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Maritime works –

Part 1-1: General – Code of practice for planning and design for operations

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 110, an inside back cover and a back cover.

Foreword

Publishing information

This part of BS 6349 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 September 2013. It was prepared by Technical Committee CB/502, *Maritime works*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

Together with BS 6349-1-2, BS 6349-1-3 and BS 6349-1-4, this part of BS 6349 supersedes BS 6349-1:2000, which will be withdrawn when all four of the new subparts have been published.

Relationship with other publications

BS 6349 is published in the following parts [1)]:

- Part 1-1: *General – Code of practice for planning and design for operations*;
- Part 1-2: *General – Code of practice for assessment of actions*; [2)]
- Part 1-3: *General – Code of practice for geotechnical design*;
- Part 1-4: *General – Code of practice for materials*;
- Part 2: *Code of practice for the design of quay walls, jetties and dolphins*;
- Part 3: *Design of dry docks, locks, slipways and shipbuilding berths, shiplifts and dock and lock gates*;
- Part 4: *Code of practice for design of fendering and mooring systems*;
- Part 5: *Code of practice for dredging and land reclamation*;
- Part 6: *Design of inshore moorings and floating structures*;
- Part 7: *Guide to the design and construction of breakwaters*;
- Part 8: *Code of practice for the design of Ro-Ro ramps, linkspans and walkways*.

Information about this document

A full revision of BS 6349-1:2000 has been undertaken and the principal change is to split the document into four smaller parts:

- BS 6349-1-1: *Code of practice for planning and design for operations*;
- BS 6349-1-2: *Code of practice for assessment of actions*;
- BS 6349-1-3: *Code of practice for geotechnical design*;
- BS 6349-1-4: *Code of practice for materials*.

The principal changes in respect of the planning and design content are:

- reduction of informative content, with informative guidance separated from recommendations;
- general updating of reference documents to reflect latest practice;

1) A new part 9, covering port surfacing, is in preparation.
2) In preparation.

- normative referencing of specific PIANC documents;
- general updating in respect of survey and data acquisition methods in line with latest technical developments of best practice, including the adoption of IHO Standards for Hydrographic Surveys for navigation;
- increased emphasis on environmental, safety and operational matters in planning and design;
- updating of recommendations and guidance on use of physical and numerical modelling and in ship simulation for design purposes in line with latest practice;
- inclusion of additional information on key ship dimensions for preliminary design and planning.

Use of this document

As a code of practice, this part of BS 6349 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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Section 1: General

1 Scope

This part of BS 6349 gives recommendations and guidance on general criteria relevant to the planning, design, construction and maintenance of structures and facilities set in the maritime environment. It also gives recommendations and guidance in respect of environmental and operational matters that need to be considered in planning and design of maritime works.

It includes a description of the various physical environmental conditions that need to be considered for investigation at a coastal site, and gives information and guidance on methods of survey and data collection.

It is applicable to coastal, nearshore, estuarine and inland marine facilities for safe navigation, berthing, mooring, loading, unloading and servicing of ships, barges and other forms of waterborne transport and the associated infrastructure, equipment and works at the ship-shore interface. It is also applicable to other civil infrastructure works at the waterfront or coastal margin such as dredging, reclamation, shoreline and coastal management works and to recreational infrastructure such as marinas.

This part of BS 6349 does not cover offshore structures for the petroleum and natural gas industries, which are specified in BS EN ISO 19900 and BS EN ISO 19901.

It does not cover recommendations for ground investigation, which are given in BS 6349-1-3.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

BS 6349-1:2000, *Maritime structures – Part 1: Code of practice for general criteria*

BS 6349-1-3, *Maritime works – Part 1-3: General – Code of practice for geotechnical design*

BS 6349-4, *Maritime structures – Part 4: Code of practice for design of fendering and mooring systems*

BS 6349-8, *Maritime structures – Part 8: Code of practice for the design of Ro-Ro ramps, linkspans and walkways*

BS EN 1990, *Eurocode – Basis of structural design* [3)]

BS EN ISO 14001, *Environmental management systems – Requirements with guidance for use*

Other publications

[N1] INTERNATIONAL HYDROGRAPHIC ORGANISATION. *IHO standards for hydrographic surveys*. Special Publication No. 44. Fifth edition. Monaco: International Hydrographic Bureau, 2008.

[3)] This part of BS 6349 also gives an informative reference to BS EN 1990:2002+A1:2005.

[N2]LOWE, J. A., HOWARD, T. P., PARDAENS, A., TINKER, J., HOLT, J., WAKELIN, S., MILNE, G., LEAKE, J., WOLF, J., HORSBURGH, K., REEDER, T., JENKINS, G., RIDLEY, J., DYE, S., and BRADLEY, S. *UK Climate Projections science report: Marine and coastal projections*. UKCP09. Exeter: Met Office Hadley Centre, 2009.

[N3]ICS, OCIMF and IAPH. *International oil tanker and terminal safety guide (ISGOTT).* Fifth edition. Livingston: Witherby Seamanship International Ltd., 2006.

[N4]PIANC. *Safety aspects affecting the berthing operations of tankers to oil and gas terminals*. MarCom Report WG116. Brussels: PIANC, 2012.

[N5]INTERNATIONAL MARITIME ORGANISATION. *International ship and port facility security code (ISPS code)*. London: IMO, 2003.

[N6]PIANC-IAPH. *Approach channels – A guide for design*. Final report of the joint Working Group PIANC and IAPH in cooperation with IMPA and IALA. PTC II Report WG30. Brussels: PIANC, 1997. [4)]

[N7]INTERNATIONAL ASSOCIATION OF MARINE AIDS TO NAVIGATION AND LIGHTHOUSE AUTHORITIES (IALA-AISM). *Vessel traffic services manual*. Fourth edition. St Germain-en-laye: IALA, 2008. [5)]

[N8]OIL COMPANIES INTERNATIONAL MARINE FORUM. *Mooring equipment guidelines*. Third edition (MEG3). London: OCIMF, 2007.

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this part of BS 6349, the terms and definitions given in BS EN 1990 and the following apply.

NOTE Where possible, definitions of meteorological and oceanographic terms are harmonized with BS EN ISO 19901, although some modifications are made to reflect the particular characteristics of the coastal environment within the scope of this part of BS 6349.

3.1.1 accidental operating condition

condition for a design situation when a facility is considered to be in operational use by ships berthing, de-berthing or in a moored condition consistent with the operating limits for the facility, but exceptional conditions occur due to deviation from facility operational procedures, or equipment malfunction

3.1.2 asset lifecycle

whole life of the maritime works, structure or facilities from inception to decommissioning

3.1.3 chart datum

local reference datum used to define water depths on a navigation chart or tidal heights over an area

NOTE Chart datum is usually an approximation to the level of the lowest astronomical tide.

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4) This document will be superseded by PIANC-IAPH. *Harbour approach channels – design guidelines*. PIANC Report No. 121. Brussels: PIANC, 2013, due to be published in late 2013.

5) Available at www.iala-aism.org [last accessed 23 September 2013].

3.1.4 concept design

design and engineering of the maritime works and preliminary planning for execution, in which site-specific data acquisition requirements are established and acquisition commences, and the level of definition is sufficient to select preferred technical options as the basis for detailed design

3.1.5 currents

3.1.5.1 residual current

part of the total current that is not constituted from harmonic tidal components

NOTE Residual currents are caused by a variety of physical mechanisms including river flows and wind effects. They comprise a large range of natural frequencies and magnitudes in different parts of the world.

3.1.5.2 tidal current

part of the total current that is driven by tidal forcing (i.e. the tidal stream)

3.1.5.3 total current

total observed current including all components from tides, waves, wind or other effects giving rise to currents at a location

3.1.6 deadweight tonnage (DWT)

total mass of cargo, stores, fuels, crew and reserves with which a vessel is laden when submerged to the summer loading line

NOTE Although this represents the load-carrying capacity of the vessel, it is not an exact measure of the cargo load.

3.1.7 design stage operating limits (DSOL)

preliminary assessment of environmental operating limits established and developed in the planning and design stages for the purposes of design of berths, channels, turning areas and other such works, and for making design-stage estimates of weather downtime

3.1.8 design working life

assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary

[SOURCE: BS EN 1990:2002+A1:2005, **1.5.2.8**]

3.1.9 detailed design

design and engineering of maritime works including site-specific data acquisition and detailed planning for execution, in which the level of definition is sufficient for construction

NOTE In some industries, including the oil, gas and petrochemical industries, this phase can commence with front end engineering design (FEED) with detailed engineering completed within an engineering, procurement and construction (EPC) contract.

3.1.10 diffraction

<of waves> bending, spreading and interference of waves when they pass by an obstruction (e.g. a breakwater) or through a gap (e.g. a harbour entrance)

3.1.11 displacement

total mass of the vessel and its contents

NOTE This is equal to the volume of water displaced by the vessel multiplied by the density of the water.

3.1.12 environmental operating limits
limiting values of metocean or other environmental parameters, including wind, wave, swell, current velocity, tidal elevation, visibility and temperature, beyond which certain operations are not permitted to be carried out as set out in the facility operating manual

3.1.13 execution
activities required to construct and install maritime works, including off-site fabrication and commissioning when necessary so that the completed works are ready for handover to the owner and operator

3.1.14 extreme high water
highest level that is predicted to occur at a location as a combination of astronomical tides, positive or negative storm surges, seiches and river flow for an extreme event of a defined return period

3.1.15 extreme low water
lowest level that is predicted to occur at a location as a combination of astronomical tides, positive or negative storm surges, seiches and river flow for an extreme event of a defined return period

3.1.16 extreme operating condition
condition for a design situation when a facility is subject to extreme environmental conditions exceeding the DSOL (**3.1.7**) whether or not in use by ships for berthing, de-berthing, or mooring

NOTE Extreme operating conditions might include extreme environmental conditions of different return periods. Typically for permanent structures this could be events of 50-year to 100-year return periods considered as persistent design situations when designing to BS EN 1990, and events of 500 years to 1 000 years considered as accidental design situations when designing structures of a certain consequence class to BS EN 1990.

3.1.17 facility operating manual
procedures and instructions established by an operator to define procedures, environmental operating limits and other such matters to ensure safe and efficient operation of the maritime works and facilities in the operation and maintenance phase

3.1.18 gross tonnage (GT)
non-dimensional index representing the overall size of a ship

NOTE Gross tonnage is different to gross register tonnage (GRT), which is an obsolete measure of the gross internal volumetric capacity of the vessel as defined by the rules of the registering authority and measured in units of 2.83 m^3 (100 ft^3).

3.1.19 gust
brief rise and fall in wind speed lasting less than 1 min

3.1.20 infragravity wave
long period wave as bound wave associated with wave grouping of swell travelling over long distances, or as free wave propagating independently after interaction of bound wave with shallow coastlines

NOTE Wave energy in the periods range 25 s to 500 s can generally be classified as infragravity wave energy. Waves of periods longer than 500 s are likely to be associated with tsunamis and tides.

3.1.21 marine facility
facility required to receive ships at a coastal marine terminal, within or outside a protected port or offshore, including but not limited to fixed berths, jetties, piers, island berths, buoy mooring facilities and liquid cargo transfer structures

3.1.22 marine growth
living organisms attached to a structure

3.1.23 maritime authority
government or non-government organization that can be consulted in the planning and design of maritime works in connection with establishing available data on such matters as: existing physical conditions; existing operational and activities in the coastal zone; safety of navigation; and safety of the public in the coastal zone

NOTE Examples of some typical organizations with statutory or other roles in coastal activities in the United Kingdom are given in Annex A. For port and shipping operations and navigation this could include the port, harbour and pilotage authorities.

3.1.24 mean low water springs (MLWS)
average, over a long period of time, of the heights of two successive low waters at springs

3.1.25 mean sea level
average of all sea levels measured at hourly intervals over a complete astronomical tidal cycle of 18.6 years

NOTE Seasonal and inter-annual changes in mean sea level can be expected in some regions, and over many years the mean sea level can change.

3.1.26 mean wind speed
time-averaged wind speed, averaged over a specified time interval and at a specific elevation

NOTE The mean wind speed varies with elevation above mean sea level and the averaging time interval; a standard reference elevation is 10 m and a standard time interval is 1 h.

3.1.27 metocean parameters
meteorological and oceanographic design and operating parameters including wind, precipitation, atmospheric conditions, solar radiation, water levels, waves, water movements, sea ice and icebergs, water quality and physical and chemical properties and marine growth

3.1.28 nautical bottom
level where physical characteristics of the bottom of a navigation channel or ship manoeuvring area reach a critical limit beyond which contact with a ship's keel causes either damage or unacceptable effects on controllability and manoeuvrability

3.1.29 nautical depth
instantaneous and local vertical distance between the nautical bottom and the undisturbed free water surface

3.1.30 normal operating condition
condition for a design situation when a facility is considered to be in operational use by ships berthing, de-berthing or in a moored condition consistent with the DSOL (**3.1.7**) for the facility

3.1.31 operation and maintenance

service usage of the completed maritime works by user, operator or owner, including planned and unplanned inspection, maintenance and repairs

NOTE Some works, such as ports and berthing structures, are usually actively operated by a harbour authority or terminal operator, whereas other works such as coastal protection structures might not be actively operated but are likely to be actively monitored and maintained.

3.1.32 operator

harbour authority, port operator, terminal operator or other such competent entity responsible for operating and maintaining a marine facility for use by vessels

3.1.33 planning phase

period of time when functional and operational requirements are defined sufficient to commence design, existing data and knowledge sources are researched and feasibility studies may be initiated

3.1.34 polar low

intense depression that forms in polar air, often near a boundary between ice and sea

3.1.35 reflection

<of waves> situation that occurs when waves reach an obstacle, e.g. a sea wall or a breakwater

NOTE Waves also reflect off beaches and at locations with sharp depth changes.

3.1.36 refraction

<of waves> bending of the wave propagation direction due to variations in the water depth under the waves

NOTE The part of a wave in shallow water moves slower than the part of a wave in deeper water, so when the depth under a wave crest varies along the crest, the wave bends.

3.1.37 return period

average period between occurrences of an event or of a particular value being exceeded

NOTE The return period in years is equal to the reciprocal of the annual probability of exceedance of the event.

3.1.38 scatter diagram

graphic representation of the joint probability of two or more (metocean) parameters

NOTE Typically used with wave parameters to show the probability of the joint occurrence of the significant wave height (H_s) and a representative period (T_z or T_p).

3.1.39 sea state

condition of the sea during a period in which its statistics remain approximately constant

NOTE In a statistical sense the sea state does not change markedly within the period. The period during which this condition exists is usually assumed to be 3 h, although it depends on the particular weather situation at any given time.

3.1.40 seiche
oscillation of a body of water at its natural period

NOTE Seiches usually take the form of standing waves or sloshing/oscillations of the free surface. These oscillations can have periods from minutes in harbours and bays to over 10 h in large lakes.

3.1.41 ship
class of sea-going and coastal vessels including general cargo ships, container ships, tankers and gas and liquid product carriers, cruise ships, Ro-Ro ships, bulk carriers

3.1.42 shoaling
<of waves> transformation of waves caused by change in depth alone as they enter shallower water

NOTE Shoaling occurs because the wave speed and wave length decrease in shallow water, therefore the energy per unit area of the wave has to increase, resulting in an increase in the wave height. The wave period remains the same in shoaling. Other shallow water transformation effects such as refraction arise separately from shoaling.

3.1.43 significant wave height
average height of the highest one third of the zero upcrossing waves in a sea state

NOTE In most measurement systems the significant wave height is calculated as $4\sqrt{m_0}$, where m_0 is the zeroth spectral moment, or 4σ, where σ is the standard deviation of the time series of water surface elevation over the duration of the measurement, typically approximately 30 min.

3.1.44 soliton
gravity wave which oscillates within the body of a fluid propagating on the interface between two fluids of different density

NOTE 1 Typically offshore in deep ocean conditions they propagate along the thermocline and are driven by tidal forcing interacting with a bathymetric feature.

NOTE 2 Solitons are also known as "internal waves".

3.1.45 spectral peak wave period
period of the maximum (peak) energy density in the spectrum

NOTE In practice, where there is more than one peak in a spectrum, the highest peak is taken.

3.1.46 squall
strong wind event characterized by a sudden onset

NOTE Squall durations are typically in the order of minutes rather than hours and are often accompanied by a change in wind direction, a drop in air temperature and by heavy precipitation. To be classed as a squall, the wind speed would typically be greater than about 8 m/s and last longer than 2 min (to differentiate it from a gust).

3.1.47 squat
steady downward displacement of a moving vessel consisting of a translation and rotation due to the flow of water past the moving hull

3.1.48 still water level
theoretical instantaneous water surface level in the absence of any wave and wind effects

NOTE 1 Still water level is typically used for the calculation of wave kinematics for global actions and wave crest elevation for minimum deck elevations.

NOTE 2 Still water level is an abstract concept for engineering purposes calculated by adding the effects of tides, storm surge and allowances for future sea level change but excluding variations due to waves to the mean sea level. It can be above or below mean sea level.

3.1.49 storm surge

change in sea level (either positive or negative) that is due to meteorological (rather than tidal) forcing

NOTE 1 Storm surges can occur on the open coast, on bays and on estuaries due to the action of wind stresses on the water surface, the atmospheric pressure reduction, storm-induced seiches, wave set-up and other causes.

NOTE 2 The term "surge" is also used in a different context to describe the longitudinal motion of a moored vessel.

3.1.50 swell

sea state in which waves generated by winds remote from the site have travelled to the site, rather than being locally generated

NOTE When categorizing wave types from a spectrum or from measurements, energy in the period range from 8 s to 25 s can be described as swell. Energy at periods longer than 25 s can be described as infragravity wave energy.

3.1.51 tides

3.1.51.1 astronomical tide

phenomenon of the alternate rising and falling of sea surface solely governed by the astronomical conditions of the sun and the moon, which is predicted with the tidal components determined from harmonic analysis of tide level readings over a long period

3.1.51.2 lowest astronomical tide (LAT)

level of low tide when all harmonic components causing the tides are in phase

NOTE The harmonic components are in phase approximately once every 18.6 years but a level equivalent to LAT is approached several times each year at most locations. LAT does not represent the lowest sea level which can be reached, because negative surges and tsunamis can cause considerably lower levels to occur. LAT is often the level selected as the chart datum for soundings on navigational charts.

3.1.51.3 neap tides

two occasions in a lunar month when the average range of two successive tides is least

3.1.51.4 spring tides

two occasions in a lunar month when the average range of two successive tides is greatest

3.1.52 tropical cyclone

closed atmospheric or oceanic circulation around a zone of low pressure that originates over the tropical oceans

NOTE 1 The circulation is counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere. At maturity, the tropical cyclone can be one of the most intense storms in the world, with wind speeds exceeding 90 m/s and accompanied by torrential rain.

NOTE 2 Tropical cyclones are typically referred to as hurricanes in the Gulf of Mexico and North Atlantic, typhoons in the South China Sea and NW Pacific, and cyclones in the South Pacific and South Indian Ocean.

3.1.53 tsunami

long period sea waves caused by rapid vertical movements of the sea floor due to earthquakes, or by submarine or coastal landslip

3.1.54 wave height

height of a wave crest above the preceding wave trough

3.1.55 wave length

distance between consecutive wave crests

3.1.56 wave period

time for two successive wave crests to pass a fixed point

3.1.57 wave spectrum

measure of the amount of energy associated with the fluctuation of the sea surface elevation per unit frequency band and per unit directional sector

NOTE 1 The wave frequency spectrum (integrated over all directions) is often described by use of some parametric form such as the Pierson-Moskowitz or JONSWAP wave spectrum.

NOTE 2 The area under the wave spectrum is the zeroth spectral moment m_0, which is a measure of the total energy in the sea state and used to calculate significant wave height.

3.1.58 weather downtime

period during which a berth is not available for berthing, mooring and cargo transfer operations as a result of adverse weather conditions, sea state, tide, currents or visibility exceeding the defined operating limits

3.1.59 vessel

craft that travels on water, including coastal and sea-going ships, inland and sea-going barges, workboats, tugs, ferries, trawlers and fishing vessels, small recreational or pleasure craft

NOTE Small vessels are considered as those of less than 24 m load line length.

3.2 Symbols

B	beam of vessel (m)
C_b	block coefficient of a vessel
D	characteristic length scale of a system
D_{z0}	median size of graded sediment (mm)
d	draught of a vessel (m)
F_r	Froude number
g	acceleration due to gravity (m/s^2)
H_s	significant wave height (m)
L_{BP}	length of hull between perpendiculars (m)
M_D	displacement of a vessel (t)
m_0	zeroth spectral moment
n	dimensionless parameter in the relationship between a vessel's DWT and its approximate displacement
q_s	suspended volumetric sediment transport rate (m^3/s/m)
T_p	period at which peak occurs in wave spectrum (s)

T_{surge}	period of vessel surge motion
T_z	zero-crossing period of primary waves (s)
t	interval over which mean wind speed is averaged (s)
$U(t)$	mean wind speed averaged over an interval of t s (m/s)
U_{3600}	mean wind speed averaged over an interval of 1 h (m/s)
u	characteristic velocity of a system (m/s)
W_{BM}	width of basic manoeuvring lane (m)
$W_{Br/Bg}$	additional channel width for bank clearance (where "r" and "g" indicate red and green channel sides) (m)
W_i	additional widths to the basic manoeuvring lane required to form the total manoeuvring lane width (m)
W_M	width of manoeuvring lane (m)
W_p	passing distance for two-way channels (m)
γ	ratio of the density of sea water to water density in the model
λ	geometric scale of a physical model
ρ_w	density of sea water (t/m^3)
σ	standard deviation of the time series of water surface elevation

3.3 Abbreviations

For the purposes of this part of BS 6349, the following abbreviations apply.

ADCP	acoustic Doppler current profiler
DSOL	design stage operating limits
DWT	deadweight tonnage
EMS	environmental management system
GPS	global positioning system
GRT	gross register tonnage
GT	gross tonnage
HAZID	hazard identification study
IFD	intensity, frequency and duration
LAT	lowest astronomical tide
LiDAR	light detection and ranging
LNG	liquefied natural gas
Lo-Lo	lift-on, lift-off
LPG	liquefied petroleum gas
MBES	multi-beam echo sounder
MLWS	mean low water springs
MM	manoeuvrability margin
RCM	recording current meter
Ro-Ro	roll-on, roll-off
RTK	real-time kinematic
SBES	single-beam echo sounder

SMP	shoreline management plan
SMS	safety management system
TEU	twenty-foot equivalent unit
UKC	under-keel clearance
VLCC	very large crude carrier

Section 2: The maritime environment

*COMMENTARY ON SECTION **2***

*A fundamental prerequisite to designing maritime works is the understanding and assessment of the physical environment in which the works are situated and the naturally occurring conditions and events to which the works are exposed. Clause **5** to Clause **12** provide recommendations for survey and data collection to characterize site physical and environmental conditions. Recommendations in respect of site investigations for geotechnical design are given in BS 6349-1-3.*

Information concerning these phenomena might already be available from existing sources, although such data can often be limited in scope and application, and further detailed investigations are frequently required to permit the selection of design parameters.

The scope of surveys and data collection for design and planning is also likely to be relevant to the definition of baseline conditions for environmental assessment. However, the full scope of environmental baseline data collection, including surveys of marine ecology, is outside the scope of this part of BS 6349.

The recommendations in this section are primarily focused on the obtaining of data for the planning and design stages, although they are also relevant to execution, operation and maintenance.

Environmental conditions need to be taken into account at all stages of construction, as well as for the completed structure for operations. During construction, maritime works are particularly sensitive to adverse weather conditions, which can hinder access to the works, prevent the use of floating plant and cause damage to work both above and below high water level. Weather conditions can limit construction activity to certain seasons or "windows" and can affect various transient load conditions such as towing, sinking and grounding of floating elements.

4 Environmental considerations

The environmental impact of the construction, operation, maintenance and commissioning of maritime structures should be assessed. The extent of the assessment depends on the magnitude of the works, and a scoping assessment should be carried out to identify environmental impacts that are significant for the works and those that are not. An environmental management system (EMS) in accordance with BS EN ISO 14001 or an equivalent system should be used to manage the environmental aspects of the works, and the system should be designed to:

- take into account the output from a formal environmental impact assessment;
- highlight environmental aspects to be considered where a formal environmental impact assessment is not required;
- provide guidance as to when specialist advice is required.

NOTE 1 Maritime works have the potential for significant adverse impacts on both the marine and terrestrial environment.

NOTE 2 The Civil Engineering Environmental Quality Assessment and Awards Scheme (CEEQUAL) (from CEEQUAL Ltd, Classic House, 174–80 Old Street, London EC1V 9BP or www.ceequal.com [6]) is an example of a suitable framework for use in an EMS based on BS EN ISO 14001.

[6] Last accessed 23 September 2013.

NOTE 3 For international development projects and in the absence of more stringent local regulations, the IFC's Environmental, health and safety guidelines for ports, harbours and terminals *[1] (known as the "EHS Guidelines") are technical reference documents with general and industry-specific examples of good international industry practice, as defined in the* Pollution prevention and abatement handbook *[2]. In addition to the general EHS Guidelines, relevant sector-specific guidelines include:*

- *ports, harbours and terminals;*
- *crude oil and petroleum product terminals.*

NOTE 4 The following PIANC Environmental Committee (EnviCom) technical reports provide guidance on environmental aspects relevant to design, construction and operation:

- *Handling and treatment of contaminated dredged material from ports and inland waterways [3];*
- *Management of aquatic disposal of dredged material [4];*
- *Environmental guidelines for aquatic, nearshore and upland confined disposal facilities for contaminated dredged material [5];*
- *Bird habitat management in ports and waterways [6];*
- *Generic biological assessment guidance for dredged material [7];*
- *Environmental risk assessment of dredging and disposal operations [8];*
- *Dredged material as a resource: options and constraints [9];*
- *Dredging management practices for the environment – A structured selection approach [10];*
- *Dredging and port construction around coral reefs [11].*

5 Bathymetric and topographic surveys

*COMMENTARY ON CLAUSE **5***

Hydrography, as defined by the IHO Manual on hydrography *[12], is concerned with systematic surveys at sea, along the coast and inland, and geo-referenced data from the perspective of the mariner in respect of requirements for navigation. Hydrography includes the consideration of the following matters:*

- *shoreline configuration, including infrastructure for maritime navigation, i.e. all those features on shore that are of interest to mariners;*
- *depths in the area of interest (including all potential hazards to navigation and other marine activities);*
- *sea bottom composition;*
- *tides and currents;*
- *physical properties of the water column.*

Requirements for surveys for planning, execution and operational monitoring and maintenance of maritime civil engineering works are frequently different or additional to the requirements defined by IHO. However, surveys for handover for operational use for navigation for completed facilities and navigation channels and structures are often required by maritime authorities or operators to meet IHO standards.

5.1 Survey control

5.1.1 General

*COMMENTARY ON **5.1.1***

For maritime civil engineering works it is essential to have a well-defined system of horizontal and vertical survey control appropriate to the geographic extent of the project, which might be very large when considering navigation channels, etc. It is important to determine an accurate relationship between levels onshore and offshore for tidal, seabed and topographic surveys.

Survey standards and horizontal and vertical control grids and map projections should be defined at an early stage in any maritime development project or survey and investigation programme. Survey parameters to be defined should include:

- geodetic model to be used;
- correction parameters;
- definition of survey projection;
- horizontal coordinate systems;
- vertical coordinate systems for onshore and offshore areas.

Physical survey control stations should be established at an onshore location at or near to the site so that onshore topographical and hydrographical surveys can be referenced to these stations. At least three control stations should be established, with additional stations being provided on larger sites. All stations should be robust, durable, stable and clearly identified. The locations should be carefully selected so that wherever possible the control stations will not need to be relocated due to construction of the works.

Where data from earlier surveys is being used, any controls used for these surveys should be checked against the site survey control stations. Where discrepancies between new and old datums are found, these should be recorded and any differences used to correct the historic data if necessary.

All site surveys should be tied into at least two of the primary survey control stations.

5.1.2 Vertical control

*COMMENTARY ON **5.1.2***

Satellite survey techniques are often used for level control, for both land- and water-based surveys. It is essential that these are referenced to mean sea level and other astronomical tide levels derived from measurements obtained using a suitably positioned tidal level gauge.

A tidal level gauge should be established as close as practicable to the location of the proposed development or area of interest. The gauge should be located and mounted to:

a) be in sufficiently deep water to avoid drying out;

b) be sheltered as far as possible from the effect of sea and swell;

c) not be in a position where water is impounded as the tide drops;

d) be reasonably close to a national or local land levelling datum reference point;

e) be sheltered from accidental damage by vessels;

f) not be mounted or fixed on members that are subject to settlement.

5.1.3 Horizontal control

*COMMENTARY ON **5.1.3***

Positioning over water at near-shore locations is normally undertaken using satellite positioning systems and land-based total stations. Whilst other methods can sometimes be adopted, their use is becoming less common. Satellite positioning is now available throughout the world with several constellations available including GPS (USA), GLONASS (Russia) and the emerging GALLILEO (European Union) and COMPASS (China) systems.

Satellite positioning is often augmented by the use of total stations for working locally around a site where shadowing of the satellites can be a problem.

To achieve the level of accuracy required for most construction projects, the survey satellite receiver needs to receive a positional correction signal from a nearby station. These differential stations are set up at a known location and are used to analyse the satellite signals at the same time as the survey is being carried out. Where the correction signals are transmitted to the survey station in real time, the system is often referred to as RTK (real-time kinematic) corrections. It is also possible to add the corrections after the survey during post-processing. These correction signals are more accurate the closer the differential station is to the area being surveyed, and on larger construction projects these correction stations are set up on site. This configuration enables survey accuracies in position of better than 5 mm in location to be achieved, and 10 mm in level. Where highly accurate measurements are essential, these can be obtained by taking several hours of satellite readings at one location.

Other systems are available which can provide corrections. In the UK there is a national network of RTK corrections provided by Trinity House which is often used for hydrographic surveys. Other commercial organizations offer correction services via the mobile phone network.

Where satellite positioning is to be used as the primary means of control for the site, the primary and secondary satellite positioning systems should be specified for use. These should be selected to ensure adequate satellite coverage of the site together with any operational restrictions. Where differential correction stations are set up on the site, these should be regularly inspected to check they have not been damaged or moved, and corrective action should be taken where necessary.

5.2 Bathymetric surveys

*COMMENTARY ON **5.2***

Bathymetric surveys are produced by taking measurements of water depth at known locations over the area of interest. Information on the various techniques available and guidance on their application to maritime engineering is given in this subclause. More detailed guidance on bathymetric surveys in relation to dredging and land reclamation work is given in BS 6349-5.

Published bathymetric charts may be used for preliminary assessments of hydrographical conditions at locations. However, such charts are produced for safe navigation, and features that can be of particular significance to the planning and design of maritime works might not necessarily be shown.

5.2.1 General

Published bathymetric charts can include old surveys neither conducted to modern standards nor at scales suited to engineering requirements. Possible changes due to siltation, dredging, dumping, shipwrecks or other causes should be taken into account, and accurate bathymetric data should be obtained for the site at an early stage in the development of a project.

The extent of hydrographic survey work required should be determined from the nature and extent of the proposed works and the availability and validity of existing survey data. For surveys for navigational purposes, the requirements of IHO Special Publication No. 44 [N1] should be adopted.

NOTE IHO requires full ensonification of the seabed, which means that if single beam echo sounding is carried out, it is to be accompanied by side-scan sonar surveys to pick up any anomalies between survey lines. Where swath bathymetry is acquired using multi-beam echo sounders, this provides full mapping of the seabed directly.

