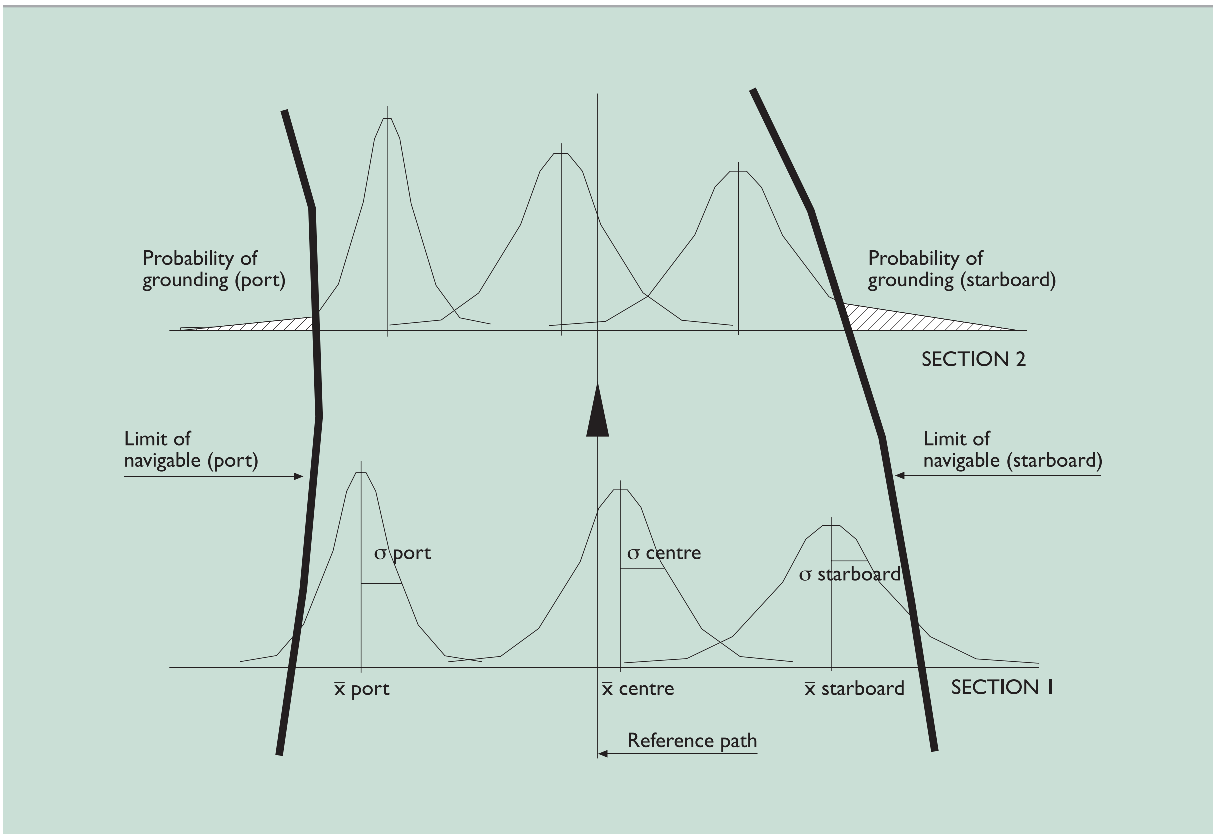
- Which are the path's critical points.
- What is the risk of accident in each area.
- What is the compared difficulty of different entrance, channel or manoeuvring area layouts.
- What influence the environmental conditions have.
- Which are the dimensions resulting in each case.

A reference path on which distances travelled are marked is defined for analysing the area occupied by the vessel during the manoeuvring. Cross sections are set in turn on this path, in each of which the navigable width is defined.

The vessel's successive positions are stored in disk after each manoeuvring simulation. Specifically, the positions of the vessel's port end (bow or stern), of its geometric centre and of the starboard end (bow or stern) are known in each of the foregoing sections. The area occupied by the vessel in its evolution can thus be calculated as the envelope of the different positions of its ends. Once the manoeuvring has been repeated several times under the same conditions, a statistical distribution can be assigned (generally a normal distribution) to the position of these three points which enables the vessel occupied area to be statistically explained.

