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Date: 29 July 2024

Origin: National

Latest date for receipt of comments: 5 October 2024

Project No. 2021/02351

Responsible committee: CB/502 Maritime works

Interested committees:

Title: Draft BS 6349-1-1 Maritime works. Part 1.1: General. Code of practice for planning and design for the asset lifecycle

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Introduction

Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international and European standards, comments will be reviewed by the relevant UK national committee before submitting the consensus UK vote and comments. If the draft standard is approved, it is usual for the resulting published standard to be adopted as a British Standard.

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BS 6349-1-1

Maritime works – Part 1-1: General – Code of practice for planning and design for the asset lifecycle

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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on **XX Month 202X**. It was prepared by Technical Committee CB/502, *Maritime works*. A list of organizations represented on this committee can be obtained on request to the committee manager.

Supersession

This British Standard supersedes BS 6349-1-1:2013, which is withdrawn.

Relationship with other publications

BS 6349 is published in the following parts¹⁾:

- Part 1-2: General – Code of practice for assessment of actions;
- 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

This is a full revision of the document, and introduces the following principal changes.

- general updating of reference documents to reflect latest practice.
- enhanced applicability of content generally with reference to the whole asset lifecycle and coastal flood and erosion control management infrastructure. The title has been changed from planning and design for operations to planning and design for the asset lifecycle.
- new Section 2 with revised Clause 4 revising environmental considerations within the broader remit of the UN sustainable development goals with additional guidance on:
 - assessment and management of environmental impacts including the sustainable management and efficient use of natural resources;
 - reduction of carbon emissions through the asset lifecycle; and
 - climate change adaptation and infrastructure resilience.
- Clause 5: revised details on bathymetric and topographic surveys, recognizing different requirements for different types of asset and lifecycle stages, and also with respect to developments in survey technology and digitization.
- Clause 6: additional guidance on:
 - climate change projections; and

¹⁾ A new part, BS 6349-9, covering port surfacing, is in preparation.

- wave measurements.
- Clause **8**: revision of long-term sea level trends.
- Clause **10**: guidance on waves.
- addition of a new Section 4 comprising Clause **13** to Clause **22** on wave and water levels for design of general applicability currently included in BS 6349-1-2 and planned for removal from that Part in a future revision.
- Section 5 comprising Clause **23** to Clause **34** now expanded in scope to include functional, operational and safety considerations.
- Clause **23**: extended guidance on definition of performance and other end-user requirements and development of a design basis including operational and stakeholder input. Recommendations included on planning for execution and the use of a Building Information Model (BIM).
- Clause **24**: general update of health safety considerations, including recommendations with respect to:
 - safety in design;
 - HAZID and risk assessment generally;
 - terminals for hazardous products and cargos; and
 - floating LNG terminals with long term moorings.
- Clause **27**: expanded from definition of design working life to include recommendations of wider applicability addressing the periods used for project appraisal and design. Amongst other things, this recognizes adaptive management approaches in planning for climate resilience.
- Clause **28** and Annex H: updated to reflect trends in vessel sizes based upon commercially available vessel databases as of early 2022.
- rearrangement of content regarding mooring studies design resulting in deletion of some content from Part 1-1 with the intention of including in future revisions of Part 1-2 and Part 4. This includes deletion from Part 1-1 of parts of Clause **30** and parts of Annex E detailing mooring studies.
- Clause **32**: edited and expanded in scope to address wider aspects of reliability and performance-based design. Previous parts of content specific to derivation of actions is excluded (since it falls within the scope of BS 6349-1-2). This clause now addresses:
 - design principles as per BS EN 1990;
 - earthquakes and seismic performance;
 - design operating conditions and actions; and
 - hydraulic response and performance requirements.
- Clause **33**: maintenance has been developed and expanded.
- Clause **34**: a new clause has been added to include recommendations for assessment of decommissioning requirements at the planning and design stage.
- Annex A: organizations with a role in coastal activities in the UK are updated.
- Annex B to Annex E: currently included as Annex A to Annex D of BS 6349-1-2 and is planned for removal from that Part in a future revision.
- Annex I: Annex I now provides updated informative guidance on typical operationally acceptable motion criteria, rather than methods for assessing acceptable wave conditions for mooring. The future revision of BS 6349-8 does not duplicate the motion

criteria provided in Annex I. Former section E.5 has been deleted and will be included in a revision of BS 6349-4.

Copyright is claimed on Figure 2, Figure 3, Figure 4, Table I.1 and Table I.3. The copyright holder is PIANC General Secretariat, Boulevard du Roi Albert II 20, Box 3, B-1000 Brussels, Belgium.

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Use of this document

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

Users may substitute any of the recommendations in this British Standard with practices of equivalent or better outcome. Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of 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.