5.2.2 Acoustic systems – Echo sounder

*COMMENTARY ON **5.2.2***

Most depth sounding is carried out using acoustic systems, which are typically multibeam (swath) systems. For large area surveys these are the preferred methods; single beam sounding is however still appropriate for simple surveys.

A conventional hydrographic echo sounder produces a large-scale paper trace, providing a permanent graphic analogue record of the seabed profile which is interpreted to provide reduced soundings. More recently, digital data recording, processing and imaging have become available.

Echo sounders can give misleading results in areas of very soft mud or where there are significant density changes in the water column.

5.2.2.1 Calibration and quality control

Acoustic systems are subject to errors due to variations in the physical properties of the water column and of the seabed. They should be used only by competent personnel and should undergo regular on-site calibration checks.

Echo sounders should be calibrated before and after any survey campaign, and if necessary at intervals during the campaign, to check the functioning of equipment and the particular instrument set up, and to take into account local hydrographical conditions.

Accurate surveying requires reasonably calm conditions at the time of the survey and appropriate quality control checks. When surveys have to be carried out in exposed locations where calm conditions are infrequent, the survey systems should include the use of a heave and roll compensation which can be achieved by accelerometers or additional satellite receivers on the survey vessel. The output from these units should be input into the survey software to provide depth corrections to the survey vessel motion.

NOTE Calibration in shallow water is normally effected by means of a bar check or a special calibration transducer. The bar check is carried out by lowering a target to a set depth below the transducer of the echo sounder and comparing the recorded depth against the actual measured depth of the target. The echo sounder can then be adjusted to record true depth. This method is effective for calibration down to depths of about 20 m. Detailed information on calibration and quality control of single beam echo sounding is given in the IHO Manual on hydrography *[12].*

5.2.2.2 Transmission frequency and beam width

*COMMENTARY ON **5.2.2.2***

Typical lightweight low energy echo sounders in shallow water operate as a minimum at a frequency of 210 kHz. Echo sounders operating at dual frequencies of 33 kHz and 210 kHz are also common.

Acoustic energy at 210 kHz is reflected from the first density horizon on the seabed, which at some locations can represent top of fluid mud or unconsolidated sediment overlying firmer material.

Beam width depends on the transducer dimensions and acoustic frequency. A lower beam width is suited to achieving higher depth accuracy.

Acoustic energy at 33 kHz can penetrate into fluid mud or silt deposits, although the density of sediment at which the 33 kHz beam reflects varies by location according to sediment characteristics.

Dual frequency echo sounders should be used at locations where siltation is anticipated, although additional location-specific investigation of vertical density profiles of sediments should also be undertaken if it is necessary to calibrate the density values at which each frequency reflects.

NOTE The identification of the thickness and density profiles of the mud layer is particularly important when a nautical depth approach is undertaken in declared depth for navigation purposes.

5.2.3 Acoustic systems – Swath acquisition

Except for preliminary surveys of limited extent for planning or feasibility study purposes, depth data acquisition for maritime works should be carried out using multi-beam echo sounder (MBES). Single beam echo sounder (SBES) sounding may be used for surveys of limited extent, and should be supplemented by side-scan sonar to achieve the required full ensonification if the survey is of an area to be used for navigation.

NOTE 1 Swath systems measure the depth in a strip (or swath) of sea floor extending outwards at right angles to the direction of survey vessel motion. The most common form of swath acquisition in connection with maritime works in shallow water depths is the MBES. Such systems gather more data than a conventional SBES and can give coverage under adjacent vessels and structures. SBES surveys might be appropriate for preliminary early surveys to support early planning, and feasibility studies.

NOTE 2 Additional information including a description of MBES and interferometric sonar systems is given in the IHO Manual on hydrography *[12].*

5.2.4 Acoustic systems – Side-scan sonar

*COMMENTARY ON **5.2.4***

Working on similar principles to an echo sounder, side-scan sonar systems transmit a fan-shaped beam of acoustic energy perpendicular to the track of the survey craft. The reflected signals from rock outcrops, sand waves, pipelines and any other projections on the seabed are recorded as changes in density on video display.

Although some indication of bathymetric changes can be gained from analysis of the side-scan records, it should primarily be used as a search device to supplement SBES surveys when it is necessary to examine the entire seabed between sounding profiles. It might then be necessary to run additional profiles where side-scan records show significant changes in the bathymetry taking place.

5.2.5 Direct measurement

Direct depth sounding measurements should be carried out when required to verify or supplement echo sounder records, where local conditions or access restrictions limit the coverage or resolution of acoustic methods.

*NOTE 1 Such measurements are usually made by hand lead line, graduated pole or sweeping with a horizontal wire (see **5.2.6**). Where highly detailed seabed information or identification of located objects is required, the use of divers or remotely operated vehicles might be necessary.*

NOTE 2 An example of a need for direct measurement is when sounding over a particularly soft seabed or when large quantities of weed or kelp are present. A further example is the need to confirm the least depth over a local rock or other such obstruction.

5.2.6 Sounding coverage

The appropriate spacing of sounding profiles should be assessed based upon the purpose of the survey, the scale and nature of the proposed maritime works and the depth and nature of the seabed.

Surveys of navigation channels and other areas to be used for navigation or marine operations should conform to the requirements of the IHO Special Publication No. 44 [N1], and the survey method should achieve full ensonification of the bed.

NOTE 1 Full ensonification for navigation channels would normally be achieved by MBES or a combination of SBES and side-scan sonar coverage. MBES is also recommended for surveys for construction quality control and monitoring for maintenance requirements of major underwater maritime construction works involving dredging, reclamation, armouring, scour protection, pipelines, outfalls, etc.

Where SBES bathymetric data is to be used for planning purposes for the study of wave and current effects, or for the study of navigation channels where the average depth is greater than 1.5 times the draught of the largest vessel expected, a chart scale of the order of 1:10 000 is normally sufficient. Lines of soundings should be spaced at about 100 m intervals, with a locational check by cross-lines at intervals of not greater than 300 m.

NOTE 2 In rock and coral areas, more detailed surveys are advisable for planning of navigation channels if the average depth is less than twice the maximum draught of the vessel.

Where the bathymetric information is required for planning and design of structures, measurement of dredging and checking navigation channels in shallow water, a detailed survey should be carried out to produce a chart to a scale of between 1:500 and 1:2 000.

NOTE 3 Typically, a survey for a maritime structure would be made at a profile spacing of 10 m to 25 m in and around the proposed position of the structure, and 50 m in the approach areas, with locational fixes taken at approximately three times the profile spacing. Side-scan sonar to supplement SBES or MBES giving full coverage of the seabed is recommended for design of major structures.

NOTE 4 A wire sweep survey might be necessary for determining the least depth over an obstruction or to prove the absence of obstructions in a particular area. The former can be achieved by suspending fore and aft from the vessel a horizontal bar, which drifts over the known obstruction. After each pass, the bar is lowered or raised by its calibrated support wires and, by noting the bar's depth setting and applying the tide correction, the least depth over the obstruction can be determined. As an alternative to side-scan sonar, for ensuring that an area is free of underwater obstruction, a fine-wire sweep survey can be conducted. The fine wire is suspended between two boats and weighted to maintain a predetermined depth. The boats proceed at approximately 1 m/s to 1.5 m/s (2 knots to 3 knots) along the necessary course lines to ensure full sweep coverage of the area.

5.2.7 Reduction of soundings

NOTE Due to the variation in water level during survey, soundings obtained have to be reduced to a standard reference plane (see also Clause ***10****).*

The datum to which the soundings are reduced should be noted on the drawing or chart, together with its relationship with the local datum and survey projection and grid system.

The relationship to onshore site horizontal and vertical control reference datums and grids should be established and indicated on drawings and in survey reports.

5.2.8 Coastal topography

Depending on the survey area and the scale of presentation, the final bathymetric plan should as a minimum portray the coastline and prominent features.

Where the bathymetric information is required for planning and design of near-shore structures and shoreline management works, more detailed survey charts should be produced to achieve the required resolution of shoreline bathymetry.

NOTE If the bathymetry is conducted over the high water period, it is usually possible to determine the low water contour from the sounding results. To obtain the high water contour, it would be necessary to carry out levelling, by land survey practice, over the area not already covered during the sounding operation.

5.2.9 Non-acoustic bathymetric survey systems

Where airborne laser scanning (light detection and ranging, or LiDAR) is used as an alternative to conventional acoustic bathymetric surveys, verification checks should be undertaken to ensure that the accuracy achieved is appropriate for the intended survey usage.

NOTE LiDAR can be an effective means for rapid survey coverage of large, shallow water areas with relatively clear water and where it is required to survey extensive intertidal areas and to obtain complementary topographic data for coastal zones areas. Additional information on airborne LiDAR systems and other methods of remote hydrographic sensing and coastal topographic surveying is given in the IHO Manual on hydrography *[12].*

5.3 Other surveys for seabed or subsurface hazards

Additional surveys should be undertaken where desk studies, nautical charts or other information provided by maritime authorities or available from published sources indicate the presence of hazards to construction on or immediately below the bed, such as submarine pipelines and cables, wrecks or unexploded shells, mines, bombs, etc. Specialist advice should be obtained to determine the scope and methods of surveys required to identify and locate such hazards.

NOTE BS 6349-5 provides some advice in respect of geophysical surveys to locate munitions for dredging works although such hazards also present a threat to other kinds of maritime works and operations. As noted in BS 6349-5, magnetometer surveys might be useful for locating hazards with a ferrous metallic component, but do not identify munitions with plastic or non-ferrous metal casings.

6 Meteorological and oceanographic considerations and data acquisition

*COMMENTARY ON CLAUSE **6***

Metocean conditions as referred to in this part of BS 6349 are the subset of physical environmental conditions relating to meteorological and oceanographic conditions, principally including:

- *meteorology:*
  - *wind;*
  - *precipitation (including rainfall, snow and ice accretion);*
  - *atmospheric conditions (including air temperature and pressure, humidity, air quality, dust, particulates and visibility);*
  - *solar radiation;*

- *oceanography:*
  - *water level (including tides, set-up and storm surges);*
  - *waves (including seiches and tsunamis);*
  - *water movements (currents);*
  - *sea ice and icebergs;*
  - *water quality and chemistry (including salinity, dissolved oxygen content, temperature, turbidity and suspended sediment);*
  - *marine growth.*

*Considerations in respect of water quality and chemistry (including salinity, dissolved oxygen content, temperature, turbidity, suspended sediment) and marine life are described in Clause **11**.*

*Shoreline and seabed morphology and sediment transport can be considered as physical responses of the environment to the influence of metocean conditions. Particular data acquisition requirements relating to the sediment transport regime are described in Clause **12**.*

Metocean data suitable for preliminary planning purposes are obtainable from the UK Meteorological Office, Exeter, England and other commercial service providers. Port Authorities, national and local government agencies may also be consulted since they often hold relevant record information. Background information is also provided in the Admiralty Pilot series of publications [13]. This information is, however, not usually sufficient for design purposes.

6.1 General

Requirements for site- and location-specific data acquisition or predictive modelling studies, additional to the information listed in the Commentary on Clause **6**, should be defined from the commencement of the planning stage and be updated through the design and execution stages.

Data acquisition should include some or all of the following, depending on the project requirements and location:

- review of publicly available data;
- data purchase or exchange;
- field data collection;
- satellite data acquisition or purchase;
- hindcast and other modelling studies.

Definition of the scope of data acquisition should take into account:

- the timescale to identify, collect and analyse data;
- the data already available;
- the variability of conditions at that location and hence the length of data required;
- the type of marine works, design criteria, construction methods and operations, and the metocean parameters needed to plan and tender construction works;
- the type of operations of the completed works and the metocean parameters needed for the facility operating manuals and for planning for start of operations.

6.2 Particular considerations for surveys and data analysis

*COMMENTARY ON **6.2***

Annex B provides complementary guidance on issues which are relevant to planning metocean data acquisition activities for planning, design, execution and operation of maritime works, including further consideration for projects outside the United Kingdom.

6.2.1 Survey scope and metocean variability

Where a site-specific survey or data collection campaign is planned, general conditions should be assessed as used in planning and scoping the proposed data collection.

The scope, timing and duration of surveys and associated analysis should take into account variability of metocean conditions during the period available for the surveys and in the life of the proposed maritime works, including:

- spatial variability in the locality of the project area, including such effects as shallow water effects on waves and shielding or funnelling of wind by natural topography or artificial structures;
- rapidly varying conditions such as squalls and storms which might or might not occur in the survey period;
- infrequent conditions such as extreme storms that are unlikely to occur in a typical survey period;
- seasonal variations;
- long-term oscillations and inter-annual variability that are not characterized in a typical survey period;
- effects of climate change.

NOTE Seasonal variability can be very significant for marine operability. In some parts of the world it is important to recognize different seasonal effects, e.g. monsoons, which are winds that blow for several months from approximately one direction.

6.2.2 Meteorological data acquisition

6.2.2.1 Wind

When measuring wind parameters, the following should be taken into account.

- The wind sensor should be sited in clear air and mounted in a way that is not shielded or impacted by turbulence from near-by structures.
- The wind sensor should be mounted at a height high enough to avoid turbulence from the ground or sea surface.
- The height of the wind sensor above sea or land height should be recorded.
- Where marine icing is possible, heated sensors should be used.
- Mean wind speed and direction data should be continuously sampled at 1 Hz and averaged over 10 min periods, and each 10 min average value recorded, together with the speed and direction of the highest 3 s wind gust within each 10 min period. Where conditions change rapidly, a sampling and averaging period of 1 min should be adopted or data should be stored using a 1 Hz sampling frequency.

Wind records should be processed and presented:

- to adjust speed values to a standard elevation of 10 m above mean sea level with a specified averaging time of 1 h;
- to calculate averages, maxima and percentage frequency tables;
- to prepare wind roses showing the frequency distribution of wind speed and direction;
- to calculate extreme wind speed values for different time averaging periods;
- to calculate wind persistence to show the expected duration and number of occurrences that will exceed or be below a particular wind speed threshold.

NOTE Wind data at open marine locations may be adjusted to a specified elevation if different from the base measured value using the wind profile given in BS EN ISO 19901-1.

6.2.2.2 Precipitation

When measuring precipitation, the following should be taken into account.

- The sensor should be sited to avoid shielding by building or other obstacles.
- The sensor should be sited to avoid contamination such as leaves or other items being blown into the funnel and blocking the sensor.
- Rainfall should be continuously measured over 10 min periods and each 10 min average value recorded.

Data should be processed and presented as a rainfall intensity frequency and duration (IFD) chart.

6.2.2.3 Temperature and humidity

When measuring temperature and humidity, the following should be taken into account.

- The sensor should be sited in clear air away from sources of airborne contamination, exhaust or vents.
- The sensors should be enclosed in a Stevenson screen to shield meteorological instruments against precipitation and direct heat radiation, while still allowing air to circulate freely.
- The proximity to the sea can have a big impact on humidity and daytime and night-time temperatures in some environments even over short distances (1 km), so measurements locations should be representative of the final development location.
- Mean temperature and humidity should be continuously measured over 10 min periods and each 10 min average value recorded.

Temperature and humidity data should be processed and presented:

- to calculate averages, maxima, minima and percentage frequency tables;
- to calculate temperature persistence to show the expected duration and number of occurrences that will exceed or be below a particular temperature and humidity threshold.

6.2.2.4 Visibility

When measuring visibility, optical visibility measurements should be recorded every 10 min continuously and simultaneously with other meteorological parameters. If detailed information is required on the rate of change of variability such as the movement of a fog bank, more frequent measurements should be recorded over 1 min averaging periods.

Visibility data should be processed and presented:

- to calculate averages, minima and percentage frequency tables;
- to calculate visibility persistence to show the expected duration and number of occurrences that will exceed or be below a particular visibility threshold.

6.2.2.5 Atmospheric pressure

When measuring atmospheric pressure, the following should be taken into account.

- The sensor should be sited in clear air, away from large structures or anywhere that could act to funnel winds and increase velocities, as this can change the measured pressure in accordance with Bernoulli's principle.
- The sensors should be mounted with a static pressure head, to minimize errors due to variations of wind speed and direction.
- Where sensors are housed within a building, a clear path by an air tight tube should be made to measure the pressure outside the building in open air.
- Atmospheric pressure changes with height above sea level and should normally be converted to a mean sea level pressure.
- Atmospheric pressure should be continuously measured over 10 min periods and each 10 min average value recorded.

  NOTE 1 Where pressure measurements are made at a height above sea level, they may be corrected to a mean sea level pressure using the method for low level stations described in CIMO Guide, Part I, Chapter 3 [14].

Atmospheric pressure records should be processed and presented:

- to calculate averages, maxima, minima and percentage frequency tables;
- to calculate the maximum rate of change of atmospheric pressure in a certain period (e.g. 24 h);
- to calculate pressure persistence to show the expected duration and number of occurrences that will be below a particular atmospheric pressure threshold.

  NOTE 2 Certain low pressure thresholds can be associated with particular types of weather systems or events.

6.2.2.6 Solar radiation

When measuring solar radiation, the following should be taken into account.

- The sensor should be sited in clear air, away from any structure which could cast a shadow across the sensor and with good ventilation of domes and body.
- Solar radiation should be continuously measured over 10 min periods and each 10 min average value recorded.

Solar radiation records should be processed and presented:

- to calculate averages, maxima, minima, total and percentage frequency tables;
- to calculate solar radiation persistence to show the expected duration and number of occurrences that will be below a particular solar radiation threshold, for the use of solar power systems.

6.2.3 Oceanographic data acquisition

6.2.3.1 Water levels

When measuring water levels using a tide gauge, the following should be taken into account.

- The gauge should be able to filter out short period level fluctuations due to wind or wash waves.
- The level of the gauge should be established relative to the local and project reference vertical survey control datums and datums of local nautical charts or bathymetric survey data.
- Location and mountings should ensure that the gauge remains stable and fixed in position and elevation for the duration of observations.
- Where derivation of astronomical harmonic constituents is required, the duration of measurements should be not less than 30 days.
- Where derivation of astronomical harmonic constituents is required to produce tidal predictions and tide tables of sufficient accuracy for operating manuals and planning, the duration of measurements should be not less than 1 year.

NOTE To permit estimation of extreme values of non-astronomical residuals from atmospheric effects (such as atmospheric pressure, wind and wave effects, local run-off and evaporation), the period of tidal observations would need to be of considerable length, typically not less than 1 year. For projects where information on water levels is important for operational procedures and planning, e.g. for port and navigation channel works, it is often most desirable to maintain the tidal gauge in service through into the operational phase, so that the most complete and accurate tidal predictions can be included with current atlases, etc. in operating manuals.

6.2.3.2 Currents

When measuring currents, the following should be taken into account.

- Current speed and direction should be measured using direct measurements of water velocity at fixed points using current meters or acoustic doppler systems.
- Current speed and direction may be measured indirectly by tracking of currents by a float or dye to supplement direct measurement and to map circulation patterns over a wide area.
- At coastal and port locations, currents frequently exhibit spatial variability both in plan and vertically through the water column. The location and depth of current measurements should be assessed, taking account of the expected main flow patterns through the tidal cycle, with particular reference to flows likely to affect navigation, sediment transport and water quality, and to any need to provide data to calibrate or verify numerical current models to be used for planning and design.
- Where derivation of astronomical harmonic constituents of tidal currents is required, the duration of measurements per location should be not less than 30 days.

- Where derivation of astronomical harmonic constituents of tidal currents is required to produce current predictions of sufficient accuracy for operating manuals and planning, the duration of measurements should be not less than 1 year.

6.2.3.3 Waves

Wave measurements should be in accordance with BS 6349-1:2000 [7]**,** with the scope, extent and timing of measurements taking account of the full range of considerations relating to functional, construction, environmental and operational aspects of planning and design set out in Clause **10**.

7 Meteorological effects

7.1 General

The following meteorological parameters should be taken into account in planning and design:

- wind speed and direction;
- precipitation;
- air temperature and humidity;
- visibility;
- atmospheric pressure;
- solar radiation.

Subclauses **7.2** to **7.7** give further recommendations and guidance regarding effects that should be taken into account in determining data acquisition activities for planning purposes, and in determining metocean parameters for design, execution and operational planning.

7.2 Wind

Wind loading acting directly on structures and indirectly from mooring systems of moored vessels and other floating facilities should be assessed in accordance with BS 6349-1:2000 [7]. In addition to structural loading, wind should be taken into account in planning and design for execution and safe operations, including:

- environmental operating limits for vessel arrival, departure, berthing and cargo transfer;
- environmental operating limits for floating and other construction equipment.

Wind roses and wind scatter diagrams presented on an annual and seasonal basis should be used for assessment of marine facilities' location, layout and orientation relative to the wind. Daily variations in wind direction and speed can also affect vessel and cargo transfer operations, and should be assessed and taken into account.

Wind speed data and statistics should always be qualified in terms of an elevation and the averaging period used.

NOTE 1 The standard reference elevation for maritime works is 10 m above mean sea level with a specified averaging time of 1 h.

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[7] The clauses in BS 6349-1:2000 that deal with loads and actions are expected to form part of the new BS 6349-1-2, which is currently in preparation.

Wind speeds used for the assessment of the behaviour of moored or moving vessels should take into account the size of the vessel and the associated response period of the vessel to the wind. In the absence of other guidance, an averaging period of 60 s should be used for assessment of the handling and mooring of ships such as large oil and gas carriers.

In the absence of detailed or local information on the relationship between mean hourly wind speeds ($U_{3\,600}$) and gust values, the following relationship should be used, where t is measured in seconds:

$$U(t) = U_{3\,600}\ \{1.277 + 0.296\ \tanh\ [0.9\ \log_{10}\ (45/t)]\}$$

NOTE 2 Wind acts on the portion of a structure above the water and the wind speed varies in elevation as well as in time and space. Over the horizontal length scale of large maritime structures, the mean wind speed averaged over the standard time period of 1 h does not vary significantly, but for shorter periods the mean varies and is higher than the hourly mean. Additionally, the shorter duration wind parameters have more variability spatially. Wind speeds are therefore only meaningful if they are qualified in terms of an elevation and an averaging period. For wind parameters, 10 m is the standard elevation, with the averaging period selected related to the length scale of the structure. For example, a 3 s gust is spatially coherent over a smaller length scale than the 1 min mean, which is coherent over a shorter length scale than the 1 h mean.

7.3 Precipitation

Precipitation should be defined in terms of both the amount (depth) and the length of time (duration) over which the precipitation occurs. These can be combined to provide a rainfall rate (in mm/h), known as a rainfall intensity. The frequency or return period for which a particular intensity is exceeded should be determined. This relationship can vary markedly for different regions and is important for drainage and loading, as a shorter duration with higher intensity can cause a maximum peak flow to be exceeded, while a longer storm can result in a higher depth of rain but a lower intensity. Therefore a rainfall intensity, frequency and duration (IFD) chart should be generated, which should show the precipitation rate for a range of durations, typically from 5 min to 72 h, and a range of return periods, typically 1 year, 2 years, 5 years, 10 years, 20 years, 50 years and 100 years.

The effect, type and intensity of precipitation should be assessed when considering the following aspects of design:

- drainage design: estimates are needed of the maximum expected rainfall for different durations for the 1-year, 10-year, 50-year or 100-year return period;
- imposed snow and ice loading: the accretion of snow or ice exerts load on a structure. Ice can form due to freezing of old wet snow, freezing sea spray or freezing rain. Structural icing can affect the stability of floating vessels as well as the operation of equipment including emergency equipment;
- cargo handling: the intensity of rainfall is important with reference to the type of cargo handled, handling rates and the storage facilities in a port;
- penetration: a high frequency of driving rain can necessitate special protection for buildings;
- construction delays: frequent rain increases construction time substantially, especially earth-moving operations.

NOTE Estimates of the effect of precipitation on cargo handling operations and storage areas are normally made for one in 10 year and one in 1 year events.

- *For the one in 10 year precipitation return period, some ponding of water can usually be accepted in certain locations for a limited period of time, depending* *on the type of cargo envisaged, subject to agreement with the end user of the terminal. Such temporary ponding is usually limited to a maximum depth of 50 mm.*

- *For the one in 1 year return period event, the drainage system is usually designed to clear all water from cargo handling operations and storage areas without significant ponding.*

7.4 Air temperature and humidity

The impact of air temperature and humidity should be assessed to determine the minimum and maximum air temperatures and the variations in relative humidity that are likely to be encountered during the life of the structure.

NOTE High or low extremes of temperature and humidity can affect both the effective operation of equipment and durability of materials. Sustained high temperatures and humidity increase corrosion rates.

7.5 Visibility

Poor visibility can present a significant hazard to navigation in inshore waters, and estimates should be made of the expected duration and persistency of periods of poor visibility.

NOTE 1 The reduction of atmospheric transparency and therefore visibility is caused by two predominant factors:

- *a suspension of extremely small dry particles, called haze;*
- *suspended microscopic water droplets or wet hygroscopic particles, known as mist.*

NOTE 2 Fog is a term conventionally applied when the horizontal visibility at the earth's surface is reduced to less than 1 km.

NOTE 3 Heavy rain and snow also significantly affect visibility.

Caution should be used when studying visibility reports from a station not directly on the coast, as the phenomenon known as sea fog is usually not experienced more than 3 km to 4 km inland, and erroneous data can therefore be extracted for navigation and piloting purposes.

Minimum visibility requirements for vessel approach, departure and manoeuvring should be agreed with the operator during the design phase, based upon operational considerations.

NOTE 4 For preliminary purposes for the planning of data collection, it may be assumed that a limiting visibility of 1 000 m due to fog, dust, rain, snow or other meteorological effects would prevent approach and departure of large ships such as oil tankers and gas carriers.

NOTE 5 Visibility often changes sharply near the coast between the widely different regions of sea and land. At coastal stations of the UK Meteorological Office, however, the visibility over the land is recorded as standard even if this is different from the visibility over the sea. The latter is recorded as a remark if it can be estimated.

7.6 Atmospheric pressure

Values of atmospheric pressure should be corrected to mean sea level, to remove the influence of altitude on the measurements. Information on pressure distribution should be used as an input parameter in estimating storm surge.

NOTE The pressure of the atmosphere at any point is the weight of the air that lies vertically above a unit area. The atmospheric pressure is recorded in millibars [8]. The pressure distribution is used as a basic input parameter in the preparation of weather and sea state forecasts and, in particular, the influence of pressure on water level is of importance. A high or low pressure decreases or increases, respectively, the depth of water to cause a storm surge, either negative or positive.

7.7 Solar radiation

The incoming, reflected and emitted radiation should be used for:

- estimation of the cooling capacity of an area of water and the potential evaporation in thermal balance equations;
- calculation of size and capability design of solar power systems (photovoltaic or solar thermal systems);
- calculation of mortality of bacteria released to the sea in sea outfall design for effluents such as domestic sewage;
- assessment of marine growth or fouling variation with depth in the water column.

NOTE The life expectancy of bacteria released to the sea is thought to be highly dependent on the intensity of solar radiation, particularly in the ultraviolet wave lengths. The effect of light intensity on marine fouling is well illustrated by the vertical sequence of species found with changing depth on immersed structures.

8 Water levels

*COMMENTARY ON CLAUSE **8***

Variations in water level at a location of maritime works are caused by a number of phenomena. The total water level change is made up of astronomical effects and residual effects, usually due to atmospheric forcing. The underlying long-period fluctuations in general water level result from astronomical tides. Tides are generated primarily by the cyclic variations in gravitational attraction of the moon and the sun on the water masses of the earth. Tidal ranges vary widely around the world and are affected by geographical factors. The shallow waters surrounding the British Isles have the effect of increasing the height of the tidal wave considerably; in the Severn estuary ranges can exceed 15 m. Tidal ranges in the open ocean, however, are often less than 2 m.

Superimposed shorter period fluctuations and non-periodic variations can be caused by such factors as atmospheric pressure, wind and wave effects, local run-off and evaporation.

Unusually high or low barometric pressure, or prolonged periods of strong winds, can result in differences between actual sea level and the predicted height. Differences between predicted and actual times of high and low water are caused mainly by the wind.

A strong wind blowing on shore tends to pile up water against the coast, resulting in a water level higher than the predicted tidal height. Winds blowing along a coast tend to set up long waves, which travel along the coast raising the sea level at the crest and lowering the sea level in the trough. Grouping of waves from distant storms can produce variations of mean sea level within the group. This results in a long-period, low-amplitude wave travelling at the same velocity as the group, which, when it approaches the shore, can cause a higher sea level and thus allow the waves to run further inshore before they break. A combination of pressure and wind effects can cause the phenomenon known as a storm surge.

[8] 1 mbar = 100 N/m^2 = 100 Pa
1 000 mbar ≈ 29.5 in Hg

8.1 Water level effects

The selection of water levels for the determination of actions on structures should be assessed in accordance with BS 6349-1:2000 [9)].

The selection of water levels for geotechnical design should be assessed in accordance with BS 6349-1-3.

Maritime structures should be designed to withstand safely the effects of the extreme range of still water level from extreme low water to extreme high water expected during the design life of the structure, taking into account the astronomical tidal range and the effects of storm surge and long-term sea level rise. These extremes should be established in relation to the purpose of the structure and the accepted probability of occurrence.

In addition to structural considerations, the effects of water levels and water level variations should be taken into account in respect of other functional, construction and operational aspects of design, including:

- design of navigation channels and assessing under-keel clearance (UKC) requirements for marine operations;
- assessment of operability and access of construction equipment and vessels;
- estimating of overtopping of coastal and maritime structures, including flood protection;
- determination of hydrostatic pressures and the level of action of waves and currents (see BS 6349-1:2000 [9)]);
- for mooring and berthing studies (see BS 6349-4);
- in relation to soil pore water pressures (see BS 6349-1-3);
- drainage discharge capacities;
- prediction of tidal flows in catchments draining into tidal areas.

8.2 Seiches

For fully or partly enclosed bodies of water such as harbours, enclosed bays and lakes, the potential effects on water levels of seiching should be assessed.

NOTE The passage of an intense depression can cause oscillations in sea level referred to as a seiche. The period of seiching can be anything from a few minutes to 2 h, and the height from a few centimetres to 2 m to 3 m. The shape, size and depth of some harbours make them very susceptible to such effects, increasing their height often to destructive proportions.

8.3 Surface water run-off

The potential for water levels in estuaries to be raised by river flow originating from surface water run-off or artesian sources should be assessed. Measures such as the opening of sluice gates upstream and seasonal flow patterns should be taken into account.

NOTE High river flows into estuaries can result in local flooding, especially when coincident with spring high tide.

9) The clauses in BS 6349-1:2000 that deal with loads and actions are expected to form part of the new BS 6349-1-2, which is currently in preparation.

8.4 Long-term sea level trends

*COMMENTARY ON **8.4***

Report UKCP09 [N2] provides:

- *"absolute" estimates of mean sea level rise based on a number of international climate models;*
- *estimates of "relative" sea level rise, which include effects from local estimates of land uplift or subsidence. An extreme, low probability, "high++" sea level rise scenario is included, based on previous high sea levels inferred from the geological record;*
- *estimates of changes in storm surges and estimates of changes in extreme high water level. Both of these are produced under a standard IPCC (Intergovernmental Panel on Climate Change) emission scenario (A1B) and for a model based on a "high++" scenario;*
- *multi-level ocean data. This includes information on water temperatures, salinity, the stability of the water column (stratification) and ocean currents around the UK.*

The projections are subject to considerable uncertainty. The extent to which these projections are taken into account in planning and design of maritime works depends on assessment of the consequences of sea level change for the works in question and a comparison with the risks to human life and relative economic case for deferring expenditure and modifying the works in future, if this is feasible.

Where allowances for long-term changes in sea level over the life of the maritime works are to be included in the design, the allowances for works in the United Kingdom should be assessed based upon UKCP09 [N2].