The probability of collision or invasion in each of the sections may then be calculated by entering with the lateral limits of the navigable area in the successive distributions. The lower tail (on port) or upper tail (on starboard) will give the probability of navigating –in each section considered– outside the safe area and an approximate indication of what the risk areas are and to what extent. See figure 9.06.

Figure 9.06. ***Normal distribution of the vessel's centre and ends positions***

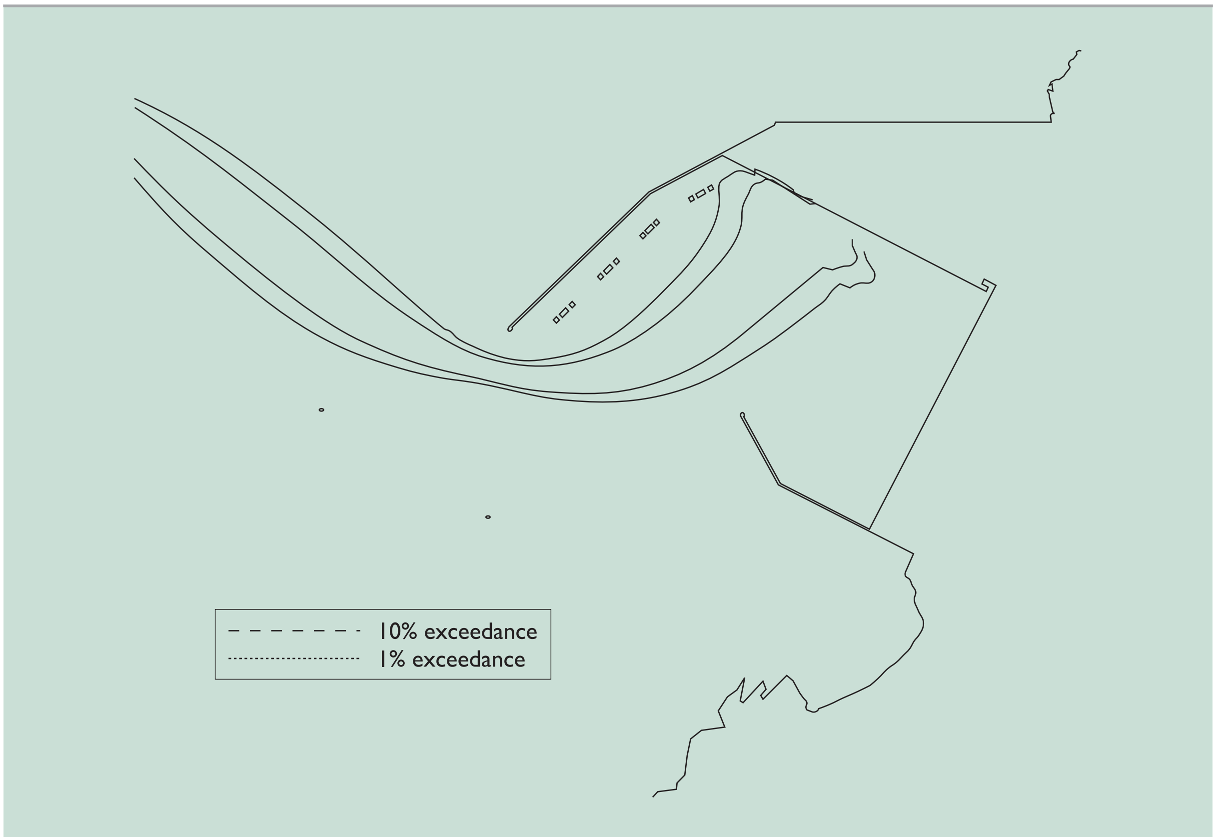


As stated above, several types of result graphs can then be drawn up:

- *Envelopes:* Swept paths obtained as the envelope of all the simulations carried out or removing the most extreme manoeuvring in each section. See figure 9.07.

- Mean vessel path: Line with the mean position of the vessel's centre in each section.