Where words have alternative spellings, the preferred spelling of the *Shorter Oxford English Dictionary* is used (e.g. “organization” rather than “organisation”).

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Section 1: General

1 Scope

This part of BS 6349 gives recommendations and guidance for general criteria relevant to the planning, design, construction, maintenance and decommissioning of structures and facilities set in the maritime environment. It also gives recommendations and guidance regarding safety, environmental and operational matters that are to be taken into account when planning and designing maritime and coastal works.

It includes a description of the various physical environmental conditions that are to be taken into account for investigation at a coastal site, and provides recommendations and information for 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 flood and coastal erosion risk management and to recreational infrastructure such as marinas.

NOTE 1 The BS 6349 series is also partly applicable to other applications such as wave effects on lakes and reservoirs.

NOTE 2 The BS 6349 series might be applicable to types of floating LNG installation (such as FSRUs and FSUs) as described in BS ISO 20257 which are permanently or semi-permanently moored to a jetty or similar structure at an inshore or protected location.

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.

NOTE 3 Recommendations for ground investigation are covered in in BS 6349-1-3.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions of this document. 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 6349-1-2, *Maritime works – Part 1-2: General – Code of practice for assessment of actions*

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

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

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

BS EN 1990, *Eurocode – Basis of structural and geotechnical design*

BS EN 1997 (all parts), *Eurocode 7 – Geotechnical design*

BS EN 1998-1, *Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings*

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

BS ISO 21931-2, *Sustainability in buildings and civil engineering works – Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment*

PAS 2080, *Carbon management in infrastructure – Specification*

Other publications

[N1] INTERNATIONAL CHAMBER OF SHIPPING (ICS), OIL COMPANIES INTERNATIONAL MARINE FORUM (OCIMF) and INTERNATIONAL ASSOCIATION OF PORTS AND HARBOURS (IAPH). *International safety guide for oil tankers and terminals (ISGOTT)*. Sixth edition. Livingston: Witherby Seamanship International Ltd., 2020.

[N2] PIANC. *Safety aspects affecting the berthing operations of tankers to oil and gas terminals*. MarCom Report WG116. Brussels: PIANC, 2012.

[N3] INTERNATIONAL MARITIME ORGANISATION (IMO). *International ship and port facility security code (ISPS code)*. London: IMO, 2003.

[N4] PIANC. *Harbour approach channels. Design guidelines*. MarCom Report 121. Brussels: PIANC in co-operation with IAPH, IALA & IMPA. 2014.

[N5] INTERNATIONAL ASSOCIATION OF MARINE AIDS TO NAVIGATION AND LIGHTHOUSE AUTHORITIES (IALA-AISM). *Vessel traffic services manual*. Sixth edition. St Germain-en-laye: IALA, 2016.

[N6] OIL COMPANIES INTERNATIONAL MARINE FORUM. *Mooring equipment guidelines*. Fourth edition (MEG4). London: OCIMF, 2018.²⁾

²⁾ Available at <https://www.ocimf.org/publications/books/mooring-equipment-guidelines-meg4>

3 Terms, definitions, symbols and abbreviated terms

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 adaptive capacity

ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences

3.1.3 adaptive management

process of iteratively planning, implementing and modifying strategies for managing resources in the face of uncertainty and change

NOTE Adaptive management involves adjusting approaches in response to observations of their effects and changes in the system brought on by resulting feedback effects and other variables.

3.1.4 asset lifecycle

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

3.1.5 bimodal sea

when swell co-exists with locally generated wind seas and two (or possibly more) peaks occur at the frequencies corresponding to the representative periods of swell and (locally generated) wind waves

3.1.6 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.

3.1.7 climate change adaptation

process of adjustment to actual or expected climate and its effects

NOTE 1 In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.

NOTE 2 In some natural systems, human intervention can facilitate adjustment to expected climate and its effects.

3.1.8 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

3.1.9 currents

3.1.9.1 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.

3.1.9.2 tidal current

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

3.1.9.3 total current

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

3.1.10 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.

3.1.11 design stage operating limits (DSOL)

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

3.1.12 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**]

3.1.13 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.

3.1.14 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)

3.1.15 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.

3.1.16 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

3.1.17 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

3.1.18 extreme high water

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

3.1.19 extreme low water

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

3.1.20 extreme operating condition

condition for a design situation when a facility is subject to extreme environmental conditions exceeding the DSOL (see 3.1.11) whether in use or not by ships for berthing, de-berthing, or mooring

3.1.21 facility operating manual

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

3.1.22 flood and coastal erosion risk management (FCERM)

management of the risks to people, property and the natural environment caused by flooding and coastal erosion including by carrying out predictive studies, construction of new or upgraded infrastructure, planned maintenance and other operational measures

3.1.23 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 m³ (100 ft³).