9 Currents and water movement

The selection of current velocities and directions for the determination of actions on structures should be assessed in accordance with BS 6349-1:2000 [10)].

Maritime structures should be designed to withstand safely the effects of the extreme range of current velocities and directions expected during the design life of the structure, taking into account the range of tidal currents from astronomical tides and other non-tidal residual components of current, including the effects of permanent ocean currents, river flows and wind-driven currents.

In addition to structural considerations, the effects of currents should be taken into account in respect of other functional, construction, environmental and operational aspects of design, including:

- orientation and layout of navigation channels and planning of marine operations;
- orientation and layout of ports, jetties, quays and berths for navigation and marine operability;
- assessment of operability and access of construction equipment and vessels;
- mooring and berthing studies (see BS 6349-4);
- effects on water quality (see Clause **11**);
- effects on sediment transport, including scour (see Clause **12**).

10) The clauses in BS 6349-1:2000 that deal with loads and actions are expected to form part of the new BS 6349-1-2, which is currently in preparation.

Currents vary with depth and with time at any location and the proposed maritime works can have a significant effect on the existing current regime, so numerical modelling should be used to assess any change in currents caused by the proposed works. Such assessments should be used in design and in navigation, operability and mooring studies. Numerical models of current conditions used for detailed design and operational planning should be validated against current measurements for the existing current regime at the site of the works.

When assessing current effects on moored or manoeuvring vessels, the current velocity used should be depth-averaged over the draught of the vessel based on the current–depth profile established for the location. The current velocity–depth profile should be established by representative measurements at the site location or from published empirical relationships applying to the local flow regime.

NOTE 1 The largest scale global water movements are the permanent ocean currents. These currents are the result of the response of the ocean and atmosphere to the global distribution of solar energy and the resultant flow of energy from the tropics to the poles. The surface ocean current systems correspond quite closely to the generalized global atmospheric circulation and shift seasonally with the passage of the overhead sun. Good local descriptions of these basic water movements can be found in the Admiralty Pilot series of publications [13].

NOTE 2 The local currents (both speed and direction) are a combination of both tidal forcing, which is predictable, and residual effects, which are not predictable. They are usually the result of permanent ocean currents, direct or indirect atmospheric forcing and local effects such as run-off or density-driven. In the coastal zone, where tidal currents are strong, they normally dominate residual current, but in many areas of the ocean, where the tidal range is approximately 2 m, tidal currents are low and residual currents dominate the current regime.

NOTE 3 ISO 21650:2007, Annex C provides typical empirical relationships for current velocity with depth.

10 Waves

*COMMENTARY ON CLAUSE **10***

Wave conditions are frequently the most dominant effect, both in the structural design of maritime works in the coastal zone and, in conjunction with wind and currents, in putting limits on marine operability. When designing maritime works it is necessary to obtain comprehensive information defining the expected sea state for the site of interest as essential information in determining normal operating conditions, extreme operating conditions and environmental conditions to be considered as accidental design situations.

The selection of wave conditions for the determination of actions on structures should be assessed in accordance with BS 6349-1:2000 [11].

Maritime works should be designed to withstand safely the effects of the extreme range of wave conditions expected during the design life of the structure.

In addition to structural considerations, the effects of waves should be taken into account in respect of other functional, construction, environmental and operational aspects of design, including:

- response of and effects on sediment transport, including scour (see Clause **12**);

[11] The clauses in BS 6349-1:2000 that deal with loads and actions are expected to form part of the new BS 6349-1-2, which is currently in preparation.

- orientation and layout of navigation channels and planning of marine operations (see Clause **19**);
- orientation and layout of ports, jetties, quays and berths for navigation and marine operability, including the definition of design stage operating limits (see Clause **19** and Clause **20**);
- assessment of operability of construction equipment and vessels;
- mooring and berthing (see Clause **20** and BS 6349-4);
- wave run-up, overtopping, reflection, diffraction, transmission and other such interactions at structures, shorelines and coastal features.

Preliminary information on wave conditions for the planning phase should be obtained from relevant sources (see Commentary on Clause **6**).

Whichever source of data is used, it should be assessed to verify whether or not it is representative of the precise locality under consideration, the nature of the proposed maritime works and operations proposed, and also to what extent the proposed works are likely to change the wave conditions in the locality of or remote from the works.

Wave conditions derived from measurements or hindcast predictions at offshore or deeper water (relative to the works location) should be transformed to the point of interest, taking account of shallow water effects which act at the location such as bed friction, refraction, shoaling, breaking, reflection and diffraction.

NOTE 1 Multiple models might need to be used when transforming conditions from observations or hindcast predictions from locations remote from the area of interest. A far-field or regional model is often used to transform from an offshore location to the area of interest. A near-field or local model is then used to simulate conditions locally to the works, including diffraction and other effects, to assess the more complex sea states around and behind local structures, including both existing and proposed breakwaters, dredged channels, training walls, etc.

Wave conditions are likely to vary spatially at inshore locations near and around proposed maritime works. Numerical and/or physical modelling should be used to assess the change in wave conditions caused by the proposed works. Such assessments should be used in design and in environmental, navigation, operability and mooring studies.

Inshore wave observations should be made to validate numerical models to enable reasonably accurate wave predictions, especially where the bathymetry is complex.

NOTE 2 An example is when offshore sand banks and bars are present, in which case the behaviour of waves is likely to be highly non-linear due to effects such as wave breaking and reformation.

When deriving characteristic wave and other coexisting metocean conditions for design, account should be taken of the use to which they are to be put in the design and planning process, noting the following.

- Conditions used for design should be appropriate to the design method, structural type and failure consequence. Failure consequence should be assessed by the designer in conjunction with the operator, based upon the type of facility, nature of operations and cargo, nature of the local environment and any hazardous materials stored or handled.
- Conditions used for the derivation of wave actions for structural design should be combinations of waves and other relevant metocean parameters for extreme conditions at appropriate joint probability of occurrence.

- Conditions for assessment of run-up and overtopping should include combinations of waves and other relevant metocean parameters at joint probability of occurrence appropriate to the use and function of the works, taking into account any operational restrictions on access that are proposed to be included in the facility operating manual.
- For assessment of operability of vessels, wave conditions should be defined under conditions that are relevant to normal and extreme operating conditions, including when vessels are navigating to and from the maritime works or when they are moored and transferring cargo. In this respect, the annual and seasonal variability of wave conditions, in combination with other limiting metocean parameters, should be statistically and visually characterized using scatter diagrams, wave roses and vector plots or similar means suitable for use in design, including definition of design stage operating limits.
- In situations where large vessels or structures are to be moored inshore or inside harbours that are in a relatively exposed location, the risk of significant infragravity wave energy being present should be assessed. Where appropriate, local wave measurement should include instrumentation to characterize infragravity wave energy.
- Where the wave data are to be used for the design of a beach, or beach management operations or structures, the design should take into account the annual and inter-annual wave climate – height, period and direction, in addition to extremes. The design should take into account the frequency distribution of the wave energy spectrum, as longer period (swell) waves can often be more damaging to a beach than shorter period waves of greater height within the wave spectrum.

NOTE 3 Further guidance on investigation, prediction and extrapolation for both the offshore and inshore wave climates are expected to be included in BS 6349-1-2, which is currently in preparation.

11 Water quality

11.1 General

The effect of water quality on the safe and efficient functioning of the structure should be assessed. Such an evaluation should take into account local conditions on temperature, corrosive elements, suspended solids, marine growth and other such parameters. Where local data on these conditions are not available, surveys and data acquisition should be carried out to obtain data sufficient for design.

*NOTE The influence of the structure on the water quality and other features of the surrounding environment, i.e. the environmental impact, is covered in Clause **4**. The environmental effects, which are reviewed in **11.2** to **11.6**, refer to the effect of water quality on the maritime works.*

11.2 Water temperature

11.2.1 General

The water temperature should be assessed taking account of seasonal temperature variations and stratification of the water.

NOTE 1 Significant stratification can exist in areas where there is a thermal effluent or in estuaries with high freshwater discharge, but often the water column is close to isothermal due to strong turbulent mixing.

The effects of temperature variation should be taken into account as follows.

a) **Ice formation**. The potential of sea icing forming should be taken into account when the water temperatures fall below −2 °C. The situation where ice masses can form elsewhere and float into the area of the structure should be taken into account, even in circumstances where the water is considerably warmer. When assessing icing on a structure, the effects of wind strength and air temperature should be taken into account.

   NOTE 2 Icing is unlikely to occur until sea surface temperatures fall below 6 °C.

b) **Corrosion**. The potential for higher temperatures to increase the rate of iron oxide formation and cause significant effects on bacterial corrosion should be taken into account.

c) **Marine growth**. The potential for higher temperatures to promote higher rates of encrustation on a structure and to vary the species of organisms present should be taken into account.

d) **Effluent dispersion**. The effects of temperature on the density of seawater and its salinity should be taken into account when modelling the behaviour of an effluent immediately after release.

11.2.2 Measurement

A suitable choice of method of measuring temperature should be made, taking into account the particular requirements of the structure.

NOTE Different applications require different methods of measurement. Surface temperature variations over a large area can be determined using infrared techniques from either an aircraft or satellite. Variation at a point can be monitored by comparison of multiple passes of the remote sensing apparatus. On a smaller scale or where depth profiles are required, continuous or repetitive measurements are taken using thermal sensors, such as thermistors, resistance bulbs, thermocouples and mercury-in-glass thermometers.

11.3 Chemical composition

The chemical composition of the water should be determined at an early stage of the site investigations, with particular attention being paid to potentially corrosive elements such as chloride and sulfate ions.

Coastal water is normally fully saturated with oxygen at the surface but, if there is little vertical mixing, the oxygen content decreases with depth. Under normal circumstances this decrease is unlikely to have a significant effect unless anaerobic conditions are reached, but the local distribution and seasonal variation should be taken into account when siting outfalls to discharge effluents that could act as reducing agents.

NOTE The important chemical parameters are usually analysed directly or measured with selective ion electrodes, either in the field or in the laboratory.

11.4 Turbidity

The effects of turbidity and suspended sediment should be taken into account in harbour design, with special reference to sedimentation and maintenance dredging requirements. The effects of turbidity and suspended sediment should also be taken into account when it is planned to abstract water for industrial or utility purposes, particularly with regard to design of intakes, filters and screens. The risk of blockages of water channels and pipes and wear on pumps should be assessed.

NOTE 1 Turbidity is usually caused by suspended clay or silt particles, dispersed organics and micro-organisms. A lower water temperature increases the amount of sediment that can be transported in suspension due to the viscosity change.

NOTE 2 Fine suspended sediment and living organisms in turbid water can also be drawn into the ballast systems of vessels using marine facilities. This can have operational consequences for harbour authorities or vessel operators in highly turbid environments, or where certain species are present and which therefore might require investigation at the design stage.

During the planning of the dredging and reclamation works, the effects on turbidity that can occur during dredging operations should be allowed for. An assessment should also be made to reduce the risk that disposed dredged material is not wholly or partly re-deposited back into the dredged area.

It is sometimes possible for dredging operations to release potentially harmful substances into suspension that were present in fine sediment. The possible existence of such harmful substances, and the possibility of degradation of structural materials caused by release or redeposition of harmful substances, should be taken into account in design.

NOTE 3 Guidance on turbidity from dredging and reclamation is given in BS 6349-5.

11.5 Marine life

The effects of marine organisms, including algae, molluscs, bacteria, crustacea, etc., attaching themselves to a maritime structure should be taken into account and, where appropriate, measures should be taken to control or limit marine growth. Particular attention should be paid to the potential for marine growth to occur in intake and discharge pipes, where such growth can cause blockages, impose or increase mechanical stresses, accelerate degradation, retard flow or impede inspections for maintenance or certification purposes.

For structures with timber elements, it should be taken into account in the design that they can be affected by boring organisms as well as surface-attaching species.

For steel structures, the presence of molluscs on the surface can inhibit corrosion, and it should be determined whether or not their removal is beneficial before taking action to remove them.

NOTE Methods of controlling marine growth include the use of anti-fouling paints, scraping by hand or mechanical removal by water- or air-jetting.

11.6 Pollution

The effects of water-borne pollution on the structure should be taken into account.

NOTE 1 Some trade effluents, if insufficiently diluted, can accelerate the deterioration of concrete and steel.

NOTE 2 The effect of oil spillages is usually benign with respect to structural condition, but the surface coating makes inspection difficult.

NOTE 3 Pollution can act as nutrients or deterrents to bacteria, significantly affecting microbial induced corrosion.

12 Sediment transport

12.1 General

In any operation, dredging or construction works involving the alteration of the nearshore hydrodynamic regime, or when carrying out capital dredging of new or modified navigation or other channels in a seabed or estuary, the subsequent effects on sediment movement and shoreline and bed morphology should be taken into account.

The uncertainty associated with any such assessment should be taken into account and, where possible, the effects of the uncertainty on predicted sedimentation should be evaluated (see *Dynamics of marine sands* [15], which contains a short section on uncertainties). Where appropriate, a probabilistic approach to estimation of sediment transport and shore or bed morphology should be adopted to quantify the effect of uncertainty in predictions.

NOTE An example of an uncertainty analysis using a probabilistic method is described in Uncertainty analysis of the mud infill prediction of the Olokola LNG approach channel – Towards a probabilistic infill prediction *[16].*

Existing baseline sediment movements prior to any works should be assessed to provide a basis for comparison of impacts for different proposed future scenarios.

In some cases, for instance, if works are being carried out in order to mitigate the effects of coastal erosion, the circumstance giving rise to the problem might be known already to some degree, in which case attention can be focused on designing works or on developing management strategies to alleviate the problem. However, design should ensure that works aimed at solving a local sedimentation or erosion problem do not lead to unintended and potentially adverse impacts remote from the works.

Assessment of the effects on sediment transport should take into account the scale and extent of the effects appropriate to the particular circumstances, ranging from effects local to a structure to effects at regional scale covering a length of coastline forming a sediment cell in a coastal zone management regime.

Assessments of impact of works on sedimentation and erosion should seek to ensure that reasonable confidence can be achieved that unintended and unforeseen effects on the sediment environment can be avoided or managed.

12.2 Assessing the present sediment transport regime

*COMMENTARY ON **12.2***

*In this subclause, the term "currents" generally refers to tidal currents and river discharge. Wave-generated currents are considered with waves in **12.2.7.3**.*

There is often ambiguity arising from use of the terms "wave" and "current" in sediment transport. Wind waves (i.e. waves generated by the wind) and swells have currents associated with them due to motions in the water column that reverse as the trough and then the crest pass over a section of sea bed. Thus sediment is moved back and forth by successive waves, with only a small net movement. This net movement due to waves (i.e. to the wave-induced periodically reversing currents associated with the waves) is small, and only generally important when considering waves normally incident (and therefore sediment movement directly on- or offshore) to a section of coast. This net sediment transport rate is typically very small and notoriously difficult to estimate. The other important wave-generated currents for sediment transport are associated with the hydrodynamics of waves breaking at shorelines and coastal structures, which give rise to longshore sediment transport.

Wind-generated currents also exist, but except in very shallow water they are generally mainly a surface phenomenon and are less significant for sediment transport.

12.2.1 General

At the planning and early conceptual design phases, before commissioning detailed studies into assessing sediment transport rates, existing information and knowledge should be sought.

Possible sources should be consulted for knowledge of existing sediment movement, including net erosion and deposition, although this frequently only exists in qualitative form.

In the event that no such information exists, or to supplement and confirm limited existing data, sediment movements should be estimated. This should be done either by direct or indirect measurement of sediment transport rates, or by inferring rates from local wave and current conditions.

12.2.2 Existing knowledge of sediment movement

At a coastal location, knowledge of sediment movements often exists, in the form of observations of bathymetric changes (e.g. by observation of bathymetry at low tide, or of breaking wave patterns, or by knowledge of shipping lanes and how they might shift). Searches of scientific and engineering literature should be undertaken to establish whether any relevant previous studies exist. Maritime authorities, district councils, port, harbour and pilotage authorities, local trawler and fishing boat operators, local newspapers and any local university might have relevant information and experience, and should be consulted.

Much of the UK coast is subject to shoreline management plans (SMPs, see Annex A), the exception being Northern Ireland. Where proposed maritime works are within an existing SMP, the SMP should be consulted at an early stage of planning and conceptual design to obtain information on the coastal environment, coastal morphology and coastal management.

12.2.3 Bathymetry

Charts or other available surveys covering the area of interest should be used (see also Clause **5**) to obtain an accurate local bathymetry of an extent appropriate to the scale of the works.

A sequence of surveys covering both decadal and seasonal changes should be consulted if available.

Satellite and airborne images of coastal regions can provide high density, synoptic data of a coastal region and should be consulted and evaluated where they are available.

NOTE Comparison of surveys taken in different years and/or decades can either reveal a trend for sediment and bed-form movement, or at least characterize a degree of natural variation even if trends are not obvious.

12.2.4 Local currents and wave conditions

Currents – tidal or, at an estuary, fluvial, or wave-generated (e.g. longshore) – are mainly responsible for transporting sediment. Therefore, a reasonable, qualitative picture of sediment transport (sometimes termed sediment pathways) should be constructed by developing a realistic understanding of the current and wave regime at a site of interest.

NOTE 1 At some locations and for fine muddy sediments, near-bed sediment density currents can also be an important mechanism of sediment transport in muddy environments such as navigation channels in ports.

NOTE 2 Waves are mostly responsible for mobilizing sediment that is subsequently moved by wave-generated, tidal or density currents.

The sources noted in **12.2.2** should also be consulted to obtain an idea of local currents and wave conditions and their variation. Currents and waves are more readily observable than changes in morphology. Records of direct measurements of wave conditions might be available locally, or can be estimated by transformation from offshore measurements. Direct measurements of currents (typically to confirm positions and estimates of flood and ebb tides) should be undertaken, if none exist and reliable estimates from numerical models are not available.

The flood and ebb tides are the result of the interaction of the tidal wave and the local bathymetry. The high tide can be visualized as the crest and low tide as the trough of the tidal wave. The associated local tidal currents are complex and asymmetric in nature, and therefore flood and ebb currents are unlikely directly to oppose each other in direction, magnitude and duration. This leads to significant net (residual) currents. Residual currents are very important in assessing sediment movements due to tides and should therefore be assessed and quantified at both spring and neap tides.

Information on tides and tidal elevations is important for sediment transport assessment, and tide tables, charts and other related information sources should be obtained and reviewed. Tide levels at locations in between stations can be interpolated for planning and concept design purposes, and the following should be taken into account.

- The tidal range, though not directly influencing sediment movement, reveals the extent of the intertidal region (if not already known) and therefore the potential for sediment to be mobilized.
- Water depths influence local wave heights and the potential for waves to mobilize sediments.

Currents caused by tides can be complicated, not least due to local bathymetry. Efforts should therefore be made to obtain any knowledge of direction of movement and phasing of tides, to help predict the current pattern if this is not known, or to help validate and calibrate numerical models to be used for assessment and design.

NOTE 3 The interaction of river discharge and tide at an estuarine location leads, typically, to intense and complex patterns of currents, and sometimes causes very dynamic changes in bed morphology. Moderate to large discharges and a large tidal range exacerbate these interactions. Furthermore, because of fluvial sediment discharge, estuarine regions can be very complex in terms of sediment types. Knowledge of these environments is particularly important in these regions.

Wave conditions should be assessed to provide information on prevailing directions, periods and heights (see Clause **6** and Clause **10**) and therefore of the potential for wave-induced sediment movement. Information on wave conditions should be obtained:

- from measurements at or near to the area of interest; or
- by numerical modelling to estimate conditions at or near to the area of interest from an offshore wave climate (obtained in turn from offshore wave measurement or a hindcast model or some combination of these).

Sediment movement due to waves before they break at a shoreline is typically back and forth, as, respectively, the trough and crest pass over the sea bed. Although the net movement is usually very small, it can be important where the prevailing wave motion is onshore/offshore, especially on a seasonal scale, where it can sometimes result in the movement of a sand bar onshore (summer) and offshore (winter). In a study at an open coast this possible seasonal variation should be accounted for in any works proposed.

Waves also generate significant currents when they interact with the shoreline. Two such currents are common: longshore and rip currents.

- Longshore currents, which flow along the direction of the shore, usually have a profound effect on the sediment movement and should be taken into account in any assessment of sediment transport at shorelines.

- Rip currents, which are offshore flowing, might be of less importance to sediment transport, although they provide a potential sediment pathway through the breaker zone. Rip currents can pose a risk to bathers and should be taken into account in circumstances where such currents might be induced or intensified by proposed works (including where reef structures or offshore nourishment are proposed).

NOTE 4 Longshore currents (and rips) can only exist where waves are breaking, usually quite energetically. Estimation of alongshore sediment transport is described in ***12.2.7.3.2****.*

NOTE 5 Many sites worldwide are current- or wave-dominated; in British waters it is unusual for tidal effects to be negligible.

12.2.5 Local sediment types

The sediment size (typically characterized by D_{z0}, the median grain size) at the site of interest should be assessed at the planning and early conceptual design stage. This should be done using available local information, or by sampling sediment at particular sites of interest, or by a combination of both of these, recognizing the potential for wide variability of sediment types in a region or area of interest.

NOTE 1 Typically, coarser sediments such as sand are moved only along the bed (bed load), whereas finer sediment can be entrained in the water column and transported significant distances at the current speed. Sediments can originate locally (from cliffs or further offshore), or be transported into the area by a current (river or tidal or longshore).

In addition to particle size distribution, sediment should also be characterized by physical properties, particularly whether cohesive or not.

NOTE 2 Fine sediment can be cohesive (clays: D_{z0} <0.008 mm) or non-cohesive (silts: 0.008 mm < D_{z0} < 0.062 mm). Generally speaking, fine sand 0.062 mm < D_{z0} < 0.2 mm is most readily moved. Fine cohesive material is more resistant to entrainment and coarser material moves less readily because of the larger mass of the particles. The behaviour of muddy sediments in near bed density currents is also influenced by the rheological parameter, which can in turn be influenced by the mineralogy of the sediment.

NOTE 3 For sediment classifications and information on detailed characterization and data collection requirements, guidance is given in Manual sediment transport measurements in rivers, estuaries and coastal seas *[17],* Dynamics of marine sands *[15] and, for muddy coasts,* Introduction to the physics of cohesive sediment dynamics in the marine environment *[18].*

12.2.6 Local sediment mobilization

NOTE 1 Sediment usually moves in response to water movements and is governed by them. Therefore, if no significant water motions occur at the location at which works are to be carried out, it is possible that there is no significant sediment movement.

For waves, as a preliminary guide for planning and early conceptual design, it may be assumed that if the local minimum water depth (e.g. at MLWS) is typically greater than half the wavelength associated with the spectral peak wave period at that location, then the influence of waves will not be felt by the sediment. Where a sea is significantly bimodal, the lowest frequency spectral peak should be taken into account. This criterion can be expressed as:

$$h < \frac{g \tanh \pi}{4\pi} T_p^2 \Rightarrow \text{possible sediment mobilization by waves}$$

Additionally, however, account should be taken of large wave heights, regardless of period, particularly because extreme events are likely to be incorporated into the design criteria.

NOTE 2 Dynamics of marine sands *[15] provides a further formula that can be used to make a preliminary estimate of the relationship between the water depth and the significant wave height associated with sediment mobilization as follows:*

$h < 10H_s \Rightarrow$ *wave height long enough to mobilize sediment*

Other methods of estimation are possible based on so-called depth of closure, but they are less conservative and more difficult to apply. If one or both of these criteria are satisfied it can be assumed that sediment is being mobilized by waves.

For tidal currents, in a region in which MLWS is greater than 4 m depth on a sandy bed, a near surface (i.e. less than a third of the local depth from the surface) peak tidal current (i.e. ebb or flood, but excluding any wave component) of less than 0.3 m/s indicates that sediment at the bed is probably not being mobilized by the current; otherwise it should be assumed that sediment mobilization due to the current is occurring.

NOTE 3 These estimates are crude and do not account for the effect of local bed forms (e.g. ripples, sand waves) or of significant local slopes (i.e. gravity), but they are based on typical sand grain diameters. These estimates also apply for quasi-steady currents driven by local sea-surface gradients, river outflows and other sources.

For currents in shallower water (including tidal currents, river outflows and longshore currents), it should be assumed that sediment can be mobilized.

Any area of sea bed subject to wetting and drying (e.g. intertidal, or swash region) should be assumed to be subject to erosion and deposition, and this should be taken into account in any such project undertaken thereon. Assessing this can be difficult, and expert opinion should be sought.

Even if it is determined that there is no local mobilization of sediment, it should be determined whether that fine material might already be in suspension, entrained elsewhere, and that deposition of this material (perhaps because of the reduced velocities here) might be a feature of the region. The amount of entrained material should be determined by local sampling in combination with local knowledge supplemented with the analysis of satellite images (if available); see **12.2.3**.

If neither currents nor waves are considered to be important, the possible effects of scour should still be taken into account, because if induced (e.g. by a pile), near-bed accelerations can lead to significant removal of material and therefore to destabilization of a structure.

NOTE 4 If waves (in the form of a maximum near-bed orbital velocity) and steady currents (in the form of a depth-averaged current) have the same associated velocity, the waves are more likely to mobilize (though not necessarily transport) sediment. This is because the boundary layer associated with the waves periodically reverses and therefore never develops much. It is consequently much thinner than that associated with the steady current and therefore exerts a significantly greater bed shear stress.

12.2.7 Estimating sediment transport rates in the area of interest

12.2.7.1 General

When an assessment of the currents and wave conditions in the area of interest has been made, sediment transport rates should be estimated using one or more of the following methods:

- desk study;
- numerical model study;
- in-situ measurements.

In some cases numerical model studies may be supplemented by physical model studies.

NOTE It is also possible to use physical model studies to assess sediment transport rates, but it is unusual for a physical model to be undertaken to assess existing sediment transport rates alone. Physical modelling is described further only in respect of assessment of the impact of proposed works in ***12.3****.*

Quantitative estimates for sediment transport rates are subject to significant uncertainty and are unlikely to be available from purely local knowledge. Scientific and engineering literature might therefore be an important source of information on transport rates and should be sought when available.

Evidence of larger scale effects and morphology resulting from the sediment transport regime is more likely to be available from local knowledge. Such information should also be sought and interpreted to assess sediment transport rates.

Whether currents or waves or (more usually) both pertain at the study site is important in gauging an accurate picture of the sediment transport pattern. Usually in the UK, both are significant sediment transport drivers, and assessment of wave and current conditions should be part of the sediment transport assessment.

12.2.7.2 Estimating transport due to currents

12.2.7.2.1 General

In a purely tidal environment, most sand moves as bed load, whereas silt and muds are more likely to be entrained. Where entrainment occurs, it is likely to account for the majority of sediment transported. Concentrations of entrained sediment increase toward the bed, so sampling, if undertaken, should take account of this. In a highly energetic environment (e.g. flows where the current is a substantial proportion of the wave celerity, such as some fluvially dominated estuaries or other estuaries at certain tidal phases, or some regions with large tidal currents), particular account should be taken of suspended load, and the whole water column might contain significant concentrations.

12.2.7.2.2 Desk study

Desk studies should be undertaken to estimate existing sediment transport rates from local currents (and taking into account waves when appropriate as described in **12.2.7.3**). If measurements exist or have been made, these should be used to test the accuracy of estimates obtained from sediment transport formulae.

Estimation of transport rates should be carried out at a large enough number of locations so as to reveal a picture of sediment movement associated with prevailing currents (in the case of tides, on both ebb and flood phases of spring and neap tides).

Transport rates should be estimated using appropriate published sediment transport formulae for currents and information on sediment grain sizes and depths at the location being studied. Suspended and bed load rates should be assessed separately.

NOTE 1 Examples of guidance on current-induced sediment transport rates in published literature include Dynamics of marine sands *[15] and* Mechanics of coastal sediment transport *[19].*

A first assessment of the uncertainty in estimates should be made, taking into account uncertainty in key parameters and in different calculation methods. In particular, at least two sediment transport formulae (for each phase, suspended and bed) should be utilized to obtain an idea of variation arising solely from the estimation method.

NOTE 2 Total load (bed load plus suspended load) formulae also exist and can be used instead of separate equivalents.

12.2.7.2.3 Numerical model study

In most coastal and estuarine locations, numerical model studies of sediment transport should be carried out using a model that includes both current- and wave-induced transport.

NOTE This allows different scenarios of waves and current combinations to be assessed and compared in the same context using the same model. Numerical modelling of current- and wave-driven transport is described in ***12.2.7.3****.*

12.2.7.2.4 In-situ measurements

It is possible to obtain in-situ measurements of sediment transport rates both as suspended load and bed load at locations where currents predominate.

Specialist advice should be obtained for planning and specifying in-situ measurement campaigns, and the following factors should be taken into account.

- When sampling of suspended load is proposed in water depths in excess of 4 m, the minimum sampling that should be undertaken for an initial assessment of the existing regime is point (grab) sampling. For each sampling location, at least six samples should be taken, with at least three in the lowest one third of the water column, the lowest being 0.5 m above the sea bed. In some circumstances, if the sea bed is composed of very fine sediments and the water is turbid, the sea bed itself should be defined by a certain value of sediment concentration.
- Sediment traps may be used to measure bed load sediment transport rates where bed load is significant.

NOTE 1 Measurement of bed load under currents is usually more difficult than measuring suspended load. Examples of guidance on methods of in-situ measurements of sediment transport rates in published literature include Manual sediment transport measurements in rivers, estuaries and coastal seas *[17].*

NOTE 2 Annex C gives guidance on methods of sediment transport data acquisition.

NOTE 3 For non-cohesive sediments, only coarser materials are likely to move as bed load.

12.2.7.3 Estimating transport due to waves

12.2.7.3.1 General

In a wave-dominated environment, sediment can move as both suspended load and bed load. For assessment of sediment transport effects, a wave-dominated environment should be deemed to be one in which waves have the potential to cause transport of sediments on the bed.

NOTE Typically the bed might be considered to be "felt" by the waves if the wavelength is greater than twice the local depth. Because the current associated with the waves reverses direction once every wave period, net transport by waves is usually small outside the surf zone when waves are breaking. In such conditions, the importance of waves is usually to mobilize and entrain sediment that is subsequently transported by any prevailing currents. In the breaking zone at beaches, waves can give rise to significant currents such as the important case of alongshore wave-generated currents. Breaking waves can entrain relatively coarse sand and gravel, albeit for short distances, which drives the beach profile and which, in storm events, can cause rapid change of profile and/or breaching.

12.2.7.3.2 Desk study

In cases where it is clear that specifically net, wave-only sediment transport is to be estimated (e.g. estimating onshore/offshore sediment transport due to waves only), a desk study estimating sediment transport rates from local waves only should be carried out.

Only a few empirical formulae exist that can be used for estimating wave-only sediment transport, and their associated uncertainty is typically larger than those for currents only or for waves and currents. In view of this, particular attention should be paid to assessing variations in predictions due to uncertainties in formula parameters, in addition to uncertainties in input parameters.

Different empirical formulae are used to estimate separately onshore and offshore phases of transport due to waves, so the net transport is the difference of these estimates. Interpretation of such empirically based estimates should take into account the inherent uncertainties. Wherever possible, empirical assessments should be supplemented by information from local and/or expert knowledge, including from observations of seasonal or longer term bathymetric changes, to infer knowledge of onshore/offshore transport, provided that alongshore transport is known not to be significant.