Figure 9.07. ***Diagram of occupied area envelopes***



- *Area occupied with a certain probability of exceedance:* Having set a value for the probability of exceedance, the pertinent border lines of the area occupied can be drawn according to the distribution considered for the vessel's ends. Thus, the 1% area will show the extreme positions of the vessel's sides associated to the 1% probability of exceedance, i.e., 1 vessel out of every 100 will exceed that area's limits when performing the manoeuvring under simulated conditions. See figure 9.08.

- *Confidence bands of exceedance lines:* Curves with the confidence band at the level desired of the foregoing exceedance curve can be made out also based on the distribution considered for the occupied area's borders.

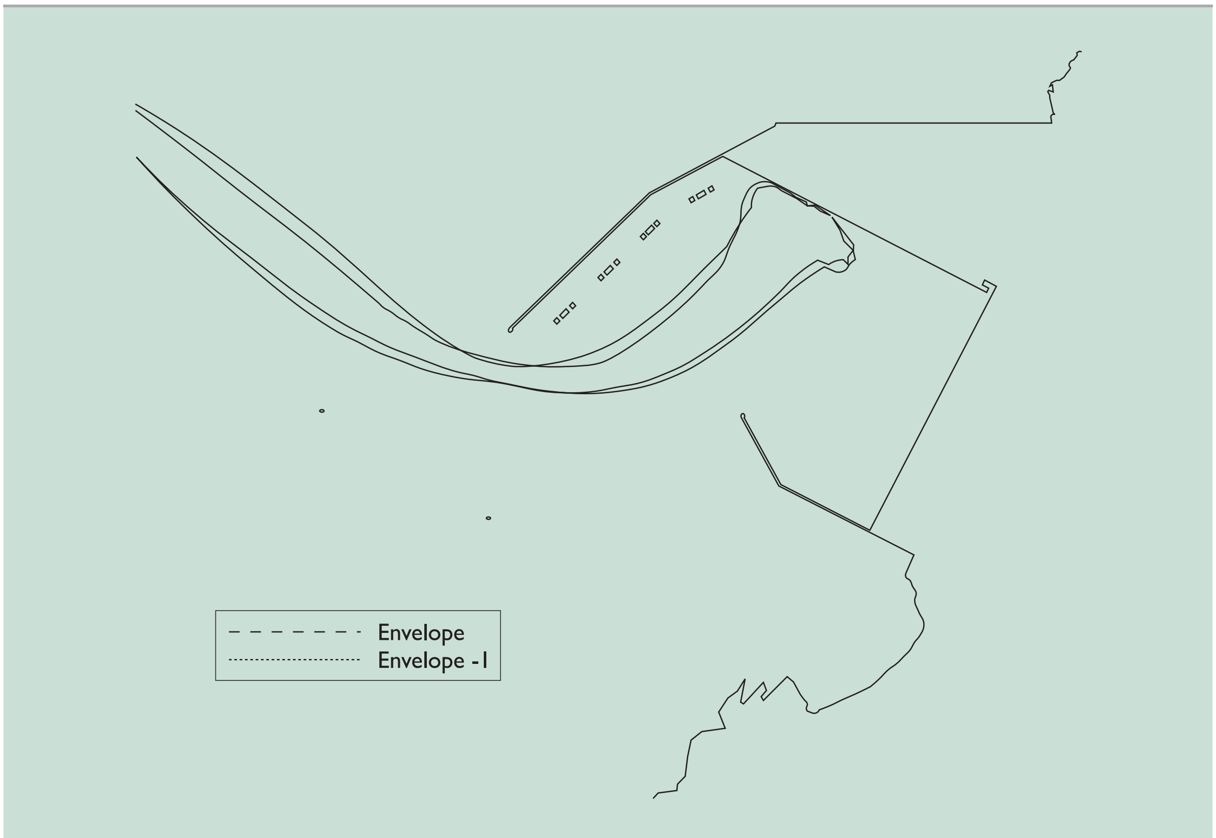
These drawings allow the risk areas in the manoeuvring to be quickly confirmed and the performance with different vessels or under different environmental conditions to be compared.

In any case, it is fundamental to bear in mind a basic statistical principle for interpreting the results presented: the population to be analysed in the study is the number of manoeuvrings possible under defined conditions. A sample has been taken from them, consisting in a limited number of simulated repetitions of each manoeuvring.