3.1.24 gust

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

NOTE The wind speed of a gust can be averaged, for design purposes, over longer or shorter time periods according to the response to be assessed.

3.1.25 human factors

environmental, organisational and job factors that interact with human and individual characteristics to influence behaviour at work which can then affect health and safety and performance

3.1.26 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.

3.1.27 marine facility

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

3.1.28 marine growth

living organisms attached to a structure

3.1.29 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.

3.1.30 maritime works

marine and coastal infrastructure assets and facilities which are set in the maritime environment including coastal, nearshore and estuarine locations subject to tidal and other water level variation, waves, currents and sediment transport processes

NOTE Maritime works include a wide range of types of infrastructure including: ports and harbour works; marine terminals; quay walls, jetties, berths and moorings; marinas and recreational facilities; flood and coastal erosion risk management works; dredging and reclamation; inshore moorings and floating structures; tidal gates and control structures; lock gates; dry-docks; breakwaters, sea walls and coastal embankments; and RoRo linkspans.

3.1.31 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.

3.1.32 mean wave period

ratio of the length of record to the number of zero-crossing waves

3.1.33 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 standard time intervals are 10 min or 1 h depending upon usage.

3.1.34 metocean parameters

meteorological and oceanographic design and operating conditions and 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

NOTE Metocean conditions are physical environmental conditions principally including or related to:

- 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); and
- marine growth.

3.1.35 nature based solutions

actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits

NOTE This definition was adopted by the IUCN in 2016 and in this standard is intended to include approaches and initiatives such as working (or building) with nature and green infrastructure. Blue carbon is a related concept and is the carbon stored in coastal and marine ecosystems (see 4.2).

3.1.36 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

3.1.37 nautical depth

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

3.1.38 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 (see 3.1.11) for the facility

3.1.39 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, marine facilities, locks, tidal gates or demountable elements within a coastal defence system are usually actively operated by a harbour authority, terminal operator or local authority or agency. Other works such as coastal protection revetments might not appear to be actively operated but are likely to be actively managed, monitored and maintained by an operator such as a government agency.

3.1.40 operator

harbour authority, port operator, terminal operator, government agency, local authority or other such competent entity responsible for operating and maintaining a marine facility for use by vessels or as part of FCERM

3.1.41 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

3.1.42 polar low

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

3.1.43 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.

3.1.44 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.

3.1.45 return period

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

NOTE The return period in years is reciprocally equal to the annual exceedance probability (AEP) of the event.

3.1.46 safety critical element

structural element, equipment or other part of an infrastructure system which supports critical equipment or operations, the loss or failure of which would result in severe safety, environmental or operational consequences, including the disproportionate escalation of an incident such as fire, explosion, earthquake or impact

NOTE For example this might include:

- sections of a jetty supporting firefighting equipment or emergency shutdown valves;
- a flood wall on the crest of a coastal embankment which prevents widespread landside flooding of residential areas in storm events; and
- long term mooring system components for an FSRU with a continuous high-pressure gas connection to shore that is not otherwise safeguarded by a fail-safe coupling.

3.1.47 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).

3.1.48 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.

3.1.49 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 ranging from minutes in harbours and bays to over 10 h in large lakes.

3.1.50 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, and bulk carriers

3.1.51 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 wavelength 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.

3.1.52 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, H_s , 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.

3.1.53 soliton

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

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

NOTE 2 Solitons are also known as “internal waves”.

3.1.54 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.

3.1.55 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).

3.1.56 squat

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

3.1.57 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.

3.1.58 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.

3.1.59 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.

3.1.60 systems thinking

understanding of cross-cutting (systemic) issues of the organization by examining internal and external interdependencies and linkages, for example through cause-and-effect relationships

NOTE 1 Examples of interdependencies and linkages include supply chains, market forces, organizational units, functions and physical boundaries, and the enabling environment.

NOTE 2 Systems thinking can be used to understand the consequences of risk being transferred.

NOTE 3 The systems approach to infrastructure delivery (SAID) referenced in 23.1 embodies systems thinking.

3.1.61 tides

3.1.61.1 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

3.1.61.2 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.

3.1.61.3 mean low water springs (MLWS)

average, over a long period of time, of the heights of two successive low waters at spring tides

3.1.61.4 neap tides

two occasions in a lunar month when the average range of two successive tides is at its lowest

3.1.61.5 spring tides

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

3.1.62 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 Northwest Pacific, and cyclones in the South Pacific and South Indian Ocean.