At shorelines, waves acting alone create the alongshore sediment transport mechanism known as littoral drift that is the dominant morphological regime of many coastal shores. Littoral drift is a combination of sediment movement by alongshore currents and swash (i.e. waves running up the beach at an angle and then running back down perpendicular to the beach). Where waves impinge at a non-normal angle to the prevailing shoreline, littoral drift may be estimated. An appropriate empirical formula should be selected to estimate alongshore sediment transport based upon specialist literature or advice taking into account wave angle and height at breaking.

NOTE Examples of guidance on sources of formulae for assessing wave-induced transport are given in Dynamics of marine sands *[15] and* Mechanics of coastal sediment transport *[19]. Such formulae estimate the sediment transport over the whole of the surf zone, although where there is a substantial tidal range, this region moves up and down the shore.*

12.2.7.3.3 Numerical model study

Numerical modelling of wave-induced sediment transport should conform to **12.2.7.4.2**.

12.2.7.3.4 In-situ measurements

Measuring net movement due to waves is very uncertain since it represents the difference between two large quantities. Similarly, making measurements in the surf zone is demanding and unlikely to be effective. Direct or indirect in-situ measurements of wave-induced sediment transport is unlikely to be feasible in most cases, although specialist advice should be taken in circumstances when it is considered necessary to support other means of assessment.

12.2.7.4 Estimating transport due to waves and currents

*NOTE In most situations sediment transport is due to the effects of currents and waves. In this subclause, "waves and currents" typically means waves plus a current that is not directly generated by waves, rather than the alongshore currents associated with breaking waves and generating littoral drift as referred to in **12.2.7.2**.*

12.2.7.4.1 Desk study

As recommended for transport due to currents in **12.2.7.2**, in order to assess uncertainty, at least two estimates should be obtained using different empirical formulae. Specific formulae should be used that account for both waves and currents. Uncertainties in both empirical formulae and input parameters should be assessed quantitatively.

NOTE Examples of sources of formulae for assessing wave and current induced transport are given in Dynamics of marine sands *[15] and* Mechanics of coastal sediment transport *[19].*

12.2.7.4.2 Numerical model study

Desk studies should normally be followed by a numerical model study of the sediment transport rates. Models should be compared with measured data, surveys or other local knowledge to demonstrate model validity for the specific local environment.

NOTE A numerical model study can provide a comprehensive overview of transport rates and sedimentation/erosion in the vicinity. Equally important, given uncertainties in estimates, it can provide a baseline for comparison with predictions with works in place, as well as comparisons with selected estimates from a desk study. Once set up, the numerical model can also be used to assess individual effects of waves and currents if required.

12.2.7.4.3 In-situ measurements

Measurements of sediment transport due to waves and currents should where possible be made separately for each component of:

- wave-induced transport;
- current-induced transport;
- bed load; and
- suspended load.

Specialist advice should be sought in planning and executing campaigns of in-situ measurements of sediment transport.

NOTE 1 In most cases, in addition to sediment transport measurements, simultaneous wind, water, current, temperature and salinity data is required, and it is often appropriate to integrate sediment measurements into a wider program of data acquisition.

NOTE 2 In some circumstances, it might be appropriate to consider measuring sedimentation by use of a trial trench. This method can be used to obtain an estimate of accretion rates when waves, currents or waves and currents are experienced. A trench (typically oriented at 90° to the prevailing current direction) can be dredged and its infill rate monitored to infer an approximate transport rate, by assuming that all bed load and a fraction of suspended load is deposited in the trench. This method is normally used only when works similar to the trial trench are to be carried out (e.g. a navigation channel), and survey methods and interpretation of results need to be carefully considered.

12.3 Assessing impacts of works on sediment transport

12.3.1 General

Once some idea of the sediment transport regime that pertains at present has been obtained, the effects of any proposed works or of different design options for the works should be assessed.

This should be done by means of a numerical model study using a model that has been validated against existing baseline conditions as described in **12.2**.

Physical models should be used to supplement numerical model studies when numerical modelling is insufficient to represent applicable processes.

NOTE 1 The assessment of scour effects and for the design of local scour protection works is an example of a situation where the use of physical modelling can be beneficial.

Specialist advice should be sought in respect of physical model studies; scale effects (typically, non-cohesive sediment scaling down to a size that is cohesive) can cause serious problems with such tests when a large spatial extent is to be modelled. At a smaller scale, scour can usefully be assessed in a physical model test.

In all cases, uncertainty in assessment of impacts should be quantified. In most cases when using complex numerical models, a deterministic approach to design should be taken and assessment of uncertainty should be undertaken, by investigating consequences of credible ranges of values for input and model parameters. However, it might in some circumstances be appropriate to address uncertainties more comprehensively using probabilistic assessment techniques.

NOTE 2 An example of a probabilistic approach to a channel infill assessment is given in Uncertainty analysis of the mud infill prediction of the Olokola LNG approach channel – Towards a probabilistic infill prediction *[16].*

12.3.2 Scour

*COMMENTARY ON **12.3.2***

Scour is the local removal of sediment due to a change in the hydrodynamic regime resulting from the following mechanisms:

- *introduction of a new structure or channel or modifying an existing structure or channel or basin;*
- *the direct action of vessel propulsion systems.*

Scour from vessel propulsion systems can be very severe and has caused numerous failures of marine structures. Vessels equipped with nozzles, thrusters and water jets can generate severe scour holes in a single berthing operation.

*In addition to local scour, "global scour" is sometimes referred to (*The mechanics of scour in the marine environment *[20]), which refers to the sediment removal due to the whole structure or facility (as opposed to individual elements of that structure). It is still, therefore, essentially local, but possibly extensive if the structure is large in some sense.*

The potential for scour should be assessed so that the effects are taken into account in overall stability and strength of proposed and existing structures, including jetty piling and quay walls. If the assessment indicates that existing structures could be destabilized by the proposed works as a result of scour, the design should be revised accordingly or scour protection works should be designed to mitigate the effect on existing structures.

The rate and extent of scour for a particular site should initially be assessed empirically using the methods of assessment of scour at some common structures (e.g. a slender, cylindrical pile in a steady current; horizontal pipeline on a flat bed in a steady current).

NOTE Appropriate methods of assessment are given in Dynamics of marine sands *[15],* The mechanics of scour in the marine environment *[20] and* Scour at marine structures *[21].*

Assessment should include both local scour effects (e.g. at a pile in a jetty) and global scour effects caused by a whole structure or by impact of dredging or other such works.

For circumstances not covered by published empirical methods, or where preliminary estimates indicate a requirement for further investigations of scour effects, numerical or physical modelling should be carried out.

The estimated scour depth should be included in the design of substructures, including in assessment of stability of laterally loaded piles and bearing capacity of vertically loaded bearing piles.

Section 3: Safety and operational considerations

COMMENTARY ON SECTION ***3***

This section gives guidance on the operational considerations in the working life of maritime structures and facilities that are relevant to planning and design. Such matters include: vessel data; navigation in approach channels; vessel handling in harbours; berthing and mooring; cargo handling; and health, safety, environmental and security considerations.

13 Operational considerations for planning and design

13.1 General

Many of the operational requirements of maritime works are specific to the particular function or functions of the individual structure, and guidance on these aspects is given in subsequent parts of BS 6349. However, in all projects, there should be consultation with appropriate maritime authorities such as the port harbour and pilotage authority, terminal or facility operator, vessel operators and handlers (the pilots and tug operators), as appropriate to the particular circumstances of the development. Consultation should be carried out at the planning and concept design phases, before the location and layout of the port, terminal or berth has been fixed.

Studies of required operations including navigation and moored vessel simulations, as described in Clause **20**, should be carried out as part of the design, to demonstrate to the operator that the proposed facilities, infrastructure and equipment are suitable to safely achieve the desired operational requirements and performances under the environmental conditions prevailing and any design stage operating limits.

13.2 Facility operating manual

Relevant information from the design and execution stages should be made available to the operator for incorporation into the facility operating manual. For berths and other facilities used by vessels this should include:

- drawings showing the key dimensions of the berth (including length, dredged depth, deck levels, mooring and fender positions);
- the types, sizes and displacement of vessels used for the basis for design;
- the allowable loading on the zones at the berth edge and behind the berth (see BS 6349-1:2000);
- the design stage operating limits (DSOL) for different operations and operating conditions;
- the environmental limits and other parameters for safe access for pedestrians and vehicles from vessel to shore considered at the design stage;
- the design working life for the berth and requirements for monitoring, inspection and maintenance;
- the design conditions used for structural design at the ultimate limit state;
- limiting deflections or other service criteria used for structural design at the serviceability limit state (and, if appropriate, in other circumstances such as under accidental loads or after earthquakes);
- the berthing velocity limits and other criteria used for fender design;

- information from navigation and mooring simulation and risk assessments produced as part of planning and design;
- any other design information that is relevant to setting of limits on how the berth and immediate hinterland is to be used.

14 Health and safety

Health and safety considerations are fundamental to the operation and maintenance of ports, marine terminals, facilities and structures, and should also be intrinsic to planning and design of such facilities.

In addition to operational safety requirements of a facility, the particular health and safety risks of construction and future maintenance should be taken into account.

NOTE 1 Attention is drawn to the Construction (Design and Management) Regulations 2007 [22] and the Construction (Design and Management) Regulations (Northern Ireland) 2007 [23] in respect of the requirement to consider the health and safety implications of any design decision, in order to minimize risks during construction and maintenance activities.

Safety in operation should be the primary consideration in design and planning of facilities for navigation, berthing and mooring of vessels and for handling of cargo. Liaison between appropriate port, terminal and shipping operators and designers should take place to ensure adequate transfer of information and appreciation of operational procedures and requirements, including:

a) numbers, types, sizes and shapes of present and/or expected vessels;

b) provision of tugs, aids to navigation and marine traffic control;

c) pilotage;

d) berthing;

e) mooring patterns, practices, systems and load measurements;

f) berth occupancy, vessel queuing times, port downtime and the effects of sea and weather conditions;

g) requirements of cargo handling, Ro-Ro traffic, storage and other activities, including the need or otherwise to allow for future change, or flexibility in operational usage;

h) requirements for safety zoning and other health, safety and environmental considerations affecting layout, particularly for terminals handling hazardous cargoes including oil, gas and petrochemical berths;

i) requirements for personnel or vehicular transfer from vessel to shore using gangways, ramps or similar systems;

j) emergency response, including fire-fighting and oil spill response.

Such liaison and coordination should commence during the planning phase and be maintained as design and construction plans are developed.

NOTE 2 Port, terminal and marine facilities expansion and refurbishment projects require close coordination between the operator and those responsible for design and construction, to ensure that the risks and particular requirements of construction works in proximity to ongoing simultaneous port operations are fully taken into account.

NOTE 3 The Port marine safety code *[24] and* Guide to good practice for port marine operations *[25] set out good practice for port authorities in respect of the management of safety of marine operations in ports, including the use of risk assessment and hazard identification (HAZID) to establish a safety management system (SMS).*

Relevant information, including risk assessments and information from navigation and mooring simulations from the design and planning for construction for port and harbour works, should be made available to the operator and harbour authority when required to inform development of the SMS and facility operating manual.

NOTE 4 Attention is drawn to the Docks Regulations 1988 [26] and the Docks Regulations (Northern Ireland) 1989 [27], and to the additional guidance given in HSE publication COP 25 [28] and its equivalent in Northern Ireland [29]. Outside the United Kingdom, attention is drawn to the ILO publication Safety and health in ports *[30].*

Particular attention is drawn to health, safety and environmental considerations affecting design and operation of terminals handling hazardous cargoes including oil, gas and petrochemical berths, and such terminals should conform to the requirements given in the *International oil tanker and terminal safety guide* [N3]. Safety aspects affecting the berthing operations of tankers to oil and gas terminals should be assessed for design purposes in accordance with the recommendations of PIANC MarCom Report WG116 [N4].

Works in the coastal zone have the potential to modify the hydrodynamic regime with adverse impact on safety of recreational users, including bathers. Such impacts should be carefully assessed in design of all such works.

NOTE 5 The Maritime and Coastguard Agency, the Royal Life Saving Society, the Royal National Lifeboat Institution and the Royal Society for the Prevention of Accidents might be able to provide specialist advice in respect of safety considerations for small commercial vessels and recreational users of the coastal zone in the UK.

15 Control of pollution and discharges to the sea

15.1 Vessel's waste

*COMMENTARY ON **15.1***

The MARPOL convention [12)] regulates vessels not to discharge wastes and polluting substances into the sea and requires ports to provide sufficient reception facilities for vessel's waste. Authorities responsible for local implementation of MARPOL through applicable coastal state legislation can also be consulted for guidance on local requirements. In the EU, MARPOL is implemented through European Community Directive 2000/59/EC [31] on port reception facilities.

IMO publications Comprehensive manual on port reception facilities *[32] and* Guidelines for ensuring the adequacy of port waste reception facilities *[33] provide guidance on requirements for reception of vessel-generated waste including oily wastes, sewage and garbage. The United Kingdom Maritime and Coastguard Agency* Port waste management planning: A guide to good practice *[34] also provides guidance including for the development of port and terminal waste management plans.*

Oily wastes include dirty ballast water, tank washing slops, oily mixtures containing chemicals, scale and sludge from tanker cleaning, oily bilge water and sludge from fuel oil purifiers.

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12) See www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx [last accessed 23 September 2013].

When designing reception facilities for vessel's waste, the types and quantities of solid and liquid wastes to be discharged or offloaded by a vessel calling at a marine facility should be assessed in consultation with the operator. Location and layout of waste reception facilities should take into account the waste transfer method for each waste type for the range of vessels to be accommodated.

15.2 Port wastewater and surface run-off

Surface water drainage systems should incorporate systems to minimize the potential for discharge of contaminated water in the event of accidental spills of oil and fuel in areas used by equipment and vehicles or for oil and fuel storage.

NOTE For example, for surface drainage of areas in a port where there is a high risk of a spill of hazardous materials (e.g. fuelling or fuel transfer locations), a basin or full retention separator capable of containing a spill might be used. For all other areas used by port vehicles, grit traps and by-pass separators are likely to be sufficient.

16 Port and maritime security

Design of port facilities should incorporate security systems and preventative measures required by the operator to address security threats to ports and shipping, and should conform to the ISPS Code [N5].

NOTE 1 The ISPS Code [N5] establishes an international framework involving cooperation between contracting governments, government agencies, local administrations and the shipping and port industries, to detect/assess security threats and take preventive measures against security incidents affecting ships or port facilities used in international trade. Although the application of the ISPS Code can be seen primarily as an operational matter, there are often implications for layout, design and detailing of aspects of maritime works, such as means of access, means of escape (including from the water) and fencing of waterfront areas and structures.

NOTE 2 Attention is drawn to the Port Security Regulations 2009 [35], under which ISPS Code provisions as applied to EU Member States are applied to the UK.

17 Design working life

The design working life of maritime works should be defined as set out in BS EN 1990 for the purpose of determining time-dependent performance, including fatigue-related calculations and design to achieve suitable durability.

NOTE 1 Indicative design working life categories for maritime works are provided in Table 1, although it is emphasized that actual working life values need to be carefully considered by project promoters according to the particular requirements and circumstances applying. For example, the requirements of an industrial development might be driven by economics of a business case, whereas for assets forming part of key national or regional infrastructure such as flood protection, works might require a similar structure to be designed for a longer working life.

The structure should be designed such that deterioration over its design working life does not impair the performance of the structure below that intended, having due regard to its environment and the anticipated level of maintenance, taking into account the aggressive nature of the marine environment and the difficulty and potential disruption to operational use arising from maintenance works in a port or exposed maritime location.

NOTE 2 The design working life is also significant when assessing probability levels for limit state design and for design condition return periods. However, the design working life is not necessarily the same as the return period of the design condition.

Table 1 **Indicative design working life categories for maritime works**

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures [A)]
2	10 to 25	Structural parts designed to be replaceable within a structure or facility of longer design working life
3	15 to 30	Structures dedicated to non-renewable natural resources, petrochemicals or similar industrial or commercial applications (such as open-piled jetties, mooring and berthing dolphins, Ro-Ro linkspans)
4	50	Common port infrastructure for commercial and industrial ports including reclamation, shore protection, breakwaters, quay walls
5	100	Common port infrastructure including breakwaters for ports of nationally-significant strategic or economic value. Infrastructure for regional flood defence or coastal management infrastructure

[A)] Structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary.

18 Vessel data

Comprehensive details of vessels to be accommodated should be established as part of the functional design basis for ports and marine terminals.

Such details should be obtained from the relevant authorities, end-users, owners and operators for the actual vessels to be accommodated and those likely in the anticipated lifetime of the structure.

Vessel details and characteristics that should be taken into account include:

- cargo type, including any potentially hazardous cargoes;
- size and shape (laden and in ballast), including overall length, beam, draught, flat of side extents, air draught, wind areas;
- vessel handling and navigational requirements;
- cargo or passenger capacity (measured according to cargo type in cubic metres, tonnes, lane metres, TEUs);
- cargo or passenger handling requirements;
- product transfer manifolds types and position (for liquid bulk tankers and gas carriers);
- mooring equipment, including deck plans of winch and fairleads, mooring line type and capacities and winch capacities;
- vessel servicing and waste reception requirements;
- propulsion systems, including thrusters and other water jets that can cause erosion and scour;
- allowable imposed loadings on the hull.

NOTE 1 Characteristic dimensions and hull forms of many ships vary considerably according to function, age and operational region.

NOTE 2 Key overall dimensions of length, beam and draught of vessels are provided for preliminary planning purposes in Annex D for the following shipand cargo types:

- *refrigerated gas carriers – LNG;*
- *refrigerated gas carriers – LPG;*
- *liquid bulk tankers (oil, oil products and chemicals);*
- *dry bulk carriers;*
- *container ships;*
- *general cargo;*
- *Ro-Ro ferries;*
- *cruise ships.*

These values are approximations and are intended to be used for preliminary purposes only. General guidance on vessel dimensions can also be obtained from the Lloyd's Register of ships *[36] and from commercially available online vessel databases.*

*NOTE 3 Vessel handling considerations are discussed in Clause **19** and Clause **20**.*

A vessel's nominal size, tonnage or capacity may be expressed or provided to a designer as follows:

- gross tonnage (GT), which is determined in accordance with the provisions of the International Convention on Tonnage Measurement of Ships, 1969 [13)];
- deadweight tonnage (DWT), which is measured in tonnes and provides an approximate indication of the carrying capacity of the vessel;
- the displacement of the vessel, which is the actual mass of the vessel and is therefore the significant parameter for computing berthing energies and for calculation of other hydrodynamic parameters.

In addition to the displacement at maximum rated cargo capacity, displacements in the unladen and ballasted state should also be established for design purposes.

NOTE 4 Gross tonnage (GT) is not to be confused with gross register tonnage (GRT). GRT is an obsolete term, although it is still used to describe vessel size by some parties.

NOTE 5 For the purposes of preliminary planning, the relationships given in Annex D, Table D.1 may be used to estimate full load displacement from DWT or gas-carrying capacity. These values are approximations and are not be used for detailed design unless confirmed by the actual vessel characteristics.

NOTE 6 Product transfer manifold configurations for oil and gas carriers are given in the following publications:

- *Manifold recommendations for liquefied gas carriers [37];*
- *Recommendations for oil tanker manifolds and associated equipment [38].*

13) See http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-on-Tonnage-Measurement-of-Ships.aspx [last accessed 23 September 2013].

19 Navigation channels and ship manoeuvring

19.1 General

*COMMENTARY ON **19.1***

The navigational ideal for the design and layout of channels and harbour entrances would typically call for:

- *straight, wide approach channels, the direction of which coincides with the direction of currents, winds and of the highest waves;*
- *a wide harbour entrance;*
- *a large area within the harbour for turning and manoeuvring to jetties and quays, and adequate separation between moored and passing ships.*

Such an ideal layout can seldom be achieved, particularly for harbours on the open coast, for the two following reasons: firstly, the dominant currents rarely coincide with the direction of the highest seas, and secondly, aligning the channel with the highest seas tends to maximize the wave penetration into the harbour. Ports located in estuaries, where the hydraulic conditions are determined mainly by the tides, normally offer better protection for seagoing navigation, and many of the larger existing sea ports are situated in such locations. Access problems can still arise, however, because vessels can be required to follow the sinuous course of a natural channel and finally cross the tidal currents to the harbour entrance or riverside quays. Often extensive dredging works have to be carried out to meet the increasing navigational demands of larger vessels, and considerable maintenance dredging operations might be needed to remove siltation both in the artificially deepened access channel and in the harbour itself.

The layout, alignment and dimensions of approach channels and manoeuvring areas for ships should be determined according to:

- the size and handling characteristics of the ships that will navigate to and from the facility;
- the need for other ships to use the approach channels concurrently;
- the marine traffic density, both initially and as forecast in the future;
- the availability, manoeuvrability and capacity of tugs;
- the hazards associated with the products carried by the ships;
- the meteorological and oceanographic conditions at the particular location;
- the engineering constraints of channel construction and maintenance arising mainly from soil conditions and the coastal or estuarial morphological environment.

*NOTE As noted in Clause **13** and Clause **14**, attention is drawn to the recommendation to involve appropriate operational personnel, such as experienced masters and pilots, in the planning of new and modified channels and manoeuvring areas.*

19.2 Planning and design studies

Approach channels should be designed in accordance with the recommendations set out in PIANC-IAPH PTC II Report WG30 [N6].

NOTE 1 Guidance is also given in PIANC MarCom Report WG116 [N4].

The scope of numerical simulation studies at the design stage should be sufficient for the quantitative assessment of DSOL for the facility, in order to inform the design stage assessment of weather downtime for the operations envisaged at the facility (see Clause **21**).

NOTE 2 Planning and design studies for channels and manoeuvring areas consistent with the PIANC methodology are normally carried out using a staged approach, summarized in Table 2.

Table 2 **Typical planning and design activities for channels and manoeuvring areas according to design stage**

Planning/design stage	Typical activities for each planning/design stage
Concept design	Relatively rapid assessment of principal dimensions based upon preliminary environmental data and physical site data, preferably informed by advice from navigation experts/master mariners and local pilots/harbour authorities
	Layout and dimensions based upon empirical rules and limited/simplified navigation simulations
	Further definition of vessel parameters and operational principles as the basis of detailed design
Detailed design	Development and refinement of the concept design informed by additional environmental and physical site data and by additional consideration of operating parameters and risks
	Metocean conditions for the proposed layout predicted using numerical simulation of wave and currents
	Real-time navigation simulations (preferably including full mission, but can be desktop when agreed with the operator to be appropriate for the planned operations) to fix and optimize layout and make assessment of operating limits on environmental conditions to be applied in the operating phase
	Morphological studies to assess potential for infill and optimization of capital versus maintenance dredging
	Dynamic studies of ship vertical motions to determine UKC requirements
Marine traffic assessment and quantitative risk assessment	Verification of design where required considering risk of collision or grounding on quantitative basis by marine traffic risk analysis and other studies, especially for: heavily utilized channels; busy ports with multiple terminals and mixed vessel types adjacent to multi-user channels; and hazardous cargoes
Operational planning	"Full-mission" simulations intended to define operating procedures in detail, for training/familiarization of masters, pilots and tug crews and to support risk assessment and contingency planning prior to the start of operations or introduction of different ship types in an existing channel or turning area

19.3 Vertical channel and manoeuvring area dimensions

19.3.1 General

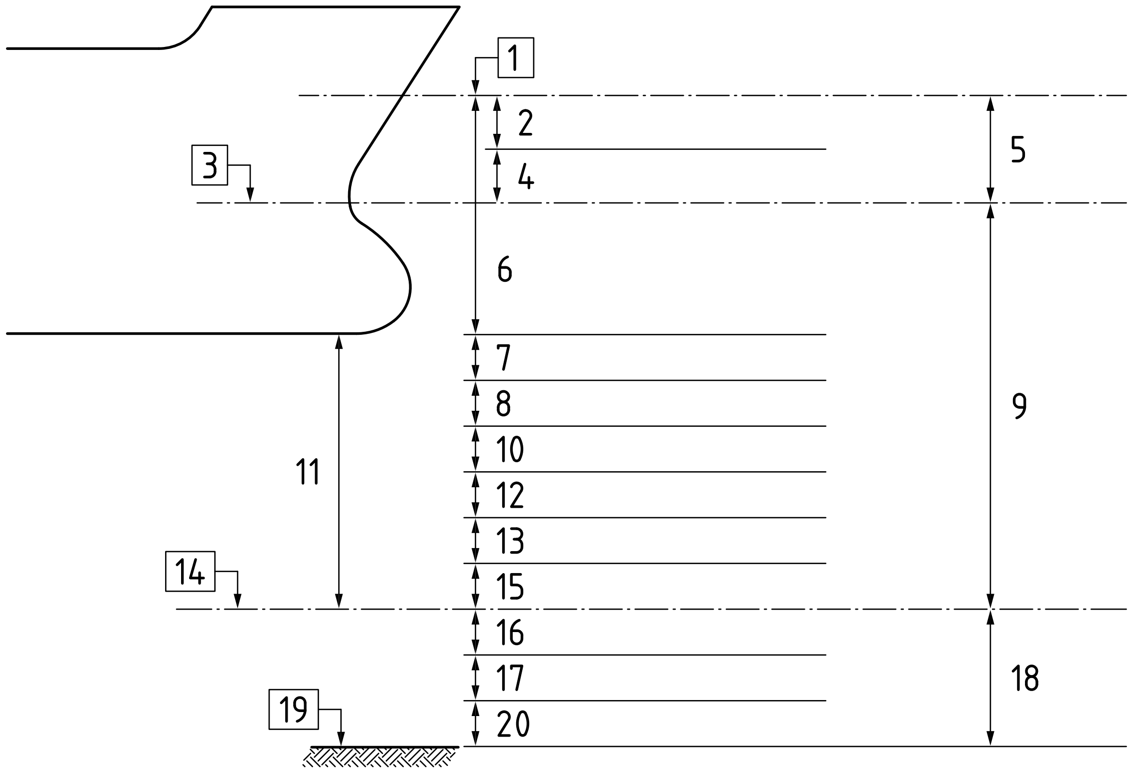
Vertical channel dimensions should be assessed based on the applicable depth factors and sub-factors set as follows:

- water level factors:
  - reference level (datum);
  - design water level;
  - tidal and meteorological effects;
- ship factors:
  - static draught;
  - allowance for static draught uncertainties including trim and list;
  - change in water density;
  - ship squat;
  - dynamic heel;
  - wave response allowance;
  - net UKC/manoeuvrability margin;
- bottom factors:
  - allowance for bed level uncertainties;
  - allowance for bottom change between maintenance dredging campaigns;
  - dredging execution tolerance;
  - muddy channel beds.

The depth factors are shown in Figure 1.

PIANC-IAPH PTC II Report WG30 [N6] provides "rule of thumb" guidance on nominal channel depths below design water level for preliminary use in conceptual design. These range from 1.10 × maximum design vessel draught in protected inner channels, with vessels at low speed, to 1.3 to 1.4 × maximum design vessel draught for outer channel environments subject to heavy swell. These factors allow for dynamic response of ships, including squat- and wave-induced motions, and should be taken into account only for draughts greater than 10 m. In any situation, additional allowances of 0.5 m (inner channels) to 1.0 m (outer channels) should be made to allow for the risk of bottom contact for firm or hard bottom types. Ship or fleet operators might have their own particular UKC policy, and should be consulted at an early stage in planning of a facility where such an operator is a stakeholder.

Figure 1 **PIANC channel depth factors**



Key

1 Design water level
2 Tidal offset during transit and manoeuvring [A)]
3 Reference level
4 Allowance for unfavourable meteorological conditions [A)]
5 Water level factors
6 Static draught
7 Allowance for static draught uncertainties
8 Change in water density
9 Ship-related factors
10 Squat
11 Gross UKC
12 Dynamic heel due to wind and turning
13 Wave response allowance
14 Nominal channel bed level
15 Net UKC
16 Allowance for bed level uncertainties (sounding and sediment conditions)
17 Allowance for bottom changes between maintenance dredging campaigns
18 Bottom-related factors
19 Channel dredged level
20 Dredging execution tolerance

NOTE This figure is based upon PIANC-IAPH PTC II Report WG30 [N6] and PIANC PTC II Report WG14 [39].

[A)] Values can be positive or negative.

19.3.2 Operational philosophy considerations

*COMMENTARY ON **19.3.2***

Key design and operational philosophy choices for a given location and range of design ship types and sizes are as follows:

- *acceptability of tidal limitations on entry or exit for some or all ships;*
- *maintenance dredging strategy, specifically:*
  - *depth of capital over-dredge to allow for siltation between maintenance dredging campaigns;*
  - *adoption of nautical depth approach for channels with beds comprising a layer of fluid mud of increasing density.*

The following factors should be taken into account according to the approach taken.

- Adoption of a tidal limitation can offer significant reduction in requirements for both capital and maintenance dredging, but results in limitations both on the overall capacity to handle shipping (and possible increased encounter frequency and collision risk of traffic in the channel during tidal passage windows) and in terms of downtime and waiting time for shipping. At some locations, tidal currents can also pose a limitation to channel transit or port entry or exit at certain stages of the tide. It might sometimes be possible to take advantage of reduced vessel dynamic response (a ship factor) at lower tidal levels if lower wave or swell action is present at times of lower tidal elevation.
- Adoption of the nautical depth approach can offer potential advantages in optimizing capital and maintenance dredging, particularly in areas of high siltation and other environments with near-bed fluid mud layers. However, there are significant practical issues and risks that should be addressed in implementation, including the following.
  - A practical criterion for the nautical bottom should be defined (e.g. selection of the physical mud characteristics acting as a parameter for the nautical bottom approach and its critical value).
  - A practical survey method should be proposed to determine both the acceptable level and the water–mud interface in an efficient and reliable way.
  - A minimum value for the required UKC relative to this nautical bottom should be established, noting the consequences of bottom "contact" for a fluid mud bottom, compared to a hard bottom.
  - The effect on the behaviour of ships in these situations should be assessed to the satisfaction of ship operators and pilots, coupled with training of operators, assessment of risks of adverse effects on controllability and manoeuvrability, and contingency plans to deal with such effects, if they are expected to occur.

NOTE 1 There is no guidance that specifies a particular density to define the nautical bottom, as there are many parameters that have an impact, including the density and rheological nature of the mud, which can vary from site to site and also within any particular site. As a consequence there is a range of values used around the world from 1 100 kg/m^3 to 1 250 kg/m^3, and in some cases there are multiple criteria, depending on the UKC. A pragmatic approach is to start with 1 150 kg/m^3 unless there is clear evidence that 1 200 kg/m^3 or greater is acceptable for the site in question, noting that it is a highly site-specific issue and will require a considerably detailed study to justify higher values. For hazardous cargoes such as liquefied gases or chemicals, ship operators are often less tolerant of grounding risk than for other types of shipping and might impose lower density limits for definition of nautical bottom than required by operators of other shipping. In addition, and in particular for gas carriers, the ship's cooling water intakes are generally located towards the bottom of the ship's hull and so can be affected if there is a high concentration of mud or sediment in the water.

NOTE 2 PIANC PTC II Report WG14 [39] provides guidance on development of maintenance dredging strategies which can be used for channel design optimization. For additional information regarding implementation of nautical depth in high turbidity regimes, see PIANC MarCom Report WG102 [40].

19.3.3 Ship factors

*COMMENTARY ON **19.3.3***

Channel depth assessment requires a comprehensive assessment of the dynamic behaviour of the design ship or ships when navigating through a channel or when manoeuvring in a port or near a marine terminal, including:

- *ship squat;*
- *dynamic heel;*
- *wave response.*

Squat is experienced by a ship as it moves through water, and the effect is increased in shallow water and in channels where hydrodynamic interaction between the water body and the moving ship is further affected.