The statistical distribution obtained for the sample is not that for the total population but only an estimation of the latter. In other words, all the statistics expounded beforehand (means, deviations, exceedance values, etc.) must not be taken as fixed values but as affected by a certain variability around the mean values estimated.

On increasing the size of the sample (number of simulations), the variability of results is naturally reduced and sample distribution approximates more to that of the population. However, the increase in size of the sample involves a major cost in hours of simulation and, therefore, a balance must be sought between the accuracy of results and the cost of obtaining them.

Figure 9.08. ***Extrapolation of the occupied area***



9.7. ADVANTAGES AND DISADVANTAGES

Applying these tools provides major advantages both for the Port Engineering field and for navigation and pilotage, amongst which the following are worth highlighting:

- They enable design and operating conditions for fairways and manoeuvring areas in ports with a high specificity (topography and bathymetry, meteorological conditions, vessel, established operating procedures, local peculiarities, etc.), to be analysed.

- Autopilot models are determinist as they eliminate the involvement of man during the manoeuvring. This is why this type of simulator is particularly indicated for analysing port structures designs in cases not involving the performance of complete manoeuvring, since it ensures uniform behaviour and enables various design alternatives or manoeuvring performing conditions to be coherently compared.

- Considering they require a moderate calculation capacity, they can be implemented on low cost computers.

- Manoeuvring is performed quickly and, therefore, a large number of simulations can be carried out in a short time. Thus, they enable simple studies to be performed relatively cheaply and quickly.

- The results obtained using mathematical autopilot models are more accurate than those based on empirical rules. In turn, applying an interactive simulator provides information of a greater richness and accuracy.

- The use of an interactive model incorporates the influence of the human factor in undertaking manoeuvring. This analysis is more valuable if the simulator works in real time.

- The concurrence of pilots, captains and port engineers in the design process leads to a much more complete analysis of the problem.

- A detailed set of rules or recommendations for access to the port can be drawn up from the simulation results taking into account the types and dimensions of vessels, environmental conditions and use of tug-boats. In short, port downtime can be more precisely assessed for physical or meteorological reasons.

- A manoeuvring risk analysis can be made based on statistical methods particularly developed for this purpose.

- The use of simulators enables the training of Merchant Marine Officers and Pilots to be speeded up by using a high quality, low cost technical tool compared to using an actual ship.

- A vessel manoeuvring simulator is an enormously useful tool for on-going training of exercising pilots and captains because of its capability of reproducing new, extreme or emergency situations whilst keeping the different parameters under control.

- Simulation systems are fundamentally based on IT equipment in which both the numerical calculation power and the graphic processing systems are highly influential. These are fields which are undergoing a very rapid growth enabling a future of enormous development to be forecast.

The main disadvantage in using fast-time models is their low applicability in complicated manoeuvring where the pilot and tug-boats operate in a major, continuous way. The control algorithms in these cases prove insufficient and their results must be analysed with great reservation.

Applying a simulator in real time for port studies also displays certain negative aspects or disadvantages:

- Simulators are costly pieces of equipment which become obsolete relatively quickly and require heavy investments for acquisition and upgrading.

- They are based on complex technologies, which means availing of a staff of highly specialised people and laying down on-going training methods.

- They need a team of engineers, pilots, captains and IT specialists to act in a coordinated way, which also involves major staff costs.

- The performance of a complete, top quality study generally takes up long periods of time, if it is wished to cover multiple manoeuvring scenarios since a high number of real time repetitions of each manoeuvring are carried out.

- Complex result analysys methods are also required, and this consumes significant IT resources.

- The vessel behaviour model is limited. Some forces which may be relevant, such as anchoring, collision, bank suction or others are lacking in many of those normally used or are not reproduced in sufficient detail.

- To this same effect, hydrodynamic vessel coefficients are necessarily simplified, do not cover all possible situations with enough accuracy and, in addition, are difficult to acquire and develop.

9.8. METHODOLOGY USED IN THE SIMULATOR

9.8.1. Selecting simulation conditions

Good working methodology is indispensable for performing a study based on manoeuvring simulation and will include, amongst other aspects:

- Drawing up a good formulation of the problem with complete compilation of general and local information which will clearly define the study targets.