3.1.63 tsunami

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

3.1.64 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 craft or pleasure craft

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

3.1.65 waves

3.1.65.1 wave frequency

inverse of a wave period

3.1.65.2 wave group velocity

velocity of propagation of a train of waves, i.e. the velocity at which the energy of the wave train travels

NOTE A train of waves of single period travelling in still water propagate at a velocity less than the phase velocity of the individual waves. Waves are created at the rear of the train, move through the train and die out at the wave front.

3.1.65.3 wave height

height of a wave crest above the preceding wave trough

3.1.65.4 wavelength

distance between consecutive wave crests

3.1.65.5 wave period

time for two successive wave crests to pass a fixed point

3.1.65.6 wave phase velocity

speed at which a wave propagates

NOTE This is sometimes referred to as a wave celerity or velocity of wave propagation.

3.1.65.7 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 is used to calculate significant wave height.

3.1.65.8 wave steepness

wave height divided by wavelength, H/L

3.1.66 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

3.2 Symbols

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

B	beam of vessel (m)
b_o	wave ray separation in deep water
C_b	block coefficient of a vessel
C_g	wave group velocity (m/s)
D	characteristic length scale of a system
D_{50}	median size of graded sediment (mm)
d	still water depth (m)
d_r	draught of a vessel (m)
E	wave energy density
F_r	Froude number
f	wave frequency (Hz)
f_p	frequency at which the peak occurs in the spectrum
g	acceleration due to gravity (m/s^2)
H	wave height (m)

H_L	limiting wave height in probability distributions (m)
H_b	breaking wave height (m)
$H_{\max}$	maximum wave height (m)
H_{m0}	spectral significant wave height (m)
H_n	n th height or height interval in a rank ordered set of n_x values
H_o	deep water wave height (m)
H_s	significant wave height (m)
H'_o	equivalent deep water wave height (m)
$H_{1/250}$	mean height of the 0.4% highest waves (m)
K_b	bed friction factor
K_f	wave height reduction factor
K_p	percent reduction in wave height
K_r	wave refraction coefficient
K_s	wave shoaling coefficient
k	wave number
k_J	dimensionless coefficient used in JONSWAP wave spectrum
k_P	dimensionless coefficient used in Pierson-Moskowitz wave spectrum
L	wavelength (m)
L_{BP}	length of hull between perpendiculars (m)
L_F	fetch length (m)
L_o	wavelength in deep water (m)
M_D	displacement of a vessel (t)
m_0	zeroth spectral moment
n	number between 1 and n_x (of any variable, e.g. years or events)
P_s	subsurface pressure
p	probability of a particular extreme condition occurring during design working life n years
q_s	suspended volumetric sediment transport rate ($m^3/s/m$)
$S(f)$	one-dimensional spectral density function
T	wave period (s)
T_m	mean wave period (s)
$T_{m-1,0}$	spectral mean energy wave period (s)
T_p	spectral peak wave period (s)
T_R	return period of an extreme condition in years
T_s	significant wave period (s)
T_{surge}	period of vessel surge motion
T_z	zero-crossing wave period (s)
T_0	period or duration of observation
$T_{1/3}$	significant wave period ($=T_s$)
t	time interval (s) or variable

U_t	mean wind speed averaged over a time interval of t (m/s)
U_w	wind speed 10 m above the sea surface
u	characteristic velocity of a system (m/s)
u	horizontal component of water particle velocity (m/s)
$\dot{u}$	horizontal component of water particle acceleration (m/s ²)
$\dot{v}$	vertical component of water particle acceleration (m/s ²)
v_c	velocity of wave propagation (m/s)
v_{co}	velocity of wave propagation in deep water (m/s)
v_{cg}	wave group velocity (m/s)
v_{cgo}	wave group velocity in deep water (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)
x	horizontal distance from a defined datum (m)
z	vertical distance from still water level (m)
α_s	seabed slope angle
β	bed slope
β_0	dimensionless coefficient used in wave shoaling and breaking estimation
β_0^*	dimensionless coefficient used in wave shoaling and breaking estimation
β_1	dimensionless coefficient used in wave shoaling and breaking estimation
β_1^*	dimensionless coefficient used in wave shoaling and breaking estimation
β_{max}	dimensionless coefficient used in wave shoaling and breaking estimation
γ	peak enhancement factor (for wave spectra)
γ_{br}	depth-limited breaker index
γ_w	ratio of the density of sea water to water density in the model
ζ_v	vertical displacement of the water particle from its mean position
ζ_h	horizontal displacement of the water particle from its mean position
η	instantaneous water surface level (e.g. of a wave profile)
θ	angle between the plane across which energy is being transmitted and the direction of wave advance
λ	geometric scale of a physical model
ξ	surf similarity parameter (Iribarren number)
ρ	mass density of water (kg/m ³)
ρ_w	density of sea water (t/m ³)
σ	standard deviation of the time series of water surface elevation
ψ	shallow water wave direction as defined in Figure C.2