The effect arises from the displacement of water, which causes an increase in return currents along the sides of the vessel and between the channel bed and the underside of the vessel. This is offset by a lowering of the adjacent water level, causing the vessel to experience sinkage and change of trim.

Additional squat is experienced by each of two ships when they pass, the effect being accentuated with reduction of UKC and vessel separation, as well as with an increase of speed. Additional sinkage is also caused by sailing in the proximity of a channel bank.

Dynamic heel arises during vessel turning and might be significant as a contributor to overall channel depth requirements in channel bends and in turning areas. During turning of a vessel, heeling can occur depending on a number of factors including ship's speed, rate of turn and tug line forces. Heel is defined here as the non-oscillating component of motion from environmental and tug forces, whereas roll is the oscillating component of ship response to waves.

The other component of the ship's dynamic response to channel depth requirements is the wave-induced response causing vertical and roll motions of the ship. The vertical component of response under waves and swell depends on the wave height and direction and the ratio of the wave length to the relevant characteristic dimension of the ship, i.e. length for pitch and heave and beam for roll. These factors determine the forces exciting the motion. The response of the vessel to these forces is mainly governed by the ratios of its natural frequencies in heave, pitch and roll to the encountered wave frequency, and by the damping of the motion in these modes.

In shallow water conditions the small UKC causes both the natural period, due to increase in added mass, and the hydraulic damping in each mode of movement, to increase.

The static draught of vessels for channel depth assessment should take into account:

- the maximum draught at the bow or stern if the ship does not have an even-keel draught;
- trim and list;
- the presence of thrusters or propulsion equipment which extend below keel level.

Given the complex hydrodynamics of vessel channel interaction giving rise to squat, there is significant uncertainty in the prediction of squat for channel design purposes using available empirical methods. This uncertainty should be taken into account in determining and optimizing overall channel depth requirements.

Response amplitude operators (RAOs) from numerical modelling of vessel response, or other suitable methods for assessing vertical ship response, should be used to determine vertical motions under expected wave conditions.

Physical modelling should be used as an alternative to numerical modelling in conditions of low UKC or other circumstances where numerical modelling cannot accurately simulate vessel dynamic response.

NOTE Use of physical models is less often required since numerical methods are usually adequate.

19.3.4 Net under-keel clearance

*COMMENTARY ON **19.3.4***

The gross UKC in channel design comprises all the components of draught and vertical dynamic response and then a further term referred to as the net UKC.

In preliminary concept design this net clearance can simply be taken as a figure of 0.5 m to 1.0 m depending on the nature of the bed, which in turn determines the consequence of contact between the ship's hull and the bed.

The definition of such a net UKC can also be used in detailed design in accordance with PIANC-IAPH PTC II Report WG30 [N6], where a deterministic approach is taken, but it is frequently more appropriate to adopt the probabilistic or semi-probabilistic approaches defined by PIANC-IAPH PTC II Report WG30 with a minimum manoeuvrability margin (MM) to ensure that reduced UKC does not result in inadequate ship manoeuvrability. Practically, this would normally be a concern only in sheltered inner harbour areas where the allowance for dynamic response caused by wave action would otherwise be low. PIANC-IAPH PTC II Report WG30 proposes a minimum MM of 5% draught or 0.6 m, whichever is greater.

The overall design gross UKC should be assessed by summation of the components of draught and vertical dynamic response and an additional net UKC to provide a safety margin against bottom contact.

19.3.5 Design philosophy

NOTE PIANC-IAPH PTC II Report WG30 [N6] envisages a concept design stage using simplified deterministic approach where applicable depth factors are assessed and combined arithmetically.

The detailed design should include a further assessment of depth factors using comprehensive analytical methods. When sufficient statistic characterization of the uncertainties and variability of the depth factors can be obtained, detailed design may allow for optimization of total depth requirements using probabilistic or partially probabilistic methods.

For probabilistic or partially probabilistic methods of depth assessment, limiting design criteria should be defined with respect to acceptable probability of contact between the channel bottom and the ship's hull or keel.

PIANC-IAPH PTC II Report WG30 [N6] indicates possible approaches to the definition of such criteria, but there are no internationally recognized criteria, and any such criteria should be agreed on a case-by-case basis with the operator in conjunction with ship operators and harbour authority when appropriate, taking into account the risks for different ship types, cargo types and channel bottom characteristics.

Probabilistic design methods should be used only when the quality and extent of the input data are sufficient for these methods. When only partially or incomplete data sets are available, partially probabilistic or empirical methods should be used.

19.4 Horizontal channel and manoeuvring area dimensions

19.4.1 Alignment and width of channels

NOTE 1 The width of access channels is governed mainly by the steering characteristics of the vessel in response to the pilot and helmsman when subject to external disturbances such as the hydrodynamic effects of cross-currents, wind, waves, bank effects and other traffic. Large ships normally take a relatively long time to respond to any change in circumstances, and can be rendered even more sluggish in their response to a given force applied by the rudder, due to the increase in the hydrodynamic forces and added mass of the ship when the UKC is small. Thus in negotiating channels with bends, large changes of helm and engine speed are common (although are often brief), and even in straight restricted channels vessels can take a sinuous course.

Channel width and alignment should be determined according to the recommendations of PIANC-IAPH PTC II Report WG30 [N6], using empirical rules for initial sizing and numerical simulation of vessel approach and departure to confirm and optimize the layout and horizontal dimensions in later stages of design.

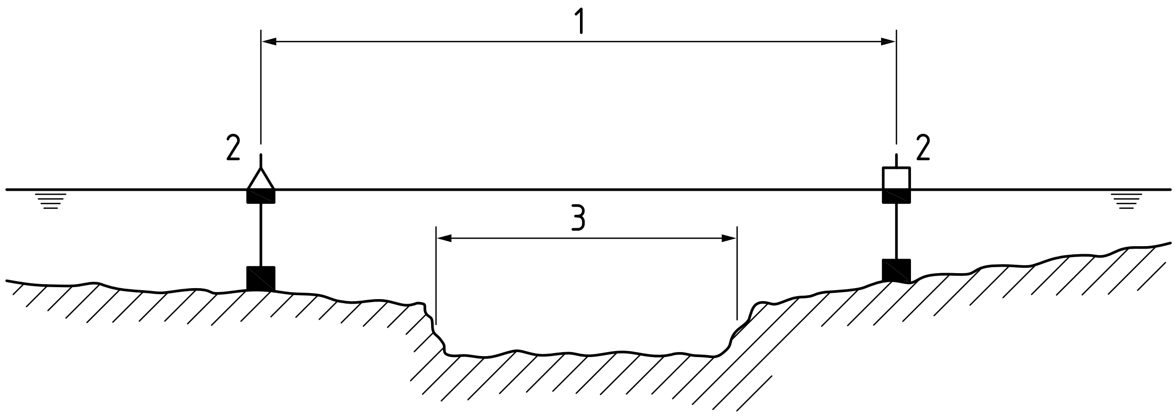
Selection of channel alignment should be primarily by the needs of safe and efficient navigation, balanced against the constraints of physical and environmental conditions and the associated engineering considerations, such as the minimization of capital and maintenance dredging. To achieve enhanced operability and minimize weather downtime and navigation risks:

- bends or curves should be minimized, and bends avoided at or close to the ends of the channel and at harbour entrances;
- channels should be aligned, where possible, so that prevailing wind, currents, waves and swell are not acting across the channel (and thus causing the ship to deviate from its course).

The effects of cross-currents and wind on manoeuvrability have the greatest effect on a ship at low speeds in inner channels and final berth approach. Where strong tidal currents exist, it might be necessary to limit approach and departure to defined periods around slack water, which should be taken into account in downtime assessment.

NOTE 2 The definition of channel and fairway dimensions and elements of channel width as used by PIANC-IAPH PTC II Report WG30 [N6] are shown in Figure 2 and Figure 3. A fairway indicates a wider space that can be used by vessels with shallower draught than vessels using the main deep draught channel.

Figure 2 **PIANC definition of channel and fairway**



Key

1 Fairway

2 Buoy

3 Channel

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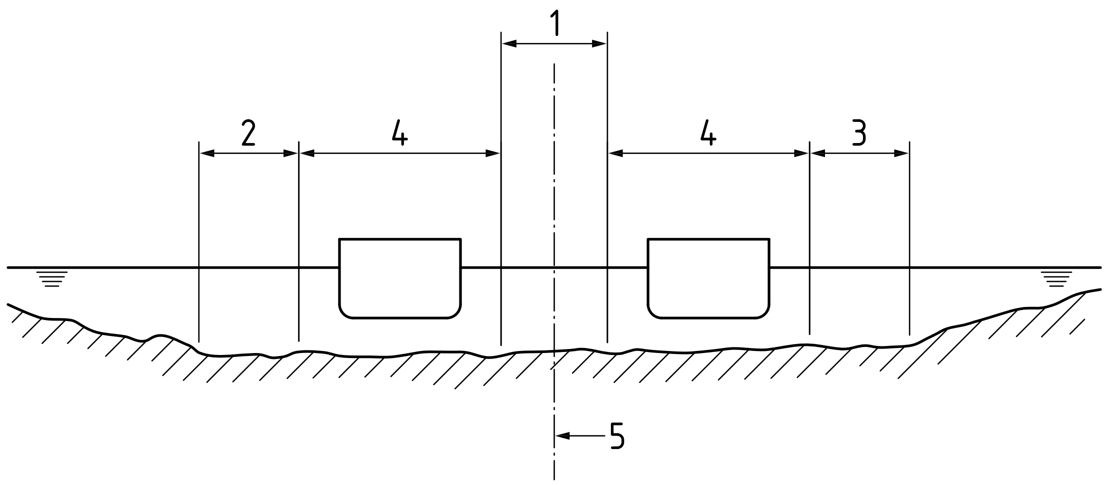
Figure 3 **PIANC definition of elements of channel width**



Key

1 Passing distance, W_p

2 Bank clearance, W_{Br}

3 Bank clearance, W_{Bg}

4 Manoeuvring lane, W_M

5 Channel axis

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The PIANC empirical channel design method for straight channels requires definition of a basic manoeuvring lane width W_{BM} of 1.3 × *B* to 1.8*B*, where *B* is the beam of the design ship, according to ship type, to which additional width allowances W_i should be added to obtain the total manoeuvring lane width W_M.

NOTE 3 These additional lane width allowances take into account the effects of:

- *vessel speed;*
- *cross-wind;*
- *cross-current;*
- *longitudinal current;*
- *wave conditions;*
- *navigation aids;*
- *channel bottom type;*
- *depth;*
- *cargo hazard level.*

An allowance W_p should be added as a separation distance between lanes for two-way channels according to PIANC-IAPH PTC II Report WG30 [N6], with regard to vessel speed, wave exposure conditions and traffic density.

The additional width for bank clearance W_{Br} or W_{Bg} (red and green channel sides respectively) should also be determined according to the recommendations of PIANC-IAPH PTC II Report WG30 [N6] according to vessel speed, wave exposure conditions and the slope and type of the bank.

NOTE 4 As a general guideline, it is suggested that the ratio of channel width to the beam of the vessel is typically between 4 and 6, for one-way movements, depending on local conditions. For somewhat smaller vessels passing one another, the minimum width of channel is typically about 6 to 8 times the beam of the larger vessels, depending on the exposure and straightness of the channels. For large tankers, of up to 300 000 DWT, with either straight or curved channels subject to cross-tidal currents, recommended ratios of channel width to beam lie between 5 and 7.

Two-way traffic of large tankers should be avoided whenever possible.

Bends in approach channels should be avoided or minimized, but if necessary guidance on determining channel radius and additional width requirements for concept design should be taken from PIANC-IAPH PTC II Report WG30 [N6], with a recommendation that the conceptual design bend radius should be at least 10 times the length of the largest vessel that is likely to use the channel on a regular basis.

Detailed design of channel alignment and width should include further assessment of the considerations from the concept design stage and optimization of engineering and navigation aspects, based upon:

- more comprehensive physical and environmental data for the location, including metocean data, soils data and sediment transport data;
- more comprehensive numerical and analytical studies, including hydrodynamic and morphological studies, ship dynamic response studies, numerical navigation simulation, traffic studies and navigation risk assessments;
- further operational and contingency planning, such as planning of tug requirements and development of design stage operating philosophies and downtime assessments.

The recommendations of PIANC-IAPH PTC II Report WG30 [N6] should be followed for the nautical aspects of detailed channel design.

19.4.2 Harbour entrances and manoeuvring areas

*COMMENTARY ON **19.4.2***

The port, harbour or terminal approach system typically comprises the following functional elements:

- *outer channel section (assumed to be fully exposed to wave action and tidal currents);*
- *the harbour entrance (where ships pass into a water space more protected from wave action and currents);*
- *inner channel section (within a protected turning basin or manoeuvring area).*

Not all ports or terminals are necessarily physically configured in this way, e.g. the approach to an oil or gas terminal which is unprotected by a breakwater, but the design principles involved remain valid.

Design of harbour entrances and manoeuvring areas should take into account the passage and handling requirements of ships through the entire approach system to and from the turning area, taking into account of the range of tides, currents and waves and the assistance available in the form of pilots, tugs and aids to navigation.

The most significant ship factor for entrance design is the stopping procedure and distance for the design ships. Actual stopping distances should be obtained if available for the design ships or ship types, although these are likely to be deepwater distances from sea trials or tank tests.

NOTE 1 Such tests are not directly applicable inside harbours where the conditions are characterized by confined and shallow water, low speeds, tug assistance and manoeuvres with rudder and propeller to hold course.

Stopping distances should be verified using numerical navigation simulation to determine actual stopping distances based on local environmental conditions, actual speeds at entrance/exit through entrance and tug assistance.

NOTE 2 For preliminary concept design for ships typically smaller than 50 000 DWT, this may be estimated by rule of thumb based on the length of the ship and the condition of the ship (in ballast or loaded); typically this indicates that stopping distances from the harbour entrance to the centre of the turning are of multiples of 3 (ballast) to 8 (loaded) of the ship's length.

NOTE 3 Similar rules of thumb exist for the preliminary sizing of turning areas. Although a turning area does not need to be circular in plan, preliminary sizing requirements are expressed as a turning circle of diameter of a multiple of the ship's length. Typically for modern vessels with tug assistance, an indicative diameter of 1.8 to 2.0 × the ship's length can be achieved subject to local wind, wave and current conditions and UKC. For ships equipped with powerful bow and stern thrusters, such as are commonly found on modern container and cruise ships, the indicative turning circle diameter may be reduced to 1.5 to 1.6 times the ship length. Without tug assistance, much larger turning area dimensions would be required, typically up to 4 × the ship's length, although turning in an enclosed basin without tug assistance is unlikely to be desirable or operationally acceptable for larger classes of vessels or for ships with hazardous cargoes. Turning areas have to be more elliptical in shape where there is a prevailing current or wind across the turning area that will cause the ship to drift during the swing.

NOTE 4 For Ro-Ro or ferry terminals, structures can be used to assist in the turning of vessels in much smaller manoeuvring areas. Such structures often take the form of turning dolphins or fendered corners of jetties/quays, where roller fenders can be used.

Numerical or physical model studies of wave and current conditions should be carried out to predict conditions along the harbour or terminal approach and in the turning area.

Conditions in and around existing, new or modified harbour entrances should be assessed, such that potentially adverse effects on navigation or the environment are taken into account in design and operational planning, including the following.

- At the immediate approach to the harbour entrance, sea conditions can sometimes be rougher than elsewhere, due to the waves becoming steeper, especially on an ebbing tide.
- Reflection of waves from the harbour walls or breakwaters, particularly when these are steep-sided, can combine with incident waves to form areas of confused seas.
- Reflection (total internal refraction) of waves from underwater channel slopes can cause enhanced wave action at the harbour entrance. This is a particular risk when prevailing wave or swell is closely aligned to the outer channel direction and, in addition to navigation hazards, can also give rise to or enhance erosion of nearby coastlines.

In determining the layout of inner channels and manoeuvring areas, account should be taken of the need to maintain adequate separation between moving vessels approaching and departing and moored ships at berths within the port or at adjacent terminals. The separation distances adopted should be sufficient to:

- reduce the risk of collision with moored ships (also referred to as allision);
- avoid excessive mooring line loads or ship movements that can disrupt cargo-handling operations of the moored ship;
- avoid encroachment into a marine exclusion zone or other such area around the berth to which entry is restricted for reasons of security management. For hazardous cargo berths, a safety zone might exist in which certain activities (including those that give rise to sources of ignition) are excluded.

For preliminary assessment with a passing ship speed of 4 knots or less, the separation distance (hull side to hull side) should be at least $2B$ and at a passing ship speed of 6 knots or less, the separation distance (hull side to hull side) should be at least $4B$. This rule of thumb is applicable to ships of $B \geq 25$ m.

19.4.3 Numerical simulation methods for channel and manoeuvring area spatial design

Numerical simulation methods are recommended for channel and manoeuvring area spatial design, and the recommendations of PIANC-IAPH PTC II Report WG30 [N6] should be used for planning and conducting numerical simulations to inform alignment and dimensions.

For design purposes, an approach should be selected according to the stage in the design process and the definition of input data from the following generic methodologies:

- fast-time simulation (desktop);
- real-time simulation (desktop);
- real-time simulation (bridge simulator, also referred to as "full-mission" simulation).

The methods of simulation, and operations and circumstances to be simulated, should, where possible, be selected with guidance from specialist personnel with experience of acting as vessel masters or pilots for similar vessel types, sizes and environmental conditions.

NOTE 1 Fast-time simulation is normally appropriate to early stages of design development using simplified characterization of environmental conditions. It is relatively rapid and is appropriate when a wide number of layout options and conditions are to be simulated and compared at the concept design stage. It might also be useful to carry out large numbers of multiple runs on a semi-automated basis to provide synthetic information on potential variability of a vessel-swept path, which can in turn inform probabilistic approach to horizontal channel and manoeuvring area dimensioning for detailed design. However, this form of simulation is only appropriate in certain circumstances. These are where the actions of a pilot are reasonably simple and where the concept of a reference track is valid, such as for the design of relatively long, straight channels, or those with few bends. In simulating the final stages of an approach to a port or berth, when using tugs or when turning the ship in a turning area, fast-time simulation might be less appropriate, due to the complexity of the manoeuvres required.

NOTE 2 Real-time simulations offer potentially more realistic and detailed simulation of operations with the involvement of mariners and pilots. Real-time simulation can incorporate up to 360° visualization and a reproduction of the environment and controls of the ships bridge. Real-time simulation with bridge simulation offers the maximum potential to realistically represent and investigate human factors in the channel design. Although the specialized nature of the facility required and the effort involved in setting up realistic visualizations normally means that such studies are carried out at later stages of design development (including for design and selection of aids to navigation) and for operational planning and training, real-time simulation can also be used effectively with relatively simplified configurations. Such simplified real-time simulations can be used in the early stages of design to examine more complex aspects of ship manoeuvring, where fast-time simulation might be less appropriate.

Whichever simulation methodology is adopted, the numerical models used should be able to accurately and realistically represent the behaviour of the ship in a shallow water environment at low speed, and should use manoeuvring strategies that are both practicable and realistic. The assistance provided by tugs should also be shown to be appropriate to the environment and the tug type and mode of assistance.

It is therefore important that in addition to selecting the methodology/human interface, particular attention should be given to:

- hydrodynamics of the ship and their response in shallow water and to wave and current effects;
- aerodynamics of the ship's response to wind effects;
- realism of the simulated effectiveness of tugs (e.g. in close-quarters push mode versus long line pull mode, in waves, flows/currents and when under way);
- representation of hydraulic interaction with channel banks or passing ships;
- type and characteristics of thrusters;
- type and characteristics of propellers (fixed or variable pitch) and rudders;
- response and reaction times (e.g. time to deliver power to propellers, time for tugs to attach a line, time for a tug to apply effective bollard pull);
- accurate representation of wind, waves and currents.

Any coupling between environmental conditions and model response should be taken into account.

NOTE 3 For example, does the model represent the reduced effectiveness of tugs in high waves or does this have to be manually adjusted by the operator?

In planning a campaign of numerical ship simulations, an assessment should be made of the range of environmental conditions, types of normal operations and types of abnormal operations or exceptional events that are to be considered in design. The combinations of environmental conditions for the simulations of normal operations should be consistent with expected environmental operating limits for the operation or manoeuvre under study. Abnormal operations or events for simulations should be evaluated by risk assessment on a ship-, cargo- and location-specific basis.

NOTE 4 PIANC MarCom Report WG116 [N4] illustrates a typical approach for oil and gas tanker studies, where abnormal or "emergency" scenarios can include:

- *ship steering gear failure at the maximum rudder angle likely to be used at a bend or turn;*
- *partial steering gear failure, where the rudder can be recovered within a certain time period (e.g. 2 min to 5 min);*
- *ship main engine failure;*
- *blackout on board ship including all onboard systems (loss of engine, steering and bridge navaid equipment);*
- *impact of squalls (or similar rapid changes in weather conditions or in visibility) in locations where they might occur with little warning.*

For hazardous cargoes it is typically required that that the ship can be safely handled in such credible abnormal events in environmental conditions up to the operating limits.

19.4.4 Marine traffic assessment

In heavily utilized channels and harbour areas, account should be taken of the need to supplement the dimensional sizing determined from nautical requirements by use of marine traffic assessment, in order to demonstrate that:

- the channel and manoeuvring area dimensions are adequate for the total shipping traffic forecast for the design working life;
- risks of collision between moving ships or between moving ships and berthed ships (allision) or port and terminal infrastructure are minimized and managed to levels considered appropriate by the harbour authority or other relevant regulatory body.

Vessel traffic services (VTS) systems should meet the requirements of the IALA VTS manual [N7].

NOTE 1 Guidance on the methods of conducting marine traffic studies and risk assessments is given in PIANC-IAPH PTC II Report WG30 [N6].

NOTE 2 In the case of hazardous cargoes or operations, a quantitative marine risk assessment might be required to establish a safety case demonstrating, for example, that risks have been reduced to as low as reasonably practicable (ALARP).

20 Berths and mooring

20.1 General

Discussion of operational practices at a planned berth should be held with the operator, pilots and ships' masters, with a view to determining the optimum layout for safe usage and the design parameters necessary for assessing mooring and berthing loads.

For berths for large ships, including bulk carriers, oil and gas tankers and container ships, the berthing and de-berthing operation should be taken into account as an input to berth layout and mooring and fender design, and in determining clearances from adjacent berths and from navigation channels and other ship movements.

Navigation studies and simulations for planning and design of channels and manoeuvring areas, as described in Clause **19**, should be used to assess optimum berth location, orientation and separation distances.

Wherever practicable, berth alignment and location should be selected to facilitate ship handling in berth approach.

NOTE 1 For example, for LNG carriers and VLCCs berths oriented with the prevailing wind, the amount of tug force required to assist in berthing is much reduced compared to an orientation with the prevailing wind beam-on to the ship. The reduced tug force enhances the degree of control in berthing for a given wind speed and reduces potential operational downtime. Large vessels are usually brought to rest a short distance off the jetty or quay and then manoeuvred on to the quay with the aid of tugs. Electronic speed and distance of approach system may be employed, using either fixed jetty-based systems with display units visible from the ship's bridge, or portable GPS units carried by the pilot. Such systems help the pilot to keep within the maximum allowable speed and to achieve the optimum angle of approach for which the fenders and jetty layout have been designed. Predictions of berthing behaviour may also be derived from measurements recorded at other berths in comparable situations.

NOTE 2 Navigation studies are not normally suitable to quantify berthing speeds, although they can provide insights into the difficulty or otherwise of berthing under certain conditions.

Design of berths for ships that make a bow or stern approach to a berth under their own power, such as ferries and Ro-Ro vessels, should in particular take into account the need to ensure safe and efficient ship operations when operating on short turnaround times. Full discussions with the relevant operators and authorities are particularly important in this respect.

Records of berthing impacts should be correlated, if possible, with ambient conditions of wave height and period, wind speed and direction, current velocity and tug assistance or technical aids.

NOTE 3 Information on safety in respect of berthing of oil and gas tankers is given in PIANC MarCom Report WG 116 [N4].

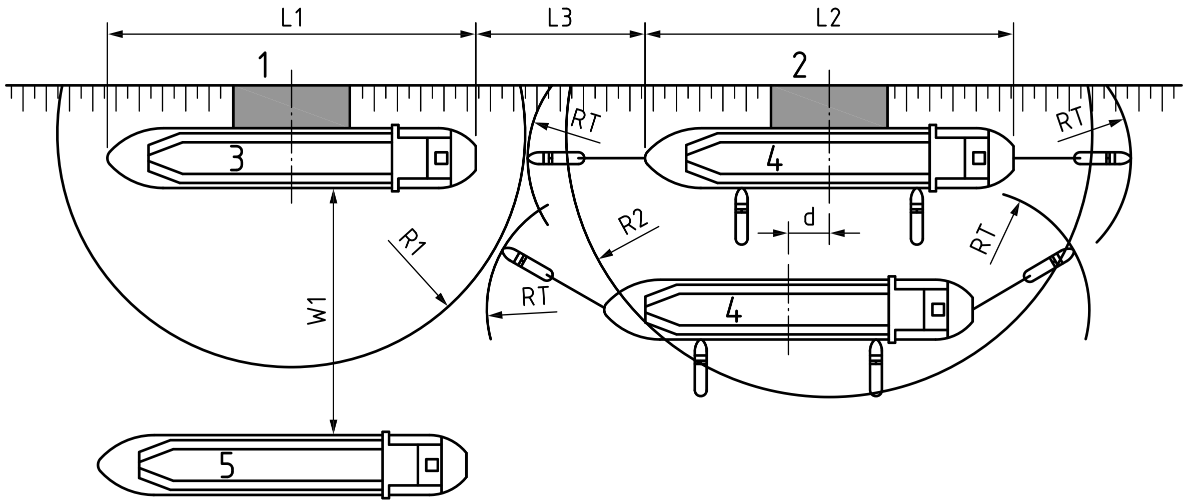
For oil, gas, petrochemical and other hazardous cargoes, berthing operations are affected by stringent security and safety requirements which should be taken into account in layout and design of berth facilities.

NOTE 4 For example, for LNG facilities, BS EN ISO 28460 defines a marine exclusion zone (MEZ), which is an area around a jetty in which no unauthorized traffic is allowed to enter, and which can vary according to jetty operations and different security levels in force from time to time. The requirements for such a zone have implications for planning the location and layout of jetties.

In addition to security issues, for oil, gas, petrochemical and other hazardous cargoes it is typically required to operate a safety zone defined in relation to the product transfer manifold in which certain operations and activities (including those giving rise to sources of ignition) are excluded. Requirements for such safety zones should be established at an early stage in design, since they can have a large impact on layout and location of hazardous cargo facilities.

NOTE 5 Figure 4, reproduced from PIANC MarCom Report WG116 [N4], illustrates the conceptual zoning and separation philosophy to be considered for oil and gas tanker berths where for preliminary planning purposes the safety zone may be taken as a radius around the product transfer manifold. Figure 4 illustrates the importance of considering the potential for interaction between berthing operations at adjacent berths, including activities of tugs and mooring boats.

Figure 4 **Considerations for layout and separation distances of oil and gas tanker berths**



Key

1 Berth 1
2 Berth 2
3 Tanker 1
4 Tanker 2
5 Passing ship
d Offset of vessel's position on approach
L1 Overall length of vessel moored to Berth 1
L2 Overall length of vessel berthing at Berth 2
L3 Length between manoeuvring vessel and end of basin/grounding line
R1 Safety zone centred on vessel manifold at Berth 1
R2 Safety zone centred on vessel manifold at Berth 2
RT Working distance of combined tow line and tug from vessel hull
W1 Spacing between moored vessels and passing vessel
W2 Spacing between a moored vessel and opposite obstruction
W3 Distance between berth fronts at finger piers

NOTE 6 Safety zoning requirements are usually determined by quantitative risk assessment, taking into account product type, credible incident scenarios around product spills such as loading arm failure, spill dispersion modelling, fire and explosion modelling, safety systems and prevailing environmental conditions. It is operationally desirable to avoid overlapping safety zones and to achieve a layout where adjacent berth operations are completely independent. Nevertheless, this is not always achievable in practice, and for a multi-berth terminal the operator might accept some limitations on activity (such as suspension of cargo transfer to reduce risk in the event of a flammable spill) for a short period when a ship is berthing or de-berthing at the adjacent berth. Any such operational restriction would need to be taken into account in plant availability and downtime estimates.

For less hazardous products/cargoes, where separation distances are required by the operator to be kept to a minimum, separation distances between ships should allow for safe manoeuvring and mooring requirements, and for ship movement on the berth that results from wind, current, wave and passing ship effects.

NOTE 7 From a safe manoeuvring point of view, typical separation distances at major container terminals are in the order of 15 m to 40 m between moored ships (dimension L3 in Figure 4) depending on vessel size, local conditions, the use of tugs and the use of the ships' propulsion/manoeuvring systems.

NOTE 8 Recommendations for the design of fendering and mooring systems, including the assessment of berthing velocities and energies and the arrangement and spacing of dolphins and fenders for different berth and quay functions, are given in BS 6349-4. Recommendations for the assessment of berthing and mooring loads and actions will be provided in BS 6349-1-2, which is currently in preparation. Recommendations for the design of quay walls, jetty and dolphin structures are provided in BS 6349-2.

20.2 Mooring and mooring conditions

20.2.1 General considerations

NOTE 1 The functional requirement of a mooring system is to safely secure the vessel in position at a berth under the action of environmental and other forces acting on the vessel when moored and during cargo handling and transfer.

Mooring systems should be designed in accordance with BS 6349-4, taking into account the particular operational and functional requirements of the facility. The layout and location of a berth facility should be assessed to determine whether or not the location will be acceptable for mooring operations for environmental conditions up to the design stage operating limits.

The assessment of safe and operationally acceptable wave conditions for vessels to stay at berths should be based upon an assessment of safety, operational and human factors, including:

- limiting loads and stresses in mooring lines and fenders;
- limiting loads and impact forces on the moored vessel;
- limiting displacements and accelerations for different cargo handling cranes and dry bulk systems requiring human control;
- limiting displacements and accelerations and consequent stresses in loading arms, hoses and manifolds for oil, gas and petrochemical products with transfer by mechanical ship-to-shore connections;
- limiting motions, displacements and accelerations for direct personnel or vehicular transfer between vessel and shore for crew and passenger access and for Ro-Ro operations;
- limiting motions, displacements and accelerations for health, safety and comfort considerations for people on the vessel;
- safety and environmental risks associated with cargo spillage for hazardous cargoes.

These factors should be investigated by carrying out mooring studies supplemented with advice from operators experienced in the relevant types of vessel and cargo types, so that the operability of the berth is established at the design stage in relation to prevailing environmental conditions. The environmental limits for different operations and operating conditions considered at the design stage should be made available for preparation of the facility operating manual and in planning for operations as described in **13.2**.

*NOTE 2 Clause **21** gives recommendations for the assessment and quantification of weather downtime from operability analysis, taking into account wave and other environmental effects.*

NOTE 3 At many locations, wind effects are the dominant factor in restricting operations with elevated cargo handling equipment such as container cranes and large petrochemical loading arms.

20.2.2 Methods for assessment of acceptable wave conditions for moored ships

20.2.2.1 General

*COMMENTARY ON **20.2.2.1***

In the absence of other operator and safety requirements, the acceptable wave conditions for moored vessels in general relate to:

- *limits of the fender and mooring system load capacity;*
- *limits of motions (displacement and velocities) affecting cargo operations or safety of personnel or vehicles transferring between vessel and shore.*

There might be other safety- or operational-related issues which could also affect a vessel's capacity to remain at a berth, e.g. a requirement for vessels to depart from a berth when winds or wave conditions are forecast to exceed a defined environmental operating limit, and before conditions become unsafe for departure.