- Availing of or building a suitable hydrodynamic model of the vessels to be studied.

- Analysing relevant phenomena (current, waves, wind, bank suction, operations with tug-boats, etc.) in the specific case under study.

- Selecting a mathematical environmental climate model suited to these phenomena and sufficiently accurate.

- Analysing important perception factors (visual or instrument references, marking, positioning systems, visibility factors –luminosity, fog, rain, etc.–, estimation of position and speed, sounds, motions, etc.).

- Making a suitable selection of conditions to be simulated, as a function of the foregoing which, with a minimum amount of use made of the system will provide a maximum of useful information.

- Selecting the tool (type of model or simulator) most suited to analysing the specific problem, especially appraising the characteristics of the mathematical manoeuvrability model, the instruments available and, should such be the case, the quality of the visual system.

- Building the synthetic port-vessel-tug boats-environmental condition models with sufficient precision and quality. It is fundamental in this process to maintain strict control of the updated configuration of each of the scenarios, taking into account the high number of parameters involved.

- Deciding the number of pilots who will perform the simulations and their characteristics (whether local, to be more aware of the way work is usually performed in the port in question and keep close to the qualities of those who will really be managing the situation; neutral, in situations requiring particular objectivity; or a combination of both in different study phases).

- Selecting professional people (engineers, captains, pilots, etc.) who will take part in the study.

Laying down an homogeneous action strategy once the model is ready and before carrying out any simulations is fundamental (beginning and end of manoeuvring conditions, intermediate references in their undertaking –passing points, speeds, etc.– manner of using tug-boats, etc.), which will be followed by all participants in the simulation. Should such be the case, modifications or alternatives to that strategy will be mutually agreed.

Now in the simulation phase, the order and rithm in which the manoeuvring will be carried out must be determined. The manoeuvring valid for the study will be addressed after a first phase for familiarization with the different scenarios chosen, from which the simulations made will be discarded. The «learning factor» can thus be eliminated and this stage can be reached with sufficient preparation and free of the bias that accommodation to the vessel and port simulated may give.

Preset sequences (manoeuvring with growing or diminishing difficulty, all manoeuvring performed consecutively under one given condition, etc.) should be avoided in carrying out successive manoeuvrings whilst, on the other hand, seeking to alternate the different conditions in a random way. The quality of the results obtained for each condition will thus be separate to the rest. As a consequence, the different simulations may be sufficiently representative of what can be expected in the real situation.

Another aspect to be appraised is the rithm of simulation. It should naturally be as great as possible in order to use the facility as efficiently as possible and reduce the study performance term but always respecting possible fatigue of those performing the simulation. If this were to happen, the results would also display scattered trends which should be avoided.

9.8.2. Number of simulations per conditions

One of the aspects to be considered is the number of simulations to be performed in each manoeuvring scenario. Naturally, a greater number of manoeuvring repetitions will provide more precise information on the specific limits of each condition, but these must be balanced with the cost of obtaining data (working hours, use of the system, result analysis time, etc.).

A small sample may be enough in those cases where appraising the feasibility and difficulty in performing certain manoeuvring is the target. In this case, a statistical analysis of the results will be unrepresentative and the greatest weight must be given to the interpretation of the captains or pilots involved based, naturally, on their experience.

Moreover, a study oriented to dimensioning channels, entrances or manoeuvring areas or to appraising the risk level calls for a high number of simulations under each condition, if a sufficient degree of precision and reliability is being sought. In the light of some experiences, repeating the manoeuvring in each simulation scenario a minimum 8-10 times is recommended. The benefits deriving from a greater number of simulations (12-15 or more) are obvious, but the cost of performing the study will have to be evaluated in each case. In any case, a critical analysis of the results should be made with the purpose of determining the margins of error in the values obtained. The methodology normally used, in which the lines of exceedance of the area occupied linked to certain levels of probability and their confidence bands are determined, enables the dimensions of the navigable areas and their degree of indetermination to be evaluated.