ψ_0	deep water wave direction as defined in Figure C.2
ω	angular frequency

3.3 Abbreviated terms

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

ADCP	acoustic doppler current profiler
AIM	asset information model
AUV	autonomous underwater vehicle
BIM	building information model
COGR	continuously operating GNSS receiver
DSOL	design stage operating limits
DWT	deadweight tonnage
EMS	environmental management system
FCERM	flood and coastal erosion risk management
FLNG	floating liquefied natural gas unit
FSRU	floating storage and regasification unit
FSU	floating storage unit
GPS	global positioning system
GRT	gross register tonnage
GT	gross tonnage
HAZID	hazard identification study
IPCC	intergovernmental panel on climate change
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	maneuverability margin
PBB	passenger boarding bridge
PIANC	world association for waterborne transport infrastructure
PIM	project information model
RCM	recording current meter
Ro-Ro	roll-on, roll-off
ROV	remotely operated vehicle
RTK	real-time kinematic
SAID	systems approach to infrastructure delivery

SBES	single-beam echo sounder
SMP	shoreline management plan
SMS	safety management system
TEU	twenty-foot equivalent unit
UAV	unmanned aerial vehicle
UKC	under-keel clearance
UKCP	UK climate projections
UN SDG	United Nations sustainable development goals
UXO	unexploded ordnance
VLCC	very large crude carrier

Section 2: Sustainable development and climate change

4 Sustainable development

COMMENTARY ON CLAUSE 4

The UN Sustainable Development Goals³⁾ (UNSDG) are a set of 17 goals comprising 169 targets launched in 2016 for the world to achieve by 2030. These goals are relevant to the planning, design, execution and operation of maritime infrastructure works, including, but not limited to:

- Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation;
- Goal 12. Responsible consumption and production;
- Goal 13. Take urgent action to combat climate change and its impacts;
- Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development; and
- Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems; sustainably manage forests; combat desertification; halt and reverse land degradation; and halt biodiversity loss.

The UK National Infrastructure Commission has published a set of four design principles for national infrastructure⁴⁾ as follows:

- climate – mitigate greenhouse gas emissions and adapt to climate change;
- people – reflect what society wants and share benefits widely;
- places – provide a sense of identity and improve our environment; and
- value – achieve multiple benefits and solve problems well.

These principles are consistent with a sustainable approach to projects taking into account climate change, reduction of carbon emissions and a focus on value, benefits and outcomes for the environment, end users and society as a whole.

The recommendations in this Clause are intended to be consistent with UN Sustainable Development Goals and UK national policy for infrastructure development with respect to:

- assessment and management of environmental impacts including the sustainable management and efficient use of natural resources;
- reduction of carbon emissions through the asset lifecycle; and
- climate change adaptation and infrastructure resilience.

The UK Government published “Net Zero Strategy: Build Back Greener” in October 2021⁵⁾ which sets out a strategy with the intent of reaching net zero emissions by 2050 and a Clean Maritime Plan which includes a vision for infrastructure in ports to support zero emission shipping by bunkering with alternative fuels and to support development and operation of offshore renewable energy projects. Electrification of ports is also envisaged to reduce carbon emissions and improve air quality. This includes supply of shore-side power to vessels’ auxiliary systems when vessels are at berth (also referred to as cold-ironing).

BS ISO 21931-2 provides a framework for methods of assessment of the sustainability performance of civil engineering works and related external works, with a life-cycle approach that focusses on:

- use of resources (materials, water and energy) and waste generation;
- discharges into water, atmosphere and soil;
- biodiversity and ecosystems;
- social impacts, throughout the value chain; and
- innovative and proactive approaches towards selecting the most beneficial and economical alternatives.

³⁾ Available from <https://sdgs.un.org/goals>

⁴⁾ Available at <https://nic.org.uk/app/uploads/NIC-Design-Principles.pdf>

⁵⁾ Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

4.1 Sustainability and environmental management

Planning, design, execution and operation of maritime infrastructure works should be based on sound principles of sustainable development consistent with the UNSDG, with particular focus on:

- a) assessment and management of environmental impacts including the sustainable management and efficient use of natural resources;
- b) reduction of carbon emissions through the asset lifecycle; and
- c) climate change adaptation and infrastructure resilience.

Sustainability performance should be assessed within the framework in accordance with BS ISO 21931-2.