For ships of 10 000 DWT and larger, assessment of acceptable wave conditions should normally be based on mooring studies to quantify mooring line loads, fender loads and vessel motions, and compare them with allowable loads and motions.

Allowable ship motions should be assessed on the basis of an analysis of the operations to be carried out when the ship is berthed. Information should be obtained from cargo handling equipment manufacturers and operators to determine the acceptable limits of displacements, velocities and accelerations.

Ro-Ro ramps, linkspans and walkways should be designed in accordance with BS 6349-8.

NOTE For vessels less than 1 000 DWT and for preliminary design for larger vessels before an operation-specific assessment has been carried out, guidance on limiting motions and displacement is given in Annex E, which is based upon PIANC PTC II Report WG24 [41], PIANC MarCom Report WG115 [42] and BS 6349-8.

In the case of cargo operations that impose no obvious limitations in the link between the vessel and shore, the amount of acceptable movement should be defined by personnel with relevant experience of similar cargo or vessel handling operations.

Oil and gas tanker berths should be designed according to the terminal design provisions of OCIMF MEG3 [N8], including:

- the specific recommendations for berth and terminal designers prescribed therein;
- the characteristics of ship's mooring equipment and operational practices also described therein.

The operational safety requirements for a berth in relation to circumstances when ships will leave the berth or when ships will remain at a berth in extreme weather events should be agreed with the operator at the design stage. These requirements should in turn be used to inform the structural capacity requirements for berthing and mooring structures and environmental operating limits.

20.2.2.2 Limits of the fender and mooring system load capacity

In addition to motion criteria, the other principal determinant of acceptable wave conditions for a moored vessel is the capacity of the mooring system including mooring lines and equipment, fenders, supporting structures. A limiting factor for fender loads is also the allowable hull pressure in contact with the fenders. The capacity of these mooring system components and of the ship should be assessed based upon the specific ship and mooring equipment types proposed and information from the operator and from data from the mooring equipment and fender manufacturer.

Capacities of mooring equipment of oil and gas tankers should be based on the provisions of OCIMF MEG3 [N8].

NOTE The degree of movement of a moored ship in conditions up to the limiting capacity of the mooring system in is a function of the softness or stiffness of the mooring system. At berths for large ships exposed to wave action, softer mooring and fendering systems can be adopted to increase the limiting wave conditions and reduce the risk of parting of mooring lines under dynamic loads, provided that the cargo handling or transfer systems can be designed to accept the increased motions. For oil, gas and petrochemical berths at exposed locations, this is typically be possible since liquid cargo transfer arms or hose systems can be designed to accept large motions. Softening of mooring systems can be achieved by the use of pneumatic fenders and extended polyamide tails on a ship's mooring lines.

20.2.2.3 Moored ship dynamic response

Prediction of acceptable wave conditions for mooring and cargo handling for design purposes should be undertaken by fully dynamic numerical model studies, supplemented by physical model studies where necessary.

NOTE 1 Some general background information regarding the dynamics of moored vessels is given in Annex E, ***E.5****.*

NOTE 2 For concept design it might be possible to make preliminary assessment of acceptable wave conditions using benchmarked values for defined classes of vessels in similar berth configurations. Such values could be compiled from previous studies, from operational records and from anecdotal information from operators (particularly pilots and ships' masters).

20.2.2.4 Numerical models

COMMENTARY ON ***20.2.2.4***

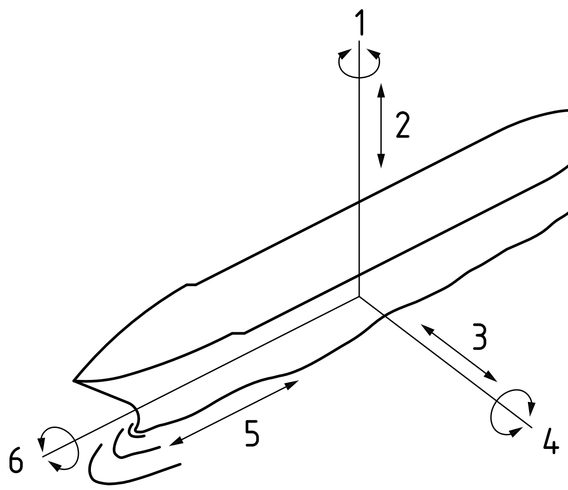
Numerical models may be used to estimate motions and mooring line loads of moored vessel under wave action in combination with other environmental effects. Such models provide solutions to the equations of motion for the six degrees of motion of the vessel, namely surge, sway, heave, roll, pitch and yaw (see Figure 5). The six modes of motion are not independent but are to some extent coupled.

The equations of motion include the following variables:

- *vessel mass;*
- *added mass;*
- *displacement;*
- *retardation function;*
- *damping force (mooring lines and viscosity);*
- *restoring force;*
- *mooring force;*
- *external forces (due to environmental locations).*

The external wave force comprises first order forces, for which the response is direct and immediate, and second order forces, where the hydraulic interaction between waves generates steady or slowly varying drift forces.

Figure 5 **The six degrees of freedom of vessel motion**



Key

1 Yaw
2 Heave
3 Sway
4 Pitch
5 Surge
6 Roll

In order to represent the effects of first and second order wave forces and in order to take into account irregular waves and non-linear mooring system behaviour, numerical simulation should be carried out for the moored ship, solving the equations at increments in time using a time domain analysis to produce a time-series of motions and loads.

NOTE 1 This is often referred to as fully dynamic mooring analysis. Wave forces on the ship hull are often modelled using potential theory using a frequency domain analysis to sum the components of wave forces in the complete spectrum. This provides a hydrodynamic transfer function in which the wave force is calculated through the time increments in the time domain simulation. Simulations normally take into account a single sea state (expressed as a spectral function) acting on the complete ship at each point in the time domain.

Alternative formulations of the equations of motion are possible in respect of the retardation function and radiation forces. Characterization of added mass and damping terms is important, and the formulation adopted should be appropriate to the prototype circumstances (e.g. a ship moored at a vertical face compared to a ship moored at an open jetty).

Coexisting wind forces should be represented in time domain simulations as a varying force using an appropriate spectral function.

All numerical models should be validated against prototype data or physical model tests to demonstrate that the models replicate motions and line forces in idealized conditions.

The uncertainties involved in numerical ship dynamic simulations should be taken into account when applying results to planning and design of maritime works. In critical cases this should include use of studies of sensitivity of results to key input or modelling parameters.

Where indicated by assessment of uncertainties, and in cases where the prototype conditions and berth configuration cannot be adequately represented in the simplified idealization inherent in numerical simulation, physical modelling should be undertaken to estimate motions and mooring line loads.

NOTE 2 For example, numerical simulations often cannot accurately represent complex wave fields, which can vary over the length of large ships. The hydrodynamic transfer function is less accurate when physical conditions deviate from the idealized conditions of the formulation such as, for example, when the seabed slopes significantly along the length of the vessel, low UKCs and complex quayside geometry.

The numerical simulation of bound and free infragravity waves in shallow water and complex harbour geometries, and the inclusion of shallow water infragravity energy into dynamic ship response, is particularly challenging. The relative influence of infragravity effects on ships response should be carefully assessed in deciding upon modelling methods for simulation of mooring of large ships such as oil tankers, LNG and LPG carriers and container ships.

20.2.2.5 Physical models

COMMENTARY ON ***20.2.2.5***

Physical moored ship models can be used as an alternative to numerical simulations to predict the dynamic response of moored ships under wave action. Physical models offer the potential to more comprehensively and realistically simulate all the hydrodynamic processes driving ship response and local bed and quay configurations compared to numerical simulations, although advances in numerical modelling techniques since the 1990s have resulted in a reduced need for physical modelling in some instances. Also, although a physical model in a wave basin can potentially reproduce complex wave conditions in a harbour, the scale of the model required to achieve this in available wave basin sizes might result in a need to compromise in the ship model size compared to the preferred maximum scale for optimum replication of ship behaviour and measurements of movement and mooring loads. A nominal minimum scale of 1:120 is generally necessary to permit reasonable accuracy in the measurement of scaled mooring loads. For these reasons it is often appropriate to adopt a hybrid approach, utilizing both numerical and physical modelling to represent all variables and circumstances of interest.

Physical model testing of moored ship response is a highly specialized activity that needs to be carried out in one of a relatively few facilities worldwide that have the necessary expertise. Recent technological developments in moored ship modelling include the systems for generating irregular waves and the use of non-contact optical systems for measuring model ship motions.

Physical models to simulate moored ship response should be scaled using Froude's scaling law.

NOTE 1 Froude's scaling law is applicable because gravity and momentum are predominant factors in the fluid motion and free surfaces occur.

Froude's law states that the Froude number, F_r, should be the same in model and nature, where F_r is calculated as:

$$F_r = \frac{u}{\sqrt{gD}}$$

Such models should have the same horizontal and vertical scale.

The linear scale of the model, to which the bathymetry is constructed, is known as the geometric scale, λ. The scaling relationships between measurements in the model and in nature should be derived from Froude's law according to the applicable scaling relationships including:

- length = λ;
- time = $\lambda^{1/2}$;
- velocity = $\lambda^{1/2}$;
- discharge = $\lambda^{5/2}$;
- force = $\lambda^3\gamma$.

The geometric scale of the model should be selected to be:

- large enough to represent the hydrodynamic conditions and bathymetry affecting the moored ship;
- small enough to ensure that the ship hull form, draught, trim and mooring properties can be represented;
- small enough to allow for accurate measurement of mooring line loads and ship motions.

The load–deflection characteristics of fenders and mooring lines should be represented in the model by a system of cantilever springs or other devices that can be made to reproduce any non-linear characteristics such as those from synthetic tails on wire or high modulus polyethylene (HMPE) lines. Fender face friction should be represented by using low friction faces, taking into account loss of friction due to wear and tear of surfaces in service.

Mooring line loads should be measured directly by means of strain gauges, and motions in the six degrees of freedom of vessel movement should be measured by a system that does not impose forces on the model vessel that could significantly affect its response, such as non-contact optical motion tracking and capture systems.

It is not usually practicable to model wind and current loads directly with wave action, and other methods of adding in such loads should be used where necessary, such as the use of constant tension lines.

Irregular sea states should be realistically generated by the wave generation device in the model so that non-linear wave forces are present in the model. Where infragravity wave energy is present at the prototype location, it should be assessed whether this is realistically represented in the model. In some cases it might be necessary to add or compensate for an appropriate infragravity wave in the wave generator. Careful attention should be given to calibrating the wave conditions in the model against measured prototype data if available or using numerical models. Particular attention should be given to the basin boundaries and to the active absorption capabilities of the wave generation device to ensure that modelling artefacts (such as reflections or resonances that are not present in the prototype) do not affect results.

NOTE 2 Passing ship effects may also be simulated by means of a towed, powered or guided model ship as a source of the waves acting on a moored ship model.

21 Operability and weather downtime

*COMMENTARY ON CLAUSE **21***

This clause deals with the assessment of weather downtime for marine facilities design. It is concerned with the effect of metocean conditions on operability and does not allow for:

- *any other operational downtime due to equipment failure, planned or unplanned maintenance, taking on stores or other procedural or logistical issues;*
- *weather effects on shipping en route to or from the facility causing delayed arrival of shipping.*

In planning and design of new and upgraded facilities, designers should establish the DSOL, comprising values of metocean conditions or values of combinations of conditions, including wind, waves, currents, water level and visibility, which are deemed to prevent specific operations from taking place.

Estimates of weather downtime should be made at the design stage to quantify the frequency and persistency over a period of time when conditions are predicted to exceed the DSOL for each operation or sequence of operations envisaged in the operating phase of the facility, including vessel arrival, mooring, cargo transfer and departure.

Functional requirements for availability and operability may be expressed quantitatively in either of the following ways:

- availability – the amount of time the berth is available, expressed as a percentage of the overall sample time;
- weather downtime – the amount of time the berth is unavailable, expressed as a percentage of the overall sample time.

At the early stages of design and layout optimization, weather downtime may be quantified by reference to the percentage exceedance of environmental limits for each of the key operations of approach/departure, mooring, and cargo handling and transfer.

At later stages of design or when appropriate to the facility requirements, potential weather downtime should be assessed using a theoretical marine operability model appropriate to the nature of the facility and operations to be carried out.

NOTE 1 The operability model normally defines a simplified sequence of operations including separate DSOL and durations for:

- *pilot pick-up;*
- *arrival transit of approach channel, connection of tugs, approach to berth;*
- *berthing and making fast;*
- *vessel berthed – cargo-specific preparations for cargo transfer (e.g. cool down of transfer arms for a liquefied gas berth);*
- *vessel berthed – cargo transfer (loading and/or unloading) taking place;*
- *vessel berthed – cargo- or vessel-specific preparations for departure;*
- *departure transit of approach channel;*
- *pilot departure.*

The values of the DSOL should be assessed according to the applicable basic criteria for safety and operability. Such basic criteria may include environmental values:

- provided by pilots, masters and operators with experience relevant to the particular operation;

- derived from navigation simulations (see **19.4**);
- derived from moored ship studies related to overall vessel motions, safety of personnel, cargo handling, mooring line loads and fender forces (see **20.2**) or from static analysis of moored ships not subject to wave action;
- relating to cargo handling or transfer equipment related to rated wind speeds for safe operations.

NOTE 2 In this context, criteria at the ship-shore interface could include those relating to:

- *connections to loading arms or hoses for liquid cargo transfer systems;*
- *cargo handling using container or other cranes for Lo-Lo operations;*
- *vehicles and wheeled cargo using Ro-Ro ramps.*

Weather downtime can exhibit significant season-to season and year-to-year variability, and downtime assessments should statistically characterize the range of variability in downtime through the design working life of the facility, utilizing, for example, long-term measured or synthesized time series data of wind, waves, currents, tidal levels and visibility.

NOTE 3 Acceptable figures for downtime vary according to the type of operation, ship type, cargo handled and frequency of ship calls. Different downtime values may be defined for specific operations (such as moored at berthed and transferring cargo) or more general downtime for all operations, from pilot boarding on ship arrival at the port approaches to pilot leaving on sailing away from the port after loading cargo. For a crude oil export terminal at an exposed location, for example, it might typically be considered acceptable to plan on an expectation of an average year-to-year weather downtime (berth closed due to weather) of 5% to 10%. However, such downtime might not be acceptable for an intensively utilized container terminal or LNG import terminal. Furthermore, the operational impact of 5% annual downtime is likely to be unacceptable if it is predicted to occur all in a single 3-month season. For many intensively used facilities which are operationally or commercially sensitive to weather downtime, it is important to characterize weather downtime statistically, including year-to-year and month-to-month variability, as an input to cargo handling, storage and shipping logistics simulations.

NOTE 4 For container terminals, PIANC MarCom Report WG115 [42] provides guidance on the assessment of ship and overall terminal efficiency, taking into account motion criteria of the range of design ships.

22 Design operating conditions

NOTE 1 Recommendations for the structural design of quay walls, jetties and dolphins are given in BS 6349-2, based upon the application of loads set out in BS EN 1990.

Design situations as the basis for structural design of marine facilities should take into account the operating philosophy established with the operator at the planning and design phases, and the DSOL.

Conditions of normal use for marine facilities appropriate to assessment of actions and combinations of actions in a persistent design situation should include both normal and extreme operating conditions (**3.1.30** and **3.1.16** respectively).

Accidental design situations should be as defined in BS EN 1990. Accidental design situations for marine facilities should include the accidental operating condition (**3.1.1**). Credible accidental design situations may be established by risk analysis for the specific operations proposed and the prevailing environmental conditions.

NOTE 2 Recommendations for the estimation of actions from moored ships based upon these design operating conditions will be included in BS 6349-1-2, which is currently in preparation.

NOTE 3 These design situations allow for the fact that for large ships and exposed berths, it is not normally expected that a ship would remain alongside in an extreme storm event, since at many locations it is unlikely that the ship's mooring lines, equipment and fittings would have sufficient strength to stay moored in extreme winds or sea states. In some circumstances, however, it could be required for moorings to be designed for extreme environmental conditions. An example might be where a floating installation is moored for a long period at a quay. Also for small vessels, it might be the case that normal operating conditions could allow for extreme environmental conditions, although it would be relatively unusual for these to be of the same magnitude as the extreme condition for structural design considered in the extreme operating condition.

NOTE 4 The environmental conditions that are "consistent with the DSOL for the facility" vary by location, operation and phase in the asset lifecycle. For example, for conceptual design of a new and exposed oil and gas jetty, it might be decided to take a berthed ship with one in 1 year return period event as the normal operating condition. At detailed design stage, however, mooring studies might have been carried out to establish limiting conditions from the moored ship according to limiting mooring line load criteria, and this might suggest environmental conditions of lesser magnitude than the one in 1 year return period event and which may be applied to detailed structural design.

NOTE 5 Accidental operating conditions might include such events as ship impact or overload of one or more mooring lines up to breaking load or ship winch render load, due to operator error or equipment malfunction.

23 Maintenance

Designers should determine requirements for maintenance in the operation and maintenance phase of the asset lifecycle, taking account the potential impacts of:

- planned or unplanned maintenance on operations;
- safety of operations arising from simultaneous maintenance activities;
- safety of personnel involved in inspection works, particularly when involving the use of divers in or close to operational areas.

Maintenance dredging activities in particular should be planned in consideration of the feasibility of carrying out dredging operations, in proximity to other shipping and small vessels as appropriate to the location in question.

NOTE 1 PIANC MarCom Report WG103 [43] provides guidance to inform development of lifecycle management strategies.

NOTE 2 Further guidance on maintenance and inspection requirements for jetties, dolphins and quay walls structures is given in BS 6349-2, and for oil and gas jetties information is given in the SIGTTO-OCIMF Jetty maintenance and inspection guide *[44].*

NOTE 3 General recommendations in respect of the materials aspect of maintenance are given in BS 6349-1-4.

Annex A (informative) Organizations with a role in coastal activities in the United Kingdom

A.1 Organizations with a statutory role

In addition to its own statutory role in managing coastal activities and development, DEFRA lists organizations with a statutory role in *Managing coastal activities: a guide for local authorities* [45] as follows:

- Maritime and Coastguard Agency;
- harbour authorities;
- Department for Transport (DfT);
- other statutory bodies:
  - Crown Estate Commissioners (foreshore and sea bed ownership);
  - Countryside Agency (landscape conservation, recreation and amenity);
  - English Nature (nature conservation);
  - Environment Agency (water quality, flood defence, conservation and recreation);
  - Health and Safety Executive;
  - National Trust (coastal landowner);
  - port health authorities;
  - sea fisheries committees.

In 2009 the Marine Management Organisation (MMO) was established (see www.marinemanagement.org.uk/about/index.htm [14)]). Activities of the MMO include:

- marine planning;
- marine licensing;
- marine nature conservation;
- fisheries management;
- enforcement;
- marine emergencies.

The MMO is an executive non-departmental public body (NDPB) established and given powers under the Marine and Coastal Access Act 2009 [46]. It incorporated the work of the Marine and Fisheries Agency (MFA) and acquired new roles, principally marine-related powers and specific functions previously associated with the Department of Energy and Climate Change (DECC) and the Department for Transport (DfT).

14) Last accessed 23 September 2013.

A.2 Shoreline management plans

Much of the UK coast is subject to shoreline management plans (SMPs), the exception being Northern Ireland. SMPs extend to sections of coast that are considered to be self-contained in terms of sediment movement and can therefore be treated as being quasi-independent of adjacent stretches of coast for management purposes. The following list indicates locations and the respective organizations responsible for managing and monitoring shorelines:

- Southern England: the Standing Conference on Problems Associated with the Coastline (SCOPAC);
- South Coast (Selsey Bill to Portland Bill): the Southern Coastal Group and the Channel Coastal Observatory;
- South East Coast (Kent and Sussex): the South East Coastal Group;
- East Anglia and the Wash: the East Anglia Coastal Group;
- Gibraltar Point in Lincolnshire (including the coastline of Yorkshire, Durham and Northumberland) to Saint Abb's Head: the North East Coastal Group;
- North West England (Cumbria and Lancashire) and North Wales to Great Orme Head: the North West England and North Wales Coastal Group;
- Great Orme Head to Pembrokeshire: the West of Wales SMP;
- Pembrokeshire to Lavernock Point: the South Wales SMP;
- Severn Estuary from Lavernock Point to Somerset: the Severn Estuary Coastal Group;
- Devon, Cornwall and Dorset to Portland Bill: the South West Coastal Group.

For coastal management on Scottish coasts, the Scottish Government or the relevant District Council might be useful sources of information. Similarly, the Northern Ireland Assembly can be contacted for coastal management issues there.

A.3 Voluntary and non-regulatory organizations

Voluntary, non-regulatory organizations are also involved in coastal activities.

The Royal Life Saving Society is the UK's leading drowning prevention organization and the governing body for life saving and life guarding. Royal Life Saving Society members patrol (some) beaches ensuring the safety of bathers. In addition, it provides a range of programmes, awards and qualifications to help people to learn skills and techniques which can help save lives.

The Royal National Lifeboat Institution exists to save lives at sea. It provides a 24-hour on-call search and rescue service up to 50 miles from the coast of the United Kingdom and the Republic of Ireland.

The Royal Society for the Prevention of Accidents is involved in the promotion of safety in all areas of life, including on or near water. It provides information, advice, resources and training and plays a vital role in advising local authorities on avoiding danger.

Annex B (informative) Metocean data acquisition

COMMENTARY ON ANNEX B

Metocean conditions, as referred to in this part of BS 6349, are the subset of physical environmental conditions relating to meteorological and oceanographic conditions. This annex provides guidance on issues which need to be considered in planning metocean data acquisition activities for planning and execution of maritime works, including considerations for projects outside the United Kingdom.

The type and method of collection of information, and some possible formats for the final presentation of data, are also outlined.

*Subclause **B.1** describes some environmental aspects that are relevant to definition of the scope, duration and timing of the data collection programme, depending on the results of initial desk studies using available data sources.*

B.1 General considerations

B.1.1 Rapidly varying conditions

If conditions in an area can vary rapidly, the data collection regime might, for example, include for measurement and recording of individual maxima, minima and continuous "high time-resolution" data in addition to averaged values, to enable extreme conditions to be derived.

Examples of rapidly varying conditions include:

- winds: squalls, microbursts, downdraughts, tornadoes, tropical storms, harmattan winds, katabatic winds;
- waves: tropical storms;
- currents: solitons, density or turbidity events, eddy events, restricted flows;
- ice: ice pressure build-up in high ice concentrations;
- atmospheric pressure: rapid pressure change such as during topical storms or depressions and polar lows.

B.1.2 Infrequent conditions

In many areas, the type of climatological conditions that cause an extreme event occur very infrequently. As a result, short- to medium-length data sets might miss any example of these phenomena and result in severe under-estimation of extreme conditions. If infrequent but severe conditions could exist in an area, data collection needs to be supplemented by other long-term data sources which cover both time and space in the region of interest, such as satellite, hindcast or public domain data.

Examples of this include:

- typhoon, hurricanes and tropical cyclones (especially when they occur outside their normal range and, when they do, dominate the metocean design criteria, e.g. a tropical storm event between 10°N and 10°S);
- tornadoes and tornadic water spouts;
- tsunamis;
- icebergs and ice islands, including major ice shelf and glacier break-off.

B.1.3 Long-term oscillations and inter-annual variability

There are several long-term oscillations which occur naturally in different areas of the globe and impact different regions. Most installations have to survive the full cycle of these oscillations, but as the oscillation periods are typically 5 years to 30 years, data acquisition rarely covers the full oscillation cycle. The phases of relevant oscillation with respect to the period of data collection need to be assessed, as the phase of an oscillation can bias data collected to be more calm/rough, hot/cold or dry/wet than the regional norm.

The main long-term oscillations include:

- the North Atlantic oscillation (NAO);
- the Arctic oscillation (AO);
- the Pacific Decadal oscillation (PDO);
- the El Niño/La Niña-Southern oscillation (ENSO);
- the Indian Ocean dipole (IOD);
- the Atlantic Multi-decadal oscillation (AMO).

B.1.4 Climate change (trend and variability)

Climate change is resulting in higher variability and trends in conditions in many areas. These need to be considered when making measurements and preparing design criteria. Short-term data collection might not capture trends, variability or fully representative conditions. This aspect is more important for installations that are expected to have extended lifetimes.

B.1.5 Parameters impacted by proximity to the coast, island and shoals

Maritime structures in coastal or shallow water are affected by the interaction of the coastline, islands, shoals and the seabed with the meteorological, oceanographic and ice-related conditions. Data collection and modelling need to take into account the complexity that can arise from this interaction. Typically specific near-shore hydrodynamic or coastal modelling studies and assessments would be required to assess the conditions in the area of interest, taking into account the following.

- Infragravity waves are low-frequency waves (nominally 0.003 Hz to 0.05 Hz) and are important for harbour oscillations, sediment transport, and other near-shore hydrodynamic processes. Infragravity waves could represent an important consideration for vessel mooring and tanker on/offloading operations, especially for large vessels, having longer natural periods. There are implications for both design and operation, including the calculation of extreme loading on mooring systems, extreme vessel motions, mooring system fatigue and the availability of on/offloading systems.
- Storm surge represents the water surface response to wind-induced surface shear stress and pressure fields. Storm-induced surges can produce short-term water surface rise to an elevation considerably above mean water levels. Where the coast resists water movement, storm surges and the associated relaxation currents can be more severe than offshore.
- Solitons are usually generated by a disturbance in the fluid interface as the water passes over a bathymetric feature and hence need to be considered in shallow water, although the waves also propagate into deep water.
- Seiches can be important for design waves in harbours bays and large lakes. Any external perturbation to the lake or embayment can induce an oscillation, and this needs to be modelled or measured.

- Turbidity currents (a rapidly moving, sediment-laden layer of water moving down a slope) can be important for structures where there is instability and an underwater slope. The risk can be higher near highly sediment-laden river outflows and submarine canyons.
- Tsunamis, although rare and unpredictable, can have a very severe impact on coastal and shallow water locations, and run-up studies are required where there is a high seismic hazard. Coastal locations need to be selected to minimize the impact of potential run-up where possible.
- Waves shoal, refract and break as they pass into shallow water.
- Waves diffract due to the interaction of waves with structures and also due to the interaction between waves and currents.
- Katabatic winds carry high-density air from a higher elevation down a slope under the force of gravity. Katabatic winds can rush down elevated slopes at very high speeds and can have a big impact on onshore and coastal facilities near where these winds occur.
- Nearshore sea ice can have very different characteristics to offshore ice floes because shallow water conditions can cause ice pile-up and ride-up with grounded ice, severe ice ridging and ice gouging.

B.2 Meteorological data acquisition

B.2.1 Wind

There are several sensor options for measurement of wind speed and direction, including the following.

- Cup and vane type. This is a commonly available instrument. The main disadvantage is bearing wear, which can result in poor responsiveness and ultimately low readings.
- Propeller type. This is a commonly available, sensitive instrument. The main disadvantage is that the speed and direction are linked, and failure of the wind vane can result in incorrect wind speed measurements.
- Acoustic type. The main advantage of this instrument is the lack of moving parts, resulting in low maintenance, although it can be affected by heavy precipitation. It can also be configured to measure vertical wind speeds.
- Doppler radar (Lidar). The main advantage of this instrument is that it can be used to measure wind profile, but it can also be affected by heavy precipitation and is less commonly used.

As wind sensors are commonly mounted in elevated locations, they might be vulnerable to lightning strikes.

B.2.2 Precipitation

Automatic sensors are available for measurement of precipitation, but it is recommended that snow depth and durations, where relevant, are measured manually in accordance with national guidelines. Types of rain gauge include the following.

- Tipping bucket. This is a commonly-used standard instrument. It is important to scale the bucket size and tipping rate to the precipitation intensity. This type of sensor is vulnerable to vibration, and has limitations in measuring snow amount even when heated.
- Optical rain gauge. The accuracy of this instrument has not been established.

B.2.3 Air temperature and humidity

Sensor options for measurement of temperature and humidity include the following.

- Thermistor type (wet and dry bulb). This is a commonly available standard solution. The water reservoir for the web bulb sensor needs to be kept full, or the sensor measures the dry bulb temperature and not the lowest temperature that can be reached by the evaporation of water. Dew point and humidity can be calculated from the wet and dry bulb temperatures.
- Humidity probe. By using direct humidity measurements, this option removes the maintenance tasks associated with the wet bulb sensor, but probes are likely to drift due to contamination caused by salt and/or other contaminants. To protect against this, it is preferable to select a probe that is solid and with a sensor protected from liquid water, dust and dirt, e.g. by a PTFE filter.

B.2.4 Visibility

While visibility can be determined manually, all optical sensors need regular cleaning. Sensor options include the following.

- Single base line transmissometer. This type of sensor is typically used on runways and is not practical in confined spaces. Precipitation can lead to window contamination. Good alignment is critical for correct operation.
- Optical forward scatter. This type of sensor assumes that the surrounding visibility is the same as that between the sensor heads, so careful positioning of the sensor is important to avoid any nearby features or facilities that might affect visibility near the sensors. Contamination by dust and other airborne particulates means that the lens needs to be cleaned regularly. Some sensors can self-correct for window contamination by precipitation.

B.2.5 Atmospheric pressure

There are several sensor options for measurement of pressure, including the following.

- Precision aneroid barometer. This type of sensor is reliable, suitable for quick pressure measurements and independent of temperature change. Its light weight and insensibility to shock and vibration means that it is ideal to use as a mobile calibration instrument.
- Silicon diaphragm. This type of sensor exhibits negligible hysteresis or temperature drift.
- Silicon capacitive absolute pressure sensor. This type of sensor has high measurement accuracy and good long-term stability.

B.2.6 Solar radiation and hours of sunshine

B.2.6.1 Solar radiation measurement

There are several sensor options for measurement of solar radiation pressure, including the following.

- Thermopile-based pyranometers designed for measurement of solar irradiance. These are reliable and low-maintenance, although the black bodes need to be calibrated every 2 years.
- Radiometers designed for the measurement of sunshine duration (i.e. as the time during which the direct solar radiation exceeds the level of 120 W/m^2). These are reliable and low-maintenance. Radiometers can be designed to be

sensitive in particular wave lengths of interest, e.g. incoming short wave lengths or outgoing long wave lengths or in the specific bands of ultraviolet or infrared.

B.3 Oceanographic data acquisition

B.3.1 Water levels

B.3.1.1 Water level measurements

There are several types of tide gauge available, including the following.

- Tide pole or staff. This is a simple graduated pole set up vertically on a fixed structure in the water so that the changing level of the sea surface can be read by an observer. While this is not useful for long-term high resolution data recording, if it can be levelled in and referenced to the local chart datum, it can provide a long-term reference for an automatic tide gauge and other measurements or surveys.
- Float operated gauges. These are normally installed in stilling wells that dampen the wave action. The vertical movement of the float is translated to a height which is recorded at regular intervals.
- Radar type. This is typically mounted above the water, and measures the distance to the water surface by measuring the time taken for a pulse to travel down to the water and be reflected back to the source. The main advantages are the low maintenance cost, as the gauge is out of the water, and generally high accuracy and reliability. Water levels can be sampled at frequencies typically up to 10 Hz and the results averaged over a specified period (typically 10 min). The raw data need to be inverted and the sensor height referenced to a local datum.
- Pressure type. This is typically mounted on the seabed, and measures the water pressure, which is converted to the height of the water column above the sensor. The height of the gauge needs to be levelled in and the data corrected for the atmospheric pressure.
- Bubbler type. This works by pumping typically compressed air into the water. The pressure created in the measuring tube is directly proportional to the length of the water column above the bubble. The sensor is able to self-correct for atmospheric pressure, as this can be measured in the same way above the water.
- Acoustic type. This is typically able to measure the distance from the sensor to a target. Sensors can be susceptible to acoustic noise. The main advantage is the low maintenance cost, as the gauge is out of the water. This sensor is cheaper than the radar type, but the data quality is usually less good.