9.8.3. Exceedance level

A further aspect to be considered involves determining the level of exceedance to be taken as a threshold in analysing the area occupied during simulated manoeuvrings. This process will usually start by establishing an acceptable risk in the fairway linked to a series of conditioning factors which are analysed in part 2 of this ROM. The distributions set there enable the risk level throughout the useful lifetime to be related to the probability of individual failure.

To this effect, the concept of «failure» refers to running outside the banks of the fairway (grounding or collision with lateral structures) or harbour basin being analysed through mere vessel steering problems and not to possible operational failures in the engine, rudder or both, nor errors or breakdowns in tug boat operation. These latter aspects call for different analysis methods.

The criteria as given in Part 2 of this ROM will be used to determine the useful lifetime of the fairway or Harbour Basin, differentiating according to the type of area being analysed and the level of safety required. The influence of three decisive factors in defining the safety of Approache Channels and Harbour Basins can thus be shown:

- *The area's physical characteristics:* The probability of grounding or collision involving damage to the vessel (soft –sandy– seabeds, which reduce the consequences of the incident, or rock, which acts to the contrary. Rigid channel banks –rubble mound slopes or gravity walls– or deformable –natural, soft material, etc.– is appraised at this point.

- *Type of traffic:* This may have a drastic influence on the consequences deriving from an accident (polluting, flammable or hazardous products which would cause spills, leaks, fires or explosions; passengers, who comprise a special sensitive type of traffic, etc.).

- *The fairway's surroundings:* Inhabited areas, facilities in industrial areas or areas with an outstanding environmental value in the vicinity of the navigation area which might suffer the consequences of a possible accident must be addressed here, as must their effect in relation to the rest of the port traffic (closure because of a blocked channel or narrow entrance through a grounded or sunken vessel, etc.).

Once the useful lifetime has been determined, the total number of manoeuvrings to be undertaken will be given by the frequency of design condition vessels accessing the port. This will be obtained from real traffic statistics or traffic estimates, depending on the cases involved, which should be provided by the Port Authority, concessionaire or operator accordingly.

The acceptable risk level is defined as the probability of at least one failure occurring throughout the period of use of the area under consideration. A damage risk can be distinguished from a total loss risk also according to the criteria given in Part 2 of this ROM. The first situation would be the most comparable in the event of grounding or collision in low speed manoeuvring or in areas with soft banks where it is unlikely that the vessel will suffer severe damage.

Consequently, once the acceptable risk level, the useful lifetime and frequency of traffic which may be expected under a certain scenario of environmental conditions, which produces a number of manoeuvrings performed in such scenario, have been determined, the probability of exceedance of the banks of the fairway or area being considered in an individual manoeuvring can be determined.

It is difficult and costly to carry out a complete analysis of the risk level. A series of scenarios, which are combinations of the following variables, should be established:

◆ Environmental conditions:	Waves (directions, periods, heights) Wind (direction, speed) Tide (water level, resulting currents)
◆ Visibility:	Day-night Fog
◆ Vessel:	Type Dimensions Cargo condition

which represent the local manoeuvring conditions in a global manner. This will be done for the different definition alternatives:

◆ Port:	Plan layout Depth of water Aids to navigation (marking, leading lights, traffic control).
◆ Operating rules:	Use of tug-boats Minimum depth of water Concurrent traffic, etc.

In general, the number of scenarios must be limited by selecting those most representative because of the combination of their frequency and severity.

Thus, once the probability of an accident has been calculated from the results of simulations in each individual situation, the total risk during the area's useful life may be appraised with the procedures as given in Part 2 of this ROM. This procedure will not lead to a complete, precise risk evaluation but to a useful estimate made on the side of safety and, particularly, to the effects of comparison.

9.8.4. Statistical distribution of the occupied area´s borders

The most usual result analysis methods consider the different passage sections of the fairway as separate from each other and their aim is to define the individual distributions on the starboard and port sides which delimit the width of the area occupied. A normal distribution is most used, adjusted in each calculation section from the mean and the deviation of the distances to the fairway's axis or to its border. This is a manageable but symmetric distribution which does not exactly fit in with the concept being analysed. In view of the pilot's or captain's presence and as a consequence of their control actions, it is natural to expect that there is a greater tendency to go towards the centre of the channel than towards the borders, avoiding risk situations, and, therefore, they should be considered as distributions with lesser symmetry. Secondly, the designer's interest lies in evaluating the position of the extreme values, linked to reduced probabilities of exceedance.