The environmental impact of the construction, operation, maintenance, and commissioning of maritime works 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. Where impacts are potentially significant and environmental approvals/licenses are likely to be required, 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:

- 1) take into account the output from a formal environmental impact assessment;
- 2) highlight environmental aspects to be considered where a formal environmental impact assessment is not required; and
- 3) 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. Early engagement with environmental licensing authorities is likely to be required for all significant maritime works. This is due to:

- *the potential for significant constraints being imposed by licensing authorities on construction methodology and timing; and*
- *the potential for significant environmental constraints to impact on the design of maritime works.*

NOTE 2 For international development projects and in the absence of more stringent local regulations, the International Finance Corporation (IFC) eight performance standards on Environmental and Social Sustainability⁶⁾ establish standards that clients and financing organisations (specifically IFC but often supported by a wide range of investors) can use to demonstrate sustainability throughout the life of an investment. Of more specific applicability to maritime works, 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 3 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];*

⁶⁾ Available at <https://www.ifc.org/content/dam/ifc/doc/2023/ifc-performance-standards-2012-en.pdf>

- *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];*
- *sustainable ports – A guide for Port Authorities [12]; and*
- *guide for applying working with nature to navigation infrastructure projects [13].*

NOTE 4 BS 6349-5, Section 5 provides recommendations on environmental design of dredging and reclamation works and may have broader applicability to maritime works.

NOTE 5 The use of nature-based solutions provides an approach which goes beyond impact avoidance or mitigation and looks for opportunities to integrate nature into project designs. In the UK the Environment Agency provides resources in the form of an evidence base for working with natural processes to reduce flood risk.⁷⁾

4.2 Carbon management

Management of whole life carbon in new and refurbished maritime infrastructure should be carried out in accordance with PAS 2080. In planning for maritime developments, reduction of carbon emissions through the asset lifecycle should be taken into account in assessing options to be taken forward to execution. The use of nature-based solutions should be assessed to identify opportunities to reduce or sequester carbon and enhance resilience to climate change.

NOTE 1 PIANC EnviCom 188 [14] includes guidance on carbon management framework with reference to PAS 2080 with focus and examples from the maritime sector. It also reviews best practice and opportunities for reducing atmospheric greenhouse gas emissions through operational practices, working with nature, land use management, “blue carbon” projects⁸⁾ and related environmental management.

NOTE 2 Building Information Modelling (BIM) systems can be used in conjunction with other commercially available digital tools to support and systematise carbon management in infrastructure design, construction and operation.

4.3 Climate change

4.3.1 General

During planning and design of maritime works, the planners and designers should take account of the fact that climate change is predicted to cause sea-level rise and changes in storm patterns, intensity and direction potentially affecting coastal surge elevations, wave conditions, rainfall intensity and river and run-off discharges.

NOTE 1 BS EN ISO 14090 includes guidance on assessing climate change impacts in general terms informed in part by systems thinking and includes and defines concepts of adaptation, adaptive capacity and adaptive management. Adaptive management involves adjusting approaches in response to observations of their effects and changes in a system brought on by resulting feedback effects and other variables.

Climate change risk assessments and adaptation planning should be carried out as part of the planning for new and refurbished maritime infrastructure based upon the latest and most reliable climate change projections for the location at the design stage. Risk assessments should take into account the complete asset lifecycle and should be updated as necessary through execution and operation. Mitigations identified in the risk assessment should be taken into account during design and any requirements for monitoring or plans or strategies for future adaption should be incorporated in the facility operating manual.

NOTE 2 Climate change represents a significant risk to operations, safety and integrity of infrastructure due to:

- *air and water temperature increases;*
- *rising sea levels;*

⁷⁾ Available at <https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/working-with-natural-processes-to-reduce-flood-risk>

⁸⁾ Available at www.thebluecarboninitiative.org

- changes in seasonal precipitation, wind and wave conditions; and
- risk of more frequent and severe extreme events such as storms, heatwaves and droughts.

NOTE 3 PIANC EnviCom178 [15] provides an introduction to the potential consequences of climate change and some of the challenges to be addressed for ports and inland waterways. It also introduces a four-stage methodological framework to help port and waterway operators plan how best to adapt.

NOTE 4 The selection of climate change allowances for design is set out in Section 4 (in England, the Environment Agency published guidance on climate change allowances for flood and coastal risk projects, schemes and strategies.⁹⁾)

NOTE 5 BS EN ISO 14090 includes guidance on assessing climate change impacts in more general terms informed in part by systems thinking.

4.3.2 Adaptation and resilience

Climate change adaptation is the process of adjustment to actual or expected climate change and requirements for adaptation should be assessed at the earliest stage of planning for new and upgraded coastal and maritime infrastructure. Climate change adaptation requirements should also be part of the management of coastal and maritime assets.