B.3.1.2 Tidal analysis

If a sufficiently large database is obtained, an analysis of the records can produce the astronomical tidal harmonic constituents, which can then be used to predict astronomical tidal heights. These predictions assume that no other changes occur at the relevant site, and their accuracy depends on the size and accuracy of the original database. It is possible to obtain sufficient harmonic constituents for a site from continuous records of 30 days to make adequate predictions. A full tidal analysis from a minimum of 1 year's continuous data is sufficient to predict accurate astronomical tidal heights. However, this can only provide astronomical tidal heights, and actual water levels can differ significantly due to meteorological effects.

Admiralty tide tables list daily predictions of times and heights of high and low waters at a selected number of standard ports. These predictions are of universal application and are usually based on continuous observations of the tide over a period of at least 1 year at that standard port. The tables also list data for secondary ports, enabling predictions to be calculated from the predictions listed for standard ports.

Harbour authorities and others also publish almanacs and tide tables. Whereas Admiralty tide tables give heights referred to chart datum, i.e. the datum of soundings on the latest edition of the largest scale Admiralty chart, it is not unusual for locally produced tide tables to be based on a different datum. Certain commercial companies also offer tide prediction services.

NOTE Commercial and harbour authorities often obtain their predictions from the Proudman Oceanographic Laboratory, Bidston, Birkenhead, England when information is required in a more detailed or specific format than is provided by the Admiralty tide tables.

B.3.2 Currents

B.3.2.1 Measurement of currents

Current speed and direction can be measured:

- directly at a location by current meter or acoustic Doppler current profilers (ADCPs) (see **B.3.2.2**);
- indirectly by float tracking or dye tracing (see **B.3.2.3**).

Float tracking or dye tracing provides information on the general circulation patterns in an area of interest.

B.3.2.2 Current meter observations

Direct current measurement provides information on current speed and direction at a specific depth or, in the case of ADCP, continuously through the water column. Current meter options include the following.

- Direct reading current meters are traditionally deployed, typically manually, from a vessel, and they give a direct reading of current. They have only a limited practicability and accuracy, although models are now available where data is recorded internally in a data logger. They have typically been superseded by more accurate electromagnetic or acoustic instruments. Current speed is measured using a horizontally mounted propeller/Savonius rotor, and current direction is measured by the alignment to the current direction using a vane compared to an internally housed compass. The main disadvantages are that the current speed is dependent on the current direction, and in low current regimes, the instrument often does not rotate to point into the current direction due to its weights and bearing friction. Additionally, care has to be taken in the presence of waves, as the rotor instruments tend to over-register speed under wave influence. Under some circumstances the impellor's movements can be affected by marine growth.
- Recording current meters (RCMs) record data internally and are typically deployed on mooring. Early RCMs also used a Savonius rotor and vane, but now all instruments measure current speed using methods that are independent of current direction. This includes electromagnetic current meters, which measure changes in an induced magnetic field, and acoustic current meters, which measure the apparent variations in the speed of sound due to the water movement. These meters normally measure the current velocity at frequent intervals, e.g. once or ten times per second, and either record a burst of data, e.g. 10 min/h, or perform a vector average to remove the orbital currents before recording.

- ADCPs measure current speed and direction over a range of depths. While the most common orientation is to place an upward looking instrument on the seabed, instruments can also be deployed on a mooring either upward or downward looking. Near shore, an instrument could be deployed sideways looking to measure currents across an estuary or harbour area. There are a number of factors that affect accuracy, resolution and range, and the ADCP type needs to be selected and configured for the specific use, including the deployment depth and required measurement accuracy. Typically temperature, heading and inclination data are also recorded and can be used to correct measurements if the sensor becomes tilted but is still within its operating range.

B.3.2.3 Float tracking

This method of tracking water movement involves the introduction of readily identifiable material that moves with the water, thus directly indicating its path. The size and shape of the floating object affects its reaction to the surrounding water movement and therefore whether it faithfully follows that movement.

The standard float assembly consists of a vaned drogue usually made out of canvas, wood, metal or plastics, joined by thin rope or wire to a surface buoy. The length of rope determines the depth of water at which the drogue lies and follows the water motion. The drogue is typically 0.5 m to 1.0 m long and, when suspended at a depth of, for example, 2 m, its path is an expression of the average horizontal movement of a water parcel between 2 m and 3 m below the surface.

The standard drogue float can be modified to follow surface water movement by reducing the length of rope between the drogue and the top mark so that the top of the vane assembly is just on the sea surface. To follow movement in the top 100 mm or to estimate the true path of a surface phenomenon such as a grease or oil film, however, specially designed surface floats may be used. These can consist of disc shapes or spheres that float on the surface, neutrally buoyant bottles, cards or even finely chopped vegetables.

Tracking is a major problem with submerged or surface floats.

For a submerged float, a large surface buoy or marker such as a flag or radar reflector is subject to windage and, in the case of a buoy, to influence from the surface water currents in which it is floating. These top marks therefore need to be kept as small as possible consistent with the need for good visibility. In order to aid relocation, small radio transmitters, GPS transmitters or underwater acoustic devices can be used together with radio direction finding antennae or acoustic receivers. Location by sonar has the advantage that the surface float can be smaller. These devices are most useful in the dark and easier to find than the flashing lights previously employed. Methods have been developed to remove the windage influence from the resultant track of a float, but further work is necessary before the techniques are widely adopted.

For surface floats, aerial tracking and/or photography can provide a useful method of recording float positions but is too expensive for most applications. Large floats can be tracked by GPS transmitter which ensures the full path and final position is accurately known.

A logship is a particular design of float used to show average horizontal motion over a greater depth of water, such as 6 m to 10 m. It consists of a long thin member with identification on one end and weights at the other, so that it floats vertically just under the water surface. Typical materials used are telegraph poles, tree trunks, bamboo poles or lengths of aluminium. Logships are particularly useful in navigation studies and harbour layout planning because their lengths can be adjusted to be representative of the relevant vessel draught.

Floats can also be used to obtain point-specific information by releasing them at the bows of a moored vessel and timing their passage over the known distance to the stern. Alternatively, floats attached to an anchored vessel by a known length of floating cord can be allowed to drift astern. The velocity can be calculated from the time for the float to run to the end of its tether, and the current direction can be found by taking the bearing of the float. In both of these applications it is likely that the presence of the vessel will modify the current speed and direction and therefore the float path. A crude estimate of current velocity can be obtained from the log reading and compass heading of a vessel moored so that it is free to lie with the current.

As stated, the floats do not follow the same turbulent flow paths as the water itself and so only indicate the average horizontal movement. Another limitation of float track information is the portrayal of a linear picture of water movement with no real cover of the water depth. However, float tracking can give a rapid and relatively cheap impression of general water movement. Several floats can be followed at any one time with repeated releases from one position, or multiple releases with drogues set at different depths. Residual tidal flows can be determined by tracking a float over a complete tidal cycle and determining the distance between its release and recovery positions.

Floats can be deployed unattended if a net movement is required rather than knowledge of the path taken to arrive at the end point. Commonly the floats have messages attached asking the finder to record the time and place of the float recovery and to return the information. To reduce the chance element of the recovery, beachwalkers can be employed to search for the landed floats. Similar methods can be used to tag bottom currents when boat following is impossible without, for example, acoustic links. The method can only yield minimum possible water speeds, as without other valid information it has to be assumed that the float took the shortest distance between the points of release and recovery and that the float was recovered as soon as it arrived at its final location.

B.3.2.4 Measurement of diffusion

Much research over many years has been carried out to develop various methods of tracing water movement, in particular for the disposal of effluent into the sea where the rate and extent of dispersion together with mass transport are important criteria. An indicator was sought with physical properties similar to those of the water to be labelled. Techniques that were developed were the use of dyes, bacterial organisms and radioactive materials, but the last of these is no longer feasible because of public health restrictions on the strength of isotopes that could be released.

B.3.2.5 Presentation and analysis of field data

The effort and cost of data collection can be significant. It is important that the method of interpretation is considered during the design of the fieldwork, to avoid spending time and money on data that are irrelevant or unnecessary. In particular, the method of position fixing and its accuracy relative to the requirements of the tracing method needs to be taken into account. Interpretation of the data can range from visual intuitive examination of a few results to sophisticated computation of a large quantity of information. It is important to remember the aims and ultimate objectives of the study, both when considering the method of data presentation and during interpretation.

Raw data need to be archived so that others can make use of them.

Charts play a major role in the presentation of water movement information, irrespective of which method of tracing is adopted. At the simplest level, the chart only shows the position of measurement. A pictorial representation of the measured data can be a useful addition, such as a scatter diagram or central vector diagram for current observations or a record of tracer concentration. Charts are essential for presenting data such as float tracks or for showing vessel tracks during dye traverses. Several spot readings can be contoured to show similarities and trends, and this can be a useful technique for the discussion of bacterial counts. A summary chart showing water movement in broad terms as derived by the survey can be a useful aid to understanding the current regime of the area. Additional information on other variable environmental conditions, such as sea state, wind and tidal levels, needs to be readily available for reference.

Annex C (informative) Sediment transport data acquisition

The most common ways of measuring suspended load under currents are as follows.

- Depth integrating sampler. This collects and accumulates a sample as it is lowered to the seabed and lifted back again. The sampler is moved at a uniform rate in both directions. If the sampler is retrieved full then measurements will be biased, because the sampler will probably have stopped filling over the last part of the water column. The aim is therefore to have the sampler full to about 90% of its capacity. Therefore, this equipment is restricted in use to shallower depths by its capacity to store the water sample. Use of such a sampler also implicitly assumes a steady current (i.e. no variation in time over the sampling duration). The dry volume of sediment captured is then interpreted as the volume of sediment transported over the sampling duration (per width of the sampling device), and can easily be converted into a standard volumetric suspended sediment transport rate, q_s $m^3/s/m$.
- Point (grab) sampler. This operates in a similar manner, except that it has an inlet valve that can be opened or closed as required. Thus, it is possible to point sample suspended sediment transport rate at known depths, interpolate between estimates at various depths, and then integrate over the water column. The method has the advantage of explicitly accounting for depth variation of suspended load.
- Optical, acoustic backscatter and other devices. A range of optical backscatter (OBS) and other devices are in use and continue to be developed for directly or indirectly measuring sediment concentrations. Use of such devices may be considered in some circumstances when very high accuracy and detailed information is required and when these can be practically be deployed. It is advisable to seek specialist literature and advice if such devices are to be deployed. Indirect measurements of sediment concentrations always need to be supplemented by local calibration against directly measured sediment concentrations.

Methods of measuring bed load under currents include the following.

- Sediment traps. These are intended to cause sediment to be deposited into a container as it is transported along the bed. Thus, the net bed load transported over a certain duration can in theory be measured. Problems include burial of the trap and contamination with suspended load just above the bed.
- Tracer studies. These involve monitoring of the movement of coloured or “tagged” sedimentary particles. These methods have been widely used in the past, but are fraught with problems: they are prone to “tagged” sediment loss, slow and subject to limitation of size of sediment (lest it become suspended load or too small to track).

Annex D (informative) Key dimensions of ships for preliminary design purposes

D.1 Vessel dimensions

Figure D.1 to Figure D.10 display dimensions from a large sample each for the major ship types that were either in operation or being ordered in 2011. Three scattergraphs displaying length overall, breadth (beam) and draught are displayed for each ship type against the parameter of most relevance to the planning process. The parameter used in most cases is DWT, which is a measure of the weight of cargo to be carried by the vessel. The exceptions are:

- container ships, for which the dimensions are displayed against TEU capacity;
- gas carriers, for which the dimensions are displayed against gross gas capacity;
- Ro-Ro ships and ferries, for which the dimensions are displayed against total lane length in metres;
- cruise ships, for which the dimensions are displayed against passenger numbers.

In the case of dry and liquid bulk ships, the data are displayed at two scales, one scale being from 0 t to 50 000 t DWT and the other covering the entire range of ships.

The scattergraphs are developed using data from www.sea-web.com [15], which covers a very large proportion of the world fleet, and the data are sorted into categories. Each figure includes a box giving the following statistics:

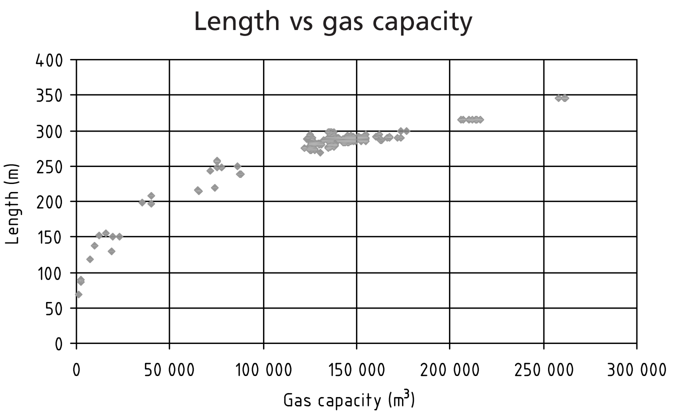
- total size of sample;
- numbers of each category of vessel included in the scattergraph dataset.

These figures are given for general planning purposes only, and are necessarily general in scope. At detailed design stage it is necessary to obtain data on a range of specific ship sizes that will be relevant to the terminal or facility in question.

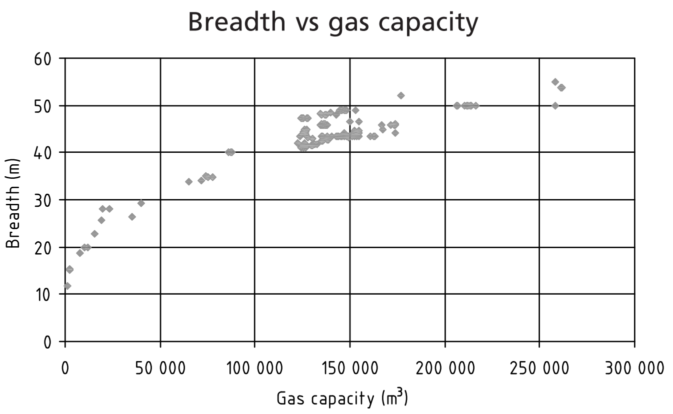
In particular, for Ro-Ro vessels the relationships provided do not allow for mezzanine decks which might give increased capacity for cars and smaller vehicles for a given vessel length.

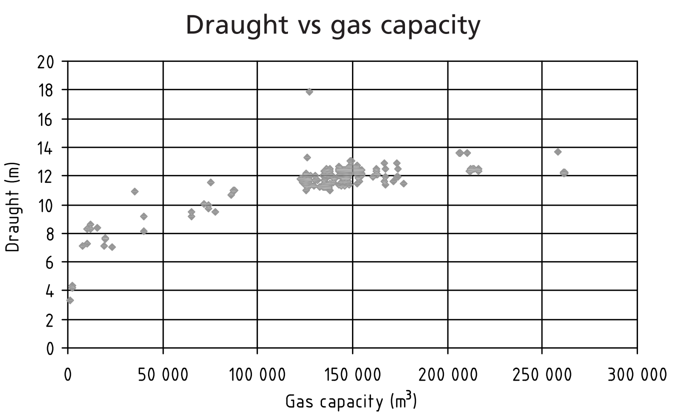
[15] Last accessed 23 September 2013.

Figure D.1 **Dimensions for LNG vessels related to gas capacity**



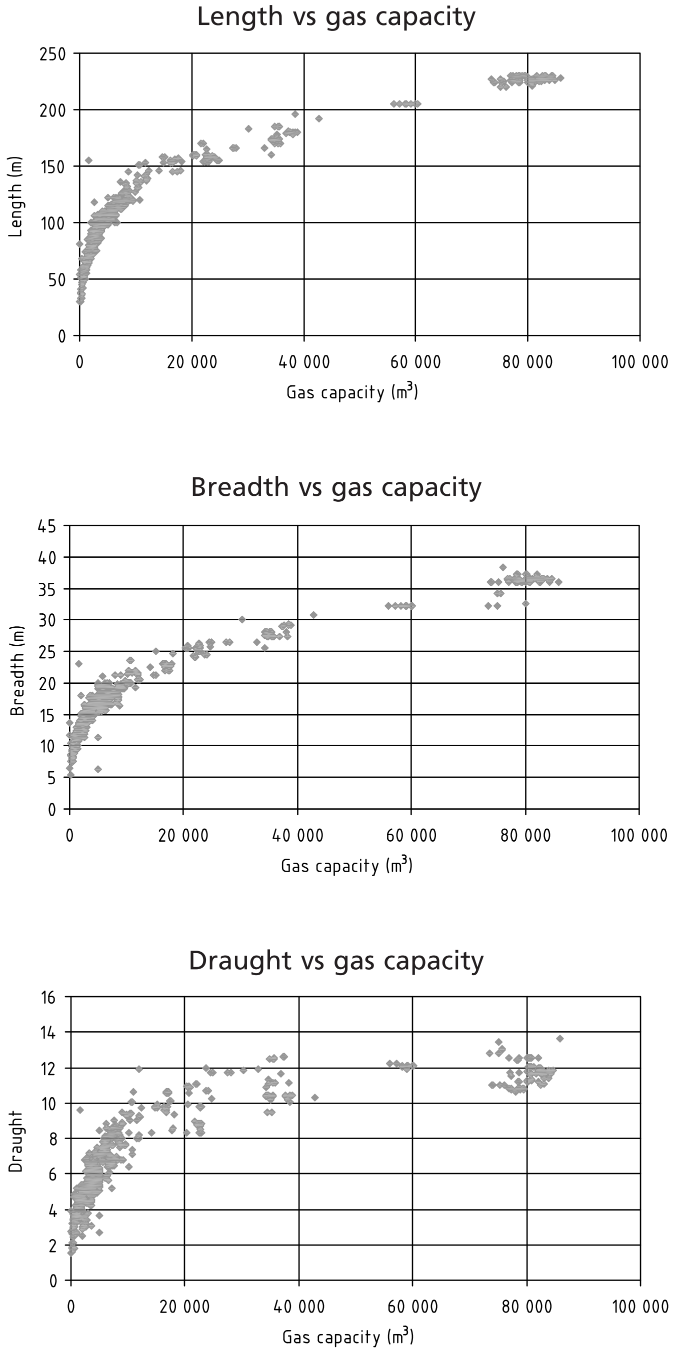
Size of sample	**391**
LNG tanker	391





Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

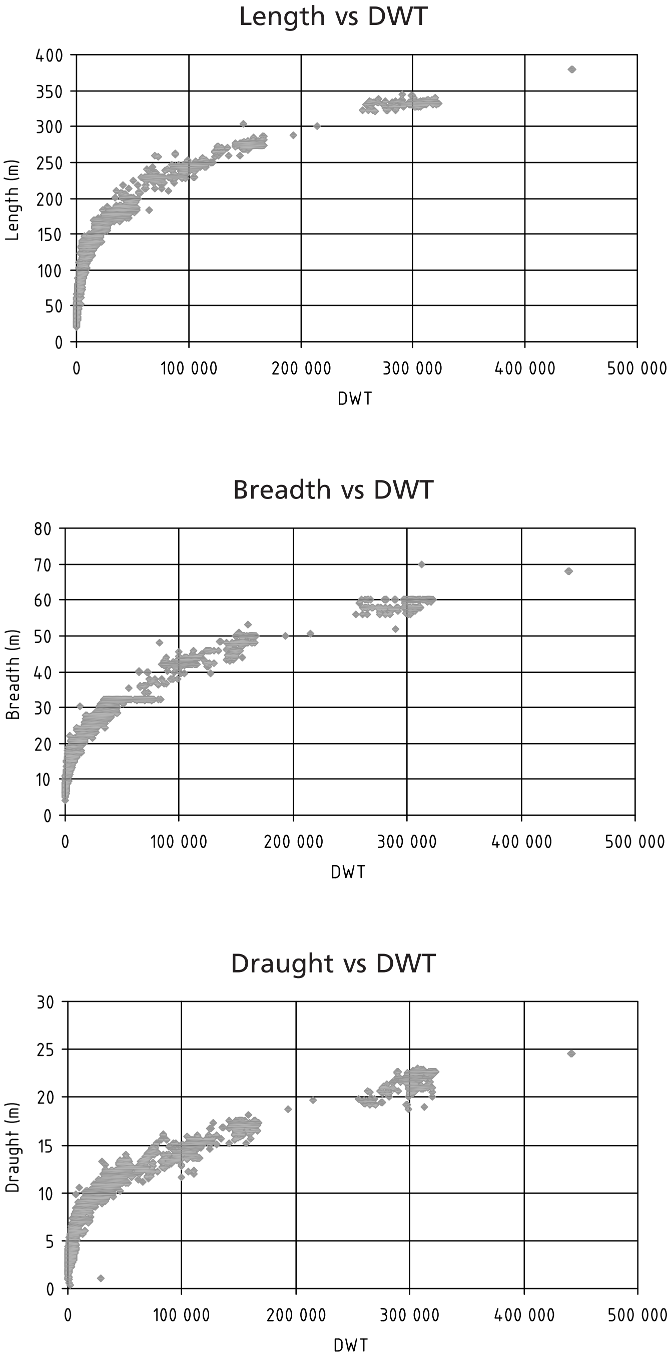
Figure D.2 **Dimensions for LPG vessels related to gas capacity**



Size of sample	**1 304**
LPG tanker	1 282
LPG/chemical tanker	22

Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

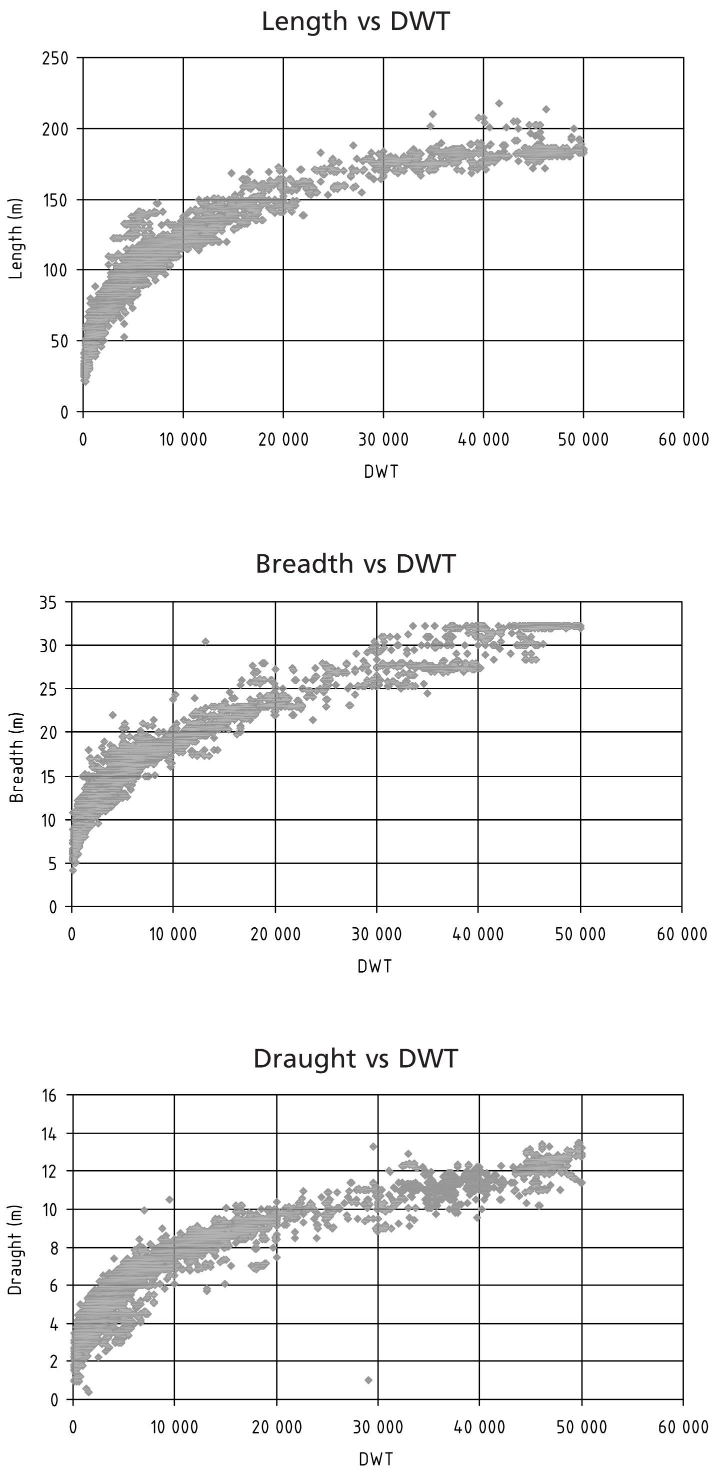
Figure D.3 **Dimensions for liquid bulk carriers and tankers related to DWT**



Size of sample	**13 371**
Alcohol tanker	4
Asphalt/bitumen tanker	197
Caprolactam tanker	4
Chemical tanker	1 094
Chemical/products tanker	4 019
Coal/oil mixture tanker	1
Crude oil tanker	1 948
Crude/oil products tanker	706
Edible oil tanker	12
Fruit juice tanker	11
Latex tanker	1
Molasses tanker	6
Molten sulfur tanker	36
Products tanker	2 360
Products tanker	1 064
Shuttle tanker	88
Tanker (unspecified)	1 650
Vegetable oil tanker	35
Water tanker	124
Wine tanker	11
Grand total	13 371

Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

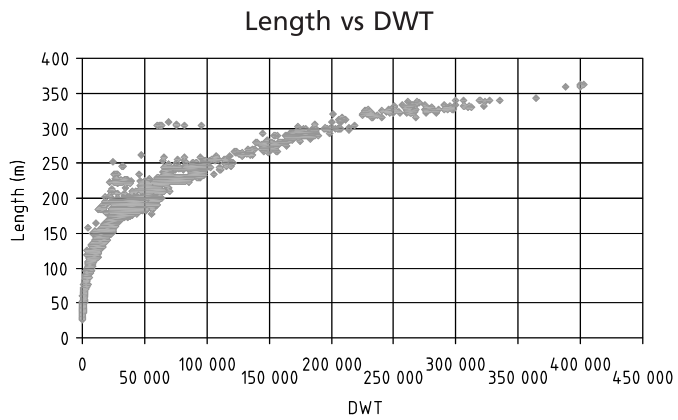
Figure D.4 **Dimensions for liquid bulk carriers and tankers related to DWT (carriers up to 50 000 DWT)**

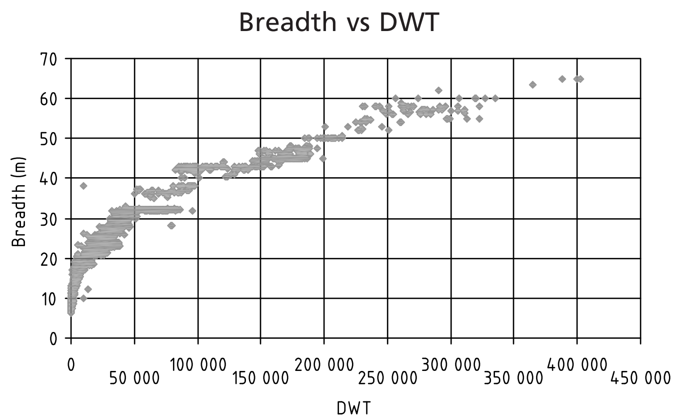


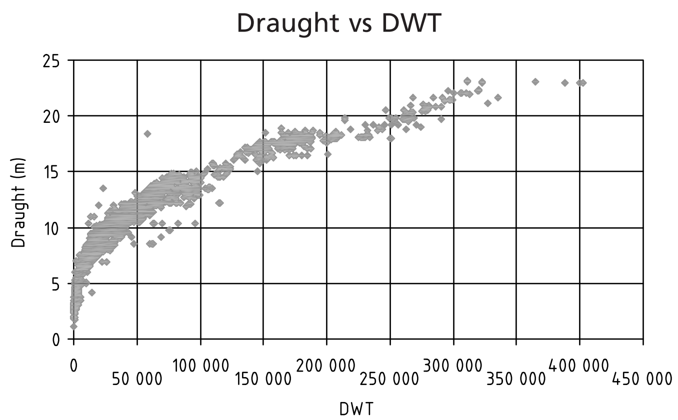
Size of sample	**9 831**
Alcohol tanker	3
Asphalt/bitumen tanker	186
Caprolactam tanker	4
Chemical tanker	1 046
Chemical/products tanker	3 647
Coal/oil mixture tanker	1
Crude oil tanker	80
Crude/oil products tanker	220
Edible oil tanker	12
Fruit juice tanker	11
Latex tanker	1
Molasses tanker	6
Molten sulfur tanker	36
Products tanker	2 038
Products tanker	866
Shuttle tanker	5
Tanker (unspecified)	1 514
Vegetable oil tanker	33
Water tanker	112
Wine tanker	10

Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

Figure D.5 **Dimensions for dry bulk carriers related to DWT**



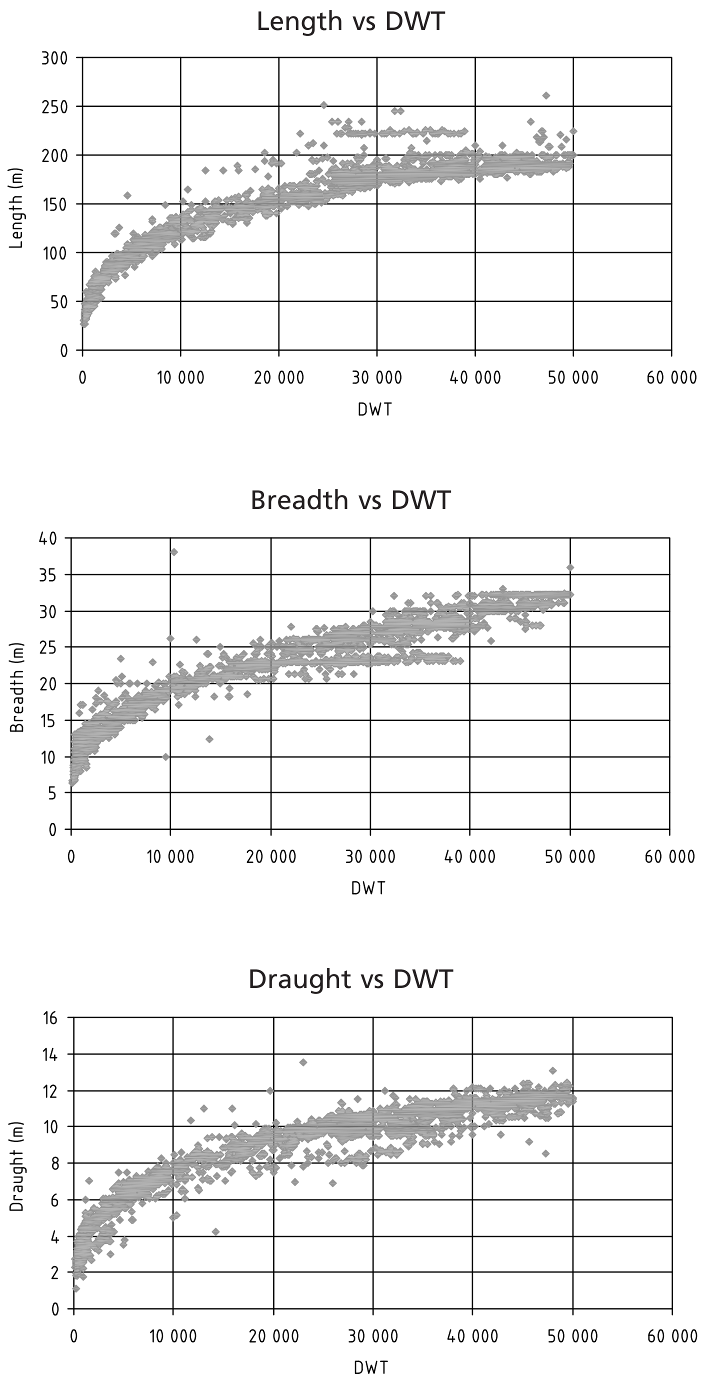




Size of sample	**12 401**
Aggregates carrier	394
Bulk carrier	10 778
Bulk carrier (with vehicle decks)	7
Bulk carrier, laker only	19
Bulk carrier, self-discharging	88
Bulk carrier, self-discharging, laker	90
Bulk/oil carrier (OBO)	25
Cement carrier	433
Limestone carrier	42
Ore carrier	273
Ore/oil carrier	56
Powder carrier	4
Refined sugar carrier	2
Urea carrier	8
Wood chips carrier	182

Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

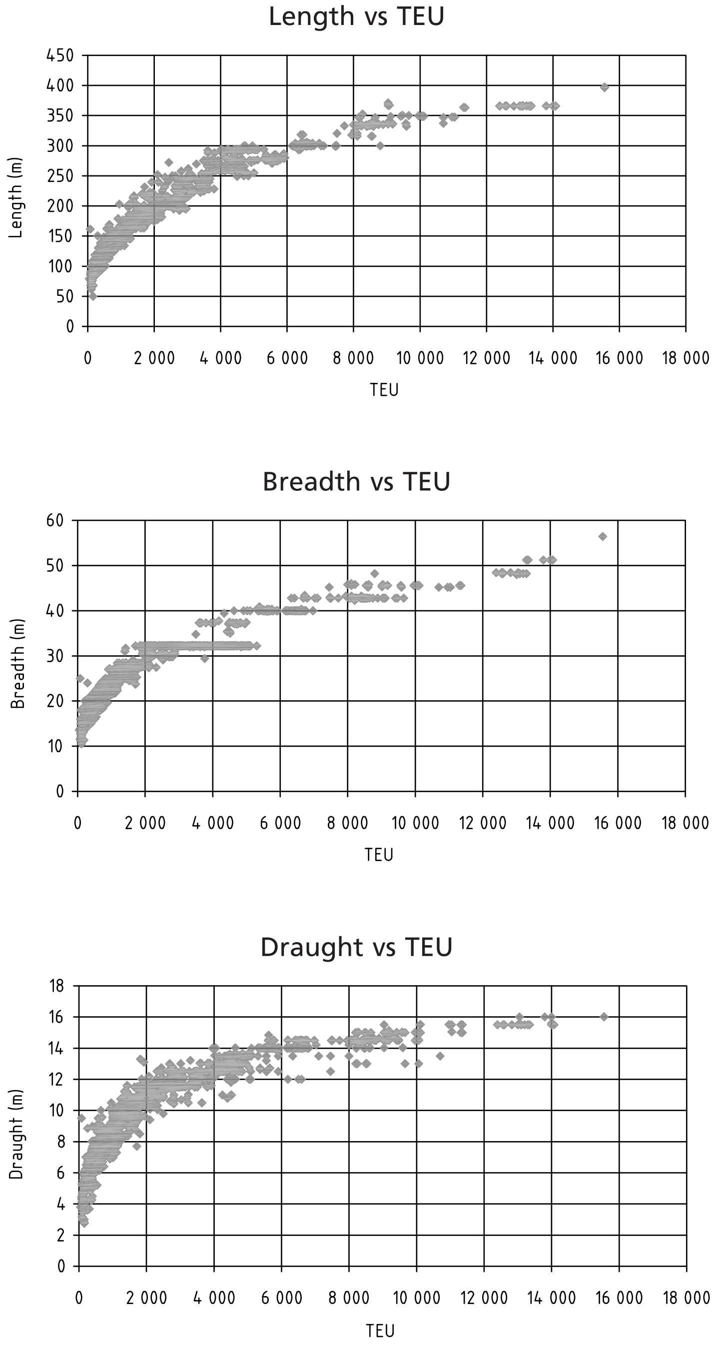
Figure D.6 **Dimensions for dry bulk carriers related to DWT (carriers up to 50 000 DWT)**



Size of sample	**5 611**
Aggregates carrier	394
Bulk carrier	4 394
Bulk carrier (with vehicle decks)	5
Bulk carrier, laker only	19
Bulk carrier, self-discharging	57
Bulk carrier, self-discharging, laker	66
Bulk/oil carrier (OBO)	1
Cement carrier	433
Limestone carrier	42
Ore carrier	21
Ore/oil carrier	51
Powder carrier	4
Refined sugar carrier	2
Urea carrier	8
Wood chips carrier	114

Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

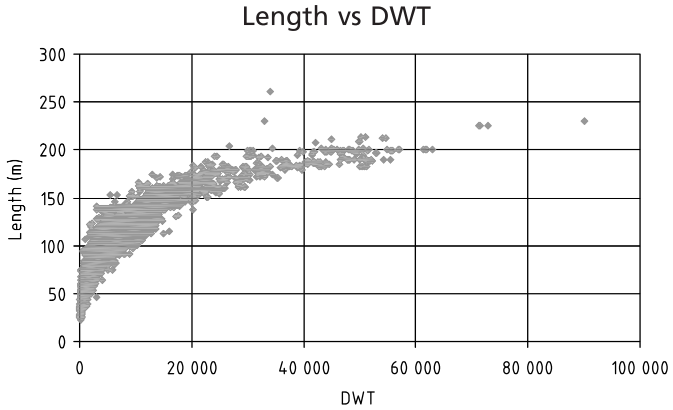
Figure D.7 **Dimensions of container ships related to TEU capacity**

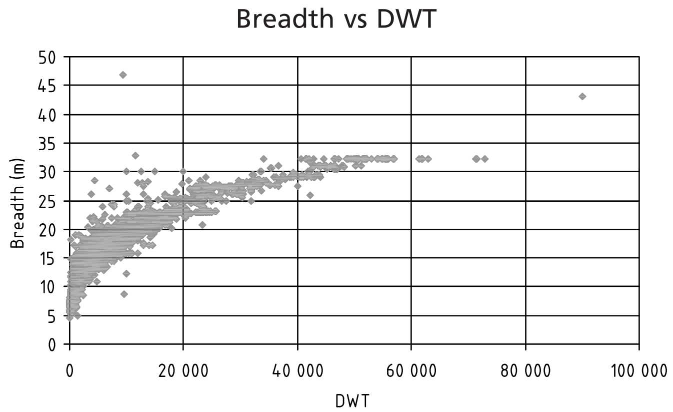


Size of sample	**5 536**
Container ship (fully cellular with Ro-Ro facility	17
Container ship (fully cellular)	5 516
Passenger/container ship	3

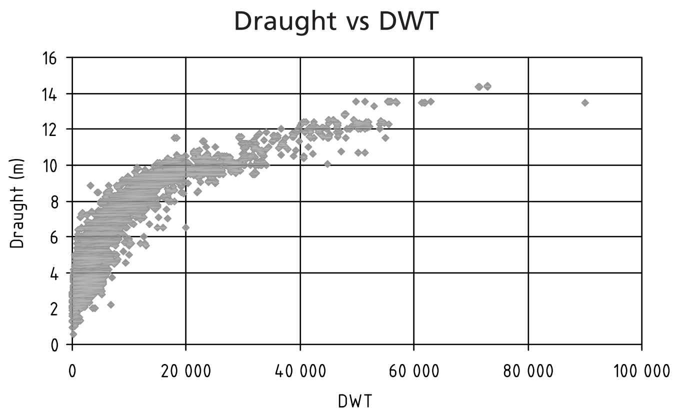
Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

Figure D.8 **Dimensions of general cargo ships related to DWT**



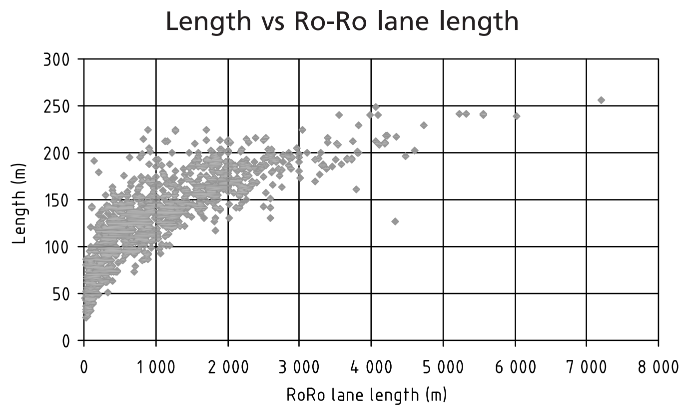


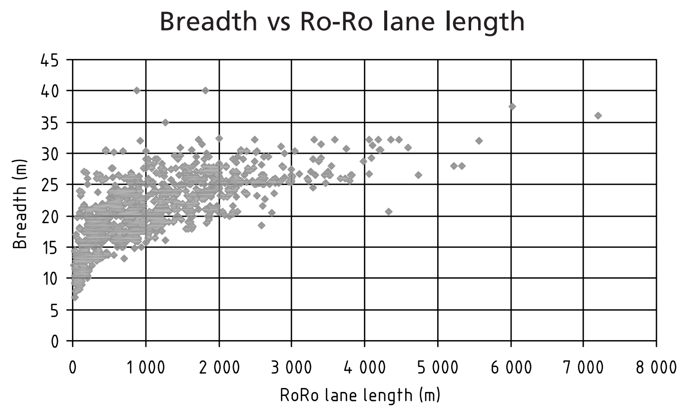
Size of sample	16 029
Deck cargo ship	183
General cargo ship	15 301
General cargo ship (with Ro-Ro facility)	107
General cargo ship, self-discharging	14
General cargo/tanker	4
Open hatch cargo ship	361
Palletized cargo ship	59



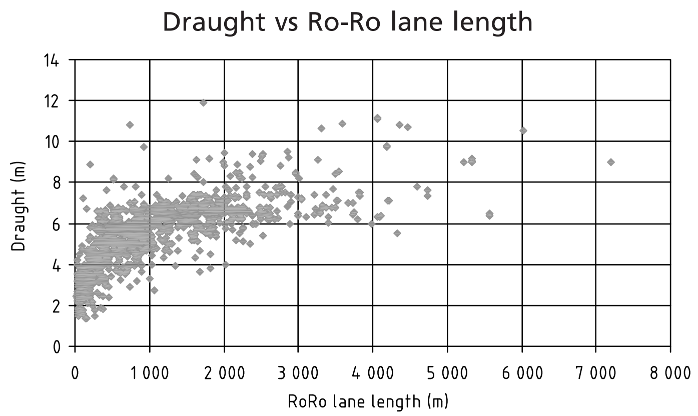
Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

Figure D.9 **Dimensions of Ro-Ro ferries related to lane length**



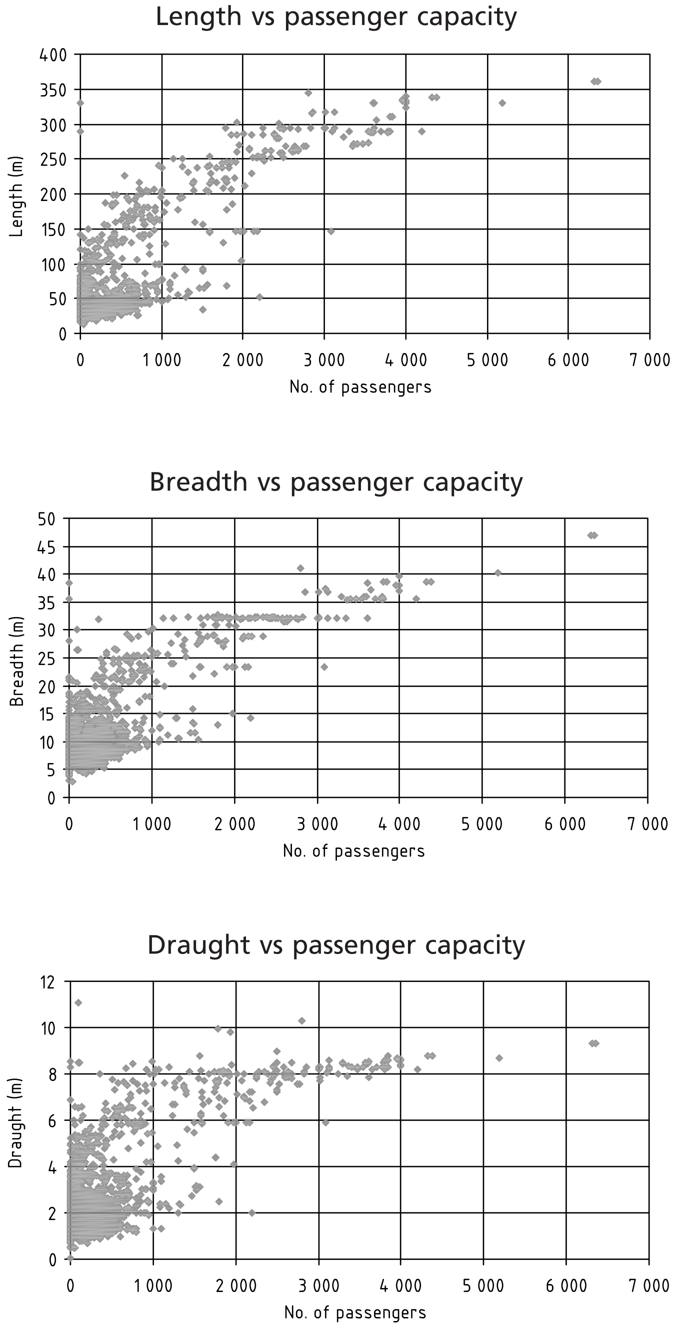


Size of sample	**1 479**
Passenger/Ro-Ro ship (vehicles)	881
Passenger/Ro-Ro ship (vehicles/rail)	61
Rail vehicles carrier	14
Ro-Ro cargo ship	523



Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

Figure D.10 **Dimensions of cruise ships related to passenger capacity**



Size of sample	**3 754**
Passenger ship	3 207
Passenger/cruise	547

Source: BSI Technical Committee CB/502, based on data from www.sea-web.com by kind permission of IHS Global Limited.

D.2 Estimation of displacement

For the purposes of preliminary planning, the relationships given in Table D.1 may be used to estimate approximate full load displacement from DWT or gas-carrying capacity. These values are approximations and are not be used for detailed design unless confirmed by the actual vessel characteristics.

Table D.1 **Approximate values of displacement from nominal ship capacity**

Vessel class	**Approximate estimate of displacement, in tonnes (t)**	
	Liquid and dry bulk carriers, container and general cargo ships	**Gas carriers**
	From deadweight tonnage (DWT), in tonnes (t)	From nominal gas capacity in cubic metres (m^3)
General cargo ships	$2.1 \times (DWT)^n$, where n = 0.953 1	—
Dry bulk carriers	$2.1 \times (DWT)^n$, where n = 0.947 5	—
Container ships	$2.1 \times (DWT)^n$, where n = 0.960 5	—
Liquid bulk tankers (oil, oil products, chemicals)	$2.1 \times (DWT)^n$, where n = 0.950 5	—
Refrigerated gas carriers – LNG	—	20 000 + 0.6 × (nom. gas capacity)
Refrigerated gas carriers – LPG	—	5 000 + 0.9 × (nom. gas capacity)

D.3 Estimation of block coefficient

The block coefficient of a vessel is used in the assessment of berthing energy (see BS 6349-4) and represents the relationship between the displacement and the overall dimensions. It is calculated as:

$$C_b = \frac{M_D}{L_{BP} B d \rho_w}$$

Table D.2 lists typical ranges of value for the block coefficient for various modern types of ships which can be used for preliminary design purposes in the absence of more specific information for the range of vessels to be accommodated at a facility.

Table D.2 **Typical ranges of C_b**

Vessel type	**Range of C_b**
Tankers and bulk carriers	0.71 to 0.88
Dry general cargo and oil and dry cargo combination carriers	0.60 to 0.85
Gas carriers (LNG)	0.69 to 0.78
Gas carriers (LPG)	0.52 to 0.66
Container	0.60 to 0.71
Ro-Ro	0.70 to 0.80
Passenger and cruise ships	0.59 to 0.70
Car carriers	0.53 to 0.66
Ferry	0.54 to 0.65

Annex E (informative) Guidance on assessment of acceptable wave conditions for moored vessels

E.1 General

The functional requirement of a mooring system is to secure the vessel safely in position at a berth under the action of environmental and other forces acting on the vessel when moored and during cargo handling and transfer.

Acceptable conditions for mooring are investigated by carrying out mooring studies supplemented with advice from operators experienced in the relevant types of ship and cargo types.

This annex gives guidance on limiting motions and displacement for planning and design purposes for small vessels less than 1 000 DWT, and for preliminary design for larger vessels before an operation-specific assessment has been carried out. The guidance in this annex is based upon PIANC PTC II Report WG24 [41], PIANC MarCom Report WG115 [42] and BS 6349-8.

PIANC PTC II Report WG24 [41] is a source of guidance on:

- the characteristics of different vessel types, moorings and cargo handling methods;
- indicative values of acceptable wave criteria for mooring small craft and pleasure boats.

PIANC MarCom Report WG115 [42] gives guidance for container vessels.

BS 6349-8 gives recommendations for the design of Ro-Ro ramps, linkspans and walkways.

E.2 Small craft and fishing harbours

PIANC PTC II Report WG24 [41] provides recommended maximum wave height criteria according to wave direction for small craft and pleasure boats up to 20 m in length, and these are reproduced in Table E.1.

Table E.1 **Wave criteria from small craft**

Length of small craft, pleasure boat	Maximum wave height criterion, beam/quartering seas		Maximum wave height criterion, head seas	
	T_z	H_s	T_z	H_s
m	s	m	s	m
4 to 10	<2	0.20	<2.5	0.20
	2 to 4	0.10	2.5 to 4	0.15
	>4	0.15	>4	0.20
10 to 16	<3	0.25	<3.5	0.30
	3 to 5	0.15	3.5 to 5.5	0.20
	>5	0.20	>5.5	0.30
20	<4	0.30	<4.5	0.30
	4 to 6	0.15	4.5 to 7	0.25
	>6	0.25	>7	0.30

NOTE Copyright is claimed in this table, which is reproduced from PIANC PTC II Report WG24 [41]. Reproduction of this table and making products from it might infringe that copyright. Details of the copyright owner can be found in the Foreword.

The values in Table E.1 typically apply to craft moored at fixed pontoons, jetties or quay walls. Larger wave heights might be tolerable in situations where careful attention is paid to selection of mooring type and design. For swinging moorings, a limiting maximum H_s of 0.6 m is often adopted for planning purposes.

The limits provided in Table E.1 are defined as conditions that have an acceptable frequency of occurrence of once per year. It is necessary to assess the risks for safety and damage to small craft and fishing vessel in the event of more infrequent events. For a harbour for permanent mooring of small craft and pleasure vessels, in the absence of other criteria, Table E.2 gives limiting indicative wave conditions for an low annual probability event (average return period T_r = 50 years).

Table E.2 **Wave climate criteria for small craft considering extreme events**

Length of small craft, pleasure boat	**Maximum wave height criterion, beam/quartering seas T_z > 4 s**		**Maximum wave height criterion, head seas T_z > 4 s**	
	T_r = 50 years	**T_r = 1 year**	**T_r = 50 years**	**T_r = 1 year**
m	m	m	m	m
10 to 20	0.30	0.15 to 0.25	0.60	0.20 to 0.30

The response of pleasure craft and fishing boats to waves with periods of 1 min or longer can be expected to be similar to the effect produced by currents. Hence wave energy at such periods is not considered significant for such craft once they are moored, and the criteria given in this subclause apply to the residual height of waves inside the harbour at storm or swell wave periods.

Table E.1 applies to the maximum wave conditions that are normally considered to be acceptable in marinas. One of the factors that led to the suggested limits is that boats are often moored close to one another so that very little movement is possible before damaging collisions occur. For marinas in exposed locations, it is frequently necessary to build a system of overlapping breakwaters, in order to achieve acceptable wave conditions. A useful guide for preliminary planning in such situations is that the open sea is not to be directly visible at water level from mooring positions inside the marina at any state of the tide. Inner harbours or basins might need to be provided where pleasure craft can be accommodated safely.

E.3 Fishing harbours

The wave criteria given in Table E.1 may also be used to make preliminary assessments of acceptable wave conditions for small fishing boats up to 20 m long, although fishing vessels are generally more strongly built than pleasure craft.

For larger fishing vessels, acceptable wave conditions can be derived from the limiting motion criteria for safe working conditions as set out in **E.4**.

E.4 Vessels larger than 1 000 DWT

Depending on vessel type, cargo handling requirements and mooring characteristics, the limiting wave conditions might be governed either by the mooring system strength or by the maximum permissible vessel motions.

In the absence of other information, the following criteria may be adopted to estimate limiting wave conditions for safe mooring:

- for fishing vessels, coasters, freighters, ferries in the range 1 000 DWT to 8 000 DWT in the range 1 000 DWT to 8 000 DWT, see Table E.3;
- for other vessels larger than 10 000 DWT, see Table E.4;

- for ferries and Ro-Ro vessels, see Table E.5;
- for container ships, see Table E.6 and Table E.7.

The values in Table E.3, reproduced from PIANC PTC II Report WG24 [41], are based on limiting the dynamic impact of a moored vessel against the quay. The limiting condition for damage to vessel and/or quay is the kinetic energy of the vessel. This has been studied in the Nordic countries for moored fishing vessels up to 3 000 GRT, and the recommended criteria are stated by PIANC PTC II Report WG24 [41] to apply to vessels up to 8 000 GRT, such as coasters, freighters, ferries and Ro-Ro vessels, as well as fishing vessels.

Table E.3 **Recommended maximum velocity limits 1 000 DWT to 8 000 DWT**

Vessel size DWT	**Surge** m/s	**Sway** m/s	**Heave** m/s	**Yaw** degree/s	**Pitch** degree/s
1 000	0.6	0.6	—	2.0	—
2 000	0.4	0.4	—	1.5	—
8 000	0.3	0.3	—	1.0	—

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For larger ships, Table E.4, based upon PIANC PTC II Report WG24 [41], gives indicative motion (displacement) criteria for safe working of cargoes for a wide range of vessel types. Guidance for container ships is given in PIANC MarCom Report WG115 [42].

NOTE The motion (displacement) criteria provided in Table E.4 are simplified and might in particular not represent latest developments for large ships and particularly for modern cargo handling equipment and control and systems. Advice from specialist cargo handling equipment and control system suppliers and operators can provide further information on most up-to-date systems.

For oil and gas tankers in particular, the preliminary motion criteria in PIANC PTC II Report WG24 [41] are very high. With recommended mooring line patterns, pre-tensioning and line tending, limitation of mooring line loads to an allowable proportion of minimum breaking load (MBL) can result in vessel excursions at the manifold which are typically reduced to displacements of less than 1 m. As noted in Table E.4, loading arms may be designed to accept larger surge, sway or yaw off the jetty as a safety precaution to prevent arm damage and hydrocarbon release from excursions due to accidental or abnormal circumstances outside the normal operating envelope. Furthermore, some petrochemical loading arms such as those for LNG and LPG include additional safety systems such as emergency shutdown (ESD) and Emergency Release Systems (ERS), which would automatically initiate at excursions less than those indicated by PIANC PTC II Report WG24 [41].

In addition to simple motion criteria, velocities and accelerations can be significant for some cargo handling systems, for connecting ship to shore connections by hoses or arms and for passenger and vehicle transfer for Ro-Ro.

Recommended maximum motion criteria for safe working conditions of Ro-Ro vessels are included in Table E.5, based upon the recommendations of BS 6349-8, which was in turn developed from the recommended values given in PIANC PTC II Report WG24 [41].

Table E.4 **Guidance on maximum motion criteria for safe working conditions**

Vessel type	Cargo handling equipment	Type of motion					
		Surge A)	Sway A)	Heave A)	Yaw A)	Pitch A)	Roll A)
		m	m	m	°	°	°
Fishing vessels	Elevator crane	0.15	0.15	0.4	3	3	3
	Lift-on-lift-off	1.0	1.0	0.4	3	3	3
	Suction pump	2.0	1.0	0.4	3	3	3
Freighters, coasters	Ship's gear	1.0	1.2	0.6	1	1	2
	Quay cranes	1.0	1.2	0.8	2	1	3
General cargo	—	2.0	1.5	1.0	3	2	5
Bulk carriers	Cranes	2.0	1.0	1.0	2	2	6
	Elevator/ bucket-wheel	1.0	0.5	1.0	2	2	2
	Conveyor belt	5.0	2.5	—	3	—	—
Oil tankers	Loading arms	0.5 to 2.0 B)	0.5 to 2.0 B)	—	—	—	—
Gas tankers	Loading arms	0.5 to 1.0 B)	0.5 to 1.0 B)	—	—	—	—

NOTE This table is based upon PIANC PTC II Report WG24 [41].

A) Motions refer to peak-peak values (except for sway: zero-peak).

B) These values are modified from PIANC since, although the loading arms may be designed to accept larger surge, sway or yaw off the jetty, the range of safe operation of the arms might be less and limit switches are likely to trigger emergency shut-down systems at lower motions.

Table E.5 **Recommended maximum motion criteria for safe working conditions of Ro-Ro vessels**

Motion	Vessel type	Movement		Velocity	
		Normal operating condition	Extreme operating condition	Normal operating condition	Extreme operating condition
Range/surge	Normal Ro-Ro	±0.3 m	±1.0 m	0.12 m/s	0.3 m/s
	Rail ramp	±0.05 m	—	0.4	As above
Sway	Normal Ro-Ro	±0.3 m	±1.0 m	0.12 m/s	0.3 m/s
	Rail ramp	±0.05 m	—	—	—
Heave	Normal Ro-Ro	±0.3 m	±1.0 m	0.12 m/s	0.3 m/s
	Rail ramp	±0.2 m	—	0.4	—
Roll/heel A)	Normal Ro-Ro	±2.0°	±5.0°	0.3°/s	0.5°/s
	Rail ramp	±1.0°	—	—	—
Yaw	Normal Ro-Ro	±0.25°	±0.5°	0.15°/s	0.2°/s
	Rail ramp	—	—	—	—
Pitch/trim B)	Normal Ro-Ro	±0.5°	±1.0°	0.08°/s	0.1°/s
	Rail ramp	±1.0°	—	—	—

NOTE This table is based upon BS 6349-8.

A) Not combined with swaying.

B) Not combined with heaving.

Recommendations on the (un)loading of container ships is given in PIANC MarCom Report WG11 [42]. The report uses the concept of significant motion criteria rather than maximum motion criteria given in PIANC PTC II Report WG24 [41]. The report recommends that ship simulation modelling is carried out for all ships in locations where motions are likely to be or known to be high. For concept design, the values in Table E.6 are applicable for an (un)loading efficiency of 95%. The basis of the range of limiting surge values given in Table E.6 is further clarified in Table E.7 according to the applicable placing criteria.

Table E.6 **Guidance on maximum allowable significant motion amplitude conditions for container ships for (un)loading efficiency of 95%**

Ship type	**Principal motion**					
	Surge A) m	**Sway** B) m	**Heave** B) m	**Yaw** B) °	**Pitch** B) °	**Roll** B) °
Container ship	0.2 to 0.4	0.4	0.3	0.3	0.3	1

NOTE This table is based upon PIANC MarCom Report WG115 [42].

A) The two values for surge are for placing criteria of 0.1 m and 0.2 m, which represents connection via twist lock pins and spreader flaps as shown in Table E.7.

B) For large container ships not exposed to beam-on swell, the limiting motion is surge. Other motions are usually found to be acceptable for an efficient (un)loading process when surge is within these limits.

Table E.7 **Surge criteria for container ships for (un)loading efficiency of 95%**

Placing criterion	**Basis for placing criterion**	**Maximum allowable significant surge motion amplitude (T_{surge} = 30 s to 100 s)**
0.1 m	Twist-lock pins	0.2 m
0.2 m	Spreader flaps	0.4 m

NOTE This table is based upon PIANC MarCom Report WG115 [42].

E.5 Further background to moored ship dynamic response

Recommendations regarding methods of numerical and physical modelling of moored ship response in order to assess acceptable wave conditions for moored ships are provided in Clause **20**. Some further background regarding factors affecting moored ship dynamic response is provided below.

In particular there are a number of factors which make it difficult to define acceptable conditions directly in terms of simple sets of wave conditions. These factors include:

- the range of ship types and hull forms;
- the hydrodynamics of moored-ship response to wave action in shallow water;
- the range of berth configurations and near-berth bed slopes (marginal quays of different types, open piled jetties) and consequent different hydrodynamic interaction with the moored ship;
- the complex nature of shallow water wave fields, particularly in harbours where reflection and diffraction effects might be significant;
- different mooring layouts;
- different mooring line and tail material and properties;
- the contribution to mooring forces and motions of other environmental effects, including wind and currents;

- the contribution to mooring forces and motions of wave energy at different frequencies, including bound or free infragravity waves of periods in excess of 25 s at some locations.

When a floating body oscillates in water, it creates a disturbance. In open water, the inertia of the surrounding water accelerated by the motion of the body effectively increases the mass of that body (added mass). Oscillation also produces waves that propagate away from the body, carrying energy with them that tends to damp out the oscillation (radiation).

The forces tending to restore a moored vessel to its equilibrium position are buoyancy forces for vertical motions and forces supplied by the moorings for horizontal motions. These restoring forces give rise to natural periods of oscillation. For vertical motions, these can be within the range of swell and storm waves. For horizontal motion, they vary from about 20 s for vessels of 3 000 t displacement to periods of 1 min or longer for vessels in excess of 100 000 t.

The wave forces that act on a vessel to cause oscillation can be divided into two types. The first type is linear wave forces of the same period as the waves, which can be obtained by integrating the fluctuating water pressure over the submerged area of the hull. Because the vessel usually alters the wave pattern around itself, the problem of diffraction of the wave system by the vessel has to be solved before the wave force can be determined. These forces are capable of exciting the natural periods of vertical oscillation of a vessel.

Non-linear moorings are also capable of exciting the natural periods of horizontal oscillation. The strongest non-linearity in moorings arises because the fenders are usually stiffer than the mooring lines. In a beam sea, a vessel can move transversely on and off the fenders at a sub-harmonic of the wave period, i.e. the wave period divided by *n*, where *n* is an integer, and the largest motion occurs at the sub-harmonic that is nearest to the natural period of this motion. This type of vessel response can be avoided by making the fenders as soft as the mooring lines. It does not necessarily follow, though, that relatively soft fenders are better than relatively stiff ones, because the second type of wave forces described in this subclause could excite a larger resonant response of a vessel on softer moorings.

The second type of wave force is non-linear. This occurs as a consequence of the irregular nature of the sea surface. Because waves travel in groups, they produce secondary wave forces with the periodicity of wave groups. These secondary forces are smaller than the linear wave forces described in this subclause but they have periods similar to the natural periods of horizontal oscillation of moored ships. Because the natural damping of these oscillations is low, quite small secondary wave forces are capable of building up large resonant oscillations of a vessel on its moorings. For a vessel that is scattering the waves, a force is produced at the waterline due to scatter of the momentum carried by the waves. Because this momentum is larger in a group of high waves than in a group of small waves, the force produced has the periodicity of wave groups.

The fluctuating water pressures produced by bound infragravity waves associated with wave grouping or free infragravity waves also act on the ship's hull to produce a significant dynamic response in shallow water at wave group periods.

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