This is why it may be of interest to work with another type of distribution: the three parameter Weibull distribution, allows for better quality of simulated data adjustment, which produces more reliable results. In addition, as it is not symmetric, it better approximates the problem to be described. In general, it results in somewhat more strict calculation widths. Both Rayleigh's and Gumbel's distribution also give good results.

More complex formulations are handled in certain cases (Pearson type III, for example) or the deviation with respect to a Gaussian distribution is measured by estimating the bias or kurtosis.

However, it is advisable to analyse each case in detail, since the manoeuvring's particular conditions will impose restrictions on the pilot's actions, naturally affecting the statistical sample.

9.8.5. Other calculation methods

There are other methods based on a different approach, which presuppose the interdependence of successive passage sections. The aim of the analysis is to build a model relating the passing point through a section (distance to the edge of the fairway) with that corresponding to the previous section or sections, based on the results of the different simulations. This approach to the problem does not presuppose how the passing points are distributed but tries to work out the pilot's action parameters and vessel's response capacity under the environmental conditioning factors and manoeuvring resources available. With y_{xi} being the distance to the edge in the channel's x section obtained in the simulation i, a linear regression model:

$$Y_x = A_a + B_a \times y_{x-1} + Z_x$$

a square regression model:

$$Y_x = A_a + B_a \times y_{x-1} + C_a \times y_{x-1} + Z_x$$

or even an auto-regressive model (AR):

$$Y_x = A_a + B_a \times y_{x-1} + C_a \times y_{x-1} - B_a \times C_a \times Y_{x-1,\, i-1} + Z_{x,i}$$

may be established.

The A_a, B_a, C_a parameters are obtained with a least square adjustment and Z_x is a random variable normally distributed according to the adjustment's mean square error.

The adjustment's parameters will be determined by the pilot's actions and the vessel's effective response under the manoeuvring's performance conditions. The usual thing is for them to respond to several action principles: when the vessel is in the centre of the fairway, control actions are not very intense and points (y_x, y_{x-1}) will show great dispersion. When approaching the edge of the fairway in a section, the desirable thing is to correct the passing point in the next one, i.e., $y_{x-1} > y_x$, or, in other words, $B_a < 1$ in the linear regression model, with less dispersion of the data. If the vessel has arrived to the vicinity of the fairway's edge in a section, it must have corrected this situation in the next one, or else it will exceed the navigable area's limits, which means $A_a > 0$ (linear model). Finally, control actions are naturally more intense the closer the ship is to the fairway's edge, which explains the convenience of using quadratic formulations with $C_a > 0$ in some cases.

The action methodology in this case consists of three phases: Firstly, interactive simulations are carried out, which will be the basis for subsequent calculations; then, adjustments are made and parameters are calculated in each of the sections, with which the «conduct» of the pilot-vessel system is defined. Finally, a high number of manoeuvrings performed under these conditioning factors are numerically simulated, usually by the Montecarlo method, which enables the risk in each situation and the critical points to be evaluated.

The fundamental limitation of these methods is their need to perform a larger number of real time simulations. Since the definition of behaviour at the fairway's edges is what is being sought, data effectively located near the banks must be available. The large majority of simulated manoeuvrings will normally have a successful end, with vessel positions near the axis, which is why, on the one hand, there will be few interesting data but, in addition, a high number of scattered data will alter the quality of the adjustment at the edges.

Further advanced methodology is based on using Markov chains to describe not only the passing point in a section but also the trend of the motion (towards the axis or towards the edge). A series of cells or «lanes» in each cross section is usually defined and the «lane» occupied and the relation with the «lane» for the previous section (centrifugal, stationary or centripetal) is recorded in each simulation. If a statistical model is built suitably describing these parameters, the probability of a failure will obviously correspond to the probability of being in a «lane» outside the fairway with a centrifugal trend. This methodology still calls for major development work and, in addition, is very costly, as it involves a large number of simulations.