Assessment of adaptation requirements should be based upon risk assessment and should include:

- a) identification of the criticality of an asset either alone or as part of a wider system where disruption or destruction would have a significant adverse impact on the continued functioning of the system or that otherwise necessary to maintain life safety or a vital economic or societal function;
- b) definition of the planning horizon which is the length of time into the future that is covered in the climate change adaptation strategy;
- c) assessment of vulnerability being the degree to which the system is susceptible to, and unable to cope with, adverse climate change effects; and
- d) assessment of resilience being the capacity of an asset or to anticipate recover from an adverse climate related event within a tolerable time period.

Adaptation approaches and strategies should include:

- 1) a precautionary approach where conservative allowances to mitigate future climate impacts are implemented as part of initial capital works;
- 2) a managed adaptive approach where planned actions or works are implemented when particular observed climate thresholds are triggered (in this case the approach can be described as an adaptation pathway); and
- 3) some combination of precautionary approach for highly likely climate change outcomes (so-called low or no regret options) and managed adaptation for climate change outcomes with high inherent uncertainty.

NOTE 1 PIANC EnviCom178 [15] provides a four-stage methodological framework to help port and waterway operators plan and manage adaptation.

NOTE 2 In England, the Environment Agency describes an adaptive approach to managing flood and coastal erosion risk. This approach has planned actions when particular thresholds are observed and provides the benefits of avoiding over-engineering assets together with flexibility to manage future climate change uncertainties. The EA state that such an approach can be appropriate where the ongoing responsibility is assigned to an operating authority which has well-defined duties for monitoring the change in risk over time and for implementing required actions.

⁹⁾ Available at <https://www.gov.uk/guidance/flood-and-coastal-risk-projects-schemes-and-strategies-climate-change-allowances>

WARNING. THIS IS A DRAFT AND MUST NOT BE REGARDED OR USED AS A BRITISH STANDARD. THIS DRAFT IS NOT CURRENT BEYOND **24 July 2024**.

NOTE 3 Natural England has published the *Climate Change Adaptation Manual (NE751)*.¹⁰⁾ The adaptation manual is a resource bringing together recent science, experience and case studies on habitat management, species, green infrastructure, geology and geomorphology, and access and recreation.

¹⁰⁾ Available at <http://publications.naturalengland.org.uk/publication/5679197848862720>

Section 3: Surveys, data collection and studies

COMMENTARY ON SECTION 3

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. More complete guidance on the assessment of metocean conditions for the design of maritime works, taking into account the effect of metocean conditions (waves, currents, water levels) throughout the lifecycle including construction and operation are provided in Section 4.

Information and data is frequently already available from existing sources, although such data can be limited in scope and applicability and therefore further detailed surveys, investigations, processing and analysis 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.

5 Bathymetric and topographic surveys

COMMENTARY ON CLAUSE 5

Accurate definition of seabed, shoreline and land elevation is required for the planning, design, construction, operation and maintenance of structures and facilities. This section provides guidance on the scope and types of surveys that can be used to provide the required level of definition according to the stage in the asset lifecycle and purpose of the survey.

In general, planning and concept design are often based on more limited or less accurate survey methods and data sources than is required for detailed design, execution, and operation. When navigation by international shipping is proposed, surveys are usually required to be carried out in accordance with IHO Publication C-13 – Manual on hydrography [16]. Requirements for surveys for design, execution and operational monitoring and maintenance of maritime civil engineering works are frequently different or additional to the requirements for navigation. However, surveys for handover of completed facilities and navigation channels and structures for operational use for navigation are often required by maritime authorities or operators to meet IHO standards.

Hydrography as defined by the IHO includes the consideration of the following matters:

- *shoreline configuration, including infrastructure for maritime navigation, i.e. all 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; and*
- *physical properties of the water column.*

In Clause 5, the first three of these matters are included. Tides, currents, and water column properties are covered in Clause 8, Clause 9 and Clause 11, respectively.

The methods and technologies selected for surveying for maritime works and operations depend upon a combination of factors related to data end use, accuracy and spatial data density requirements, accessibility, environmental conditions, and stage in the asset lifecycle.

The following documents provide guidance on planning and undertaking hydrographic and topographic surveys:

- *CIRIA 783, Unmanned aerial vehicles for managing assets [17];*
- *EM 1110-1-1005, Control and topographic surveying [18];*
- *EM 1110-2-1003, Hydrographic surveying [19];*
- *National Oceanic and Atmospheric Administration (NOAA), Hydrographic manual [20];*
- *NOAA, Office of Coast Survey, Hydrographic Surveys Division – Field procedures manual [21]; and*
- *NOAA, Office of Coast Survey, Hydrographic Surveys Division – Hydrographic survey specifications and deliverables [22].*

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 factors such as navigation channels and coastal/shoreline mapping. It is important to determine an accurate relationship between levels onshore and offshore for tidal, seabed and topographic surveys. The UK government provides geospatial data standards¹¹⁾ and it notes that geospatial standards appropriate to the spatial extent of the data would include:

- *British or Irish National Grid for data related to the UK and Northern Ireland;*
- *ETRS89 (EPSG::4258) for Europe; and*
- *WGS84 for worldwide geographic location points.*

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

- a) geodetic model to be used;
- b) correction parameters;
- c) definition of survey projection;
- d) horizontal coordinate systems; and
- e) 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 do 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, along with 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

Water-based surveys should be referenced to local mean sea level and other astronomical tide levels. This should normally be achieved by establishing a tidal level measurement device as close as practicable to the location of the proposed development or area of interest including the duration of the survey period.

Tidal measurement devices 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;

¹¹⁾ Available at <https://www.gov.uk/guidance/uk-geospatial-data-standards-coordinate-reference-systems>.

- f) not be mounted or fixed on members that are subject to settlement; and
- g) not be in a position of high current flow.

Drawings and charts based on water-based surveys should be reduced to an appropriate project or asset local marine datum (e.g. harbour or chart datum) with the relationship to the land-based survey datum and mean sea level and other astronomical tide levels clearly indicated.

NOTE 1 IHO Publication C-13 Manual [16] provides detailed information on establishing MSL considering atmospheric and weather influences.

Land-based surveys should be referenced to an appropriate project or asset land datum and the relevant national or regional vertical datum (e.g. in the UK, this would be Ordnance Datum Newlyn).

The relationship between all referenced land and marine datums for a project or asset should be established and stated on survey drawings and records.

NOTE 2 Satellite survey techniques are often used for level control, for both land- and water-based surveys. It is essential that these are also referenced to astronomical tide levels derived from measurements obtained using a suitably positioned tidal level gauge.

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), GALLILEO (European Union) and COMPASS (China) systems.

Satellite positioning is often augmented using 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. RTK corrections enable survey accuracies of better than 5 mm in plan and 10 mm in level to be achieved. 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 also 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 confirm 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.

Published bathymetric or nautical charts can 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. Published bathymetric charts are often based upon historic surveys neither conducted to modern standards nor at scales suited to engineering requirements.

Most depth sounding for new bathymetric surveys is carried out using acoustic systems, which can include use of a multi-beam echo sounder (MBES) or a single beam echo sounder (SBES). Typically, MBES systems (also referred to as swath systems) are preferred for large area surveys. Single beam sounding can also be appropriate where access for multi beam is limited or difficult. It is also good practice to conduct single beam surveys to calibrate multi beam surveys.

5.2.1 General

The extent of bathymetric survey work required should be determined from the nature and extent of the proposed works and operations and the availability, accuracy, and validity of existing survey data. When making use of existing survey data, including from nautical charts, an assessment should be made of changes since the date of acquisition of the survey data arising from siltation, dredging, dumping, shipwrecks or other causes to confirm that the data is of sufficient accuracy for the intended planning and design activities.

The selection of survey method and vessels should account for depth of water and accessibility such that full coverage required is achievable, especially for shallow areas and for channel side slopes. 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.

Survey methods supporting operation and maintenance of channels, basins and other areas designated for navigation should meet the requirement of the relevant harbour or other authority having jurisdiction over safe navigation.

NOTE 1 For surveys for navigational purposes, the requirements of IHO Special Publication No. 44 [23] are frequently adopted. 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.

NOTE 2 Where SBES bathymetric data is to be used (i.e. for planning purposes or restricted access) 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 would typically be spaced at about 100 m intervals, with a locational check by cross-lines at intervals of not greater than 300 m.

NOTE 3 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 would typically be planned alongside increasing the quantity of points surveyed to be able to plot them at the intended scale e.g. generally to produce a chart to a scale of between 1:500 and 1:2 000.

NOTE 4 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 5 Bathymetric survey data is normally acquired in digital format so that bathymetry can be processed and stored in the form of digital elevation models as described in 5.6.

5.2.2 Acoustic systems – Echo sounder

COMMENTARY ON 5.2.2

Acoustic systems are subject to errors due to variations in the physical properties of the water column and of the seabed and it is important that they are calibrated, used and have their results interpreted by suitably competent personnel. For example, echo sounders can give misleading results in areas of very soft mud or where there are significant density changes in the water column. The sensitivity can be changed to reduce multiple echoes. Refer to 5.2.2.2 for information on using dual frequency to investigate mud thickness.

5.2.2.1 Calibration and quality control

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

Survey system requirements should be assessed in advance of the survey campaign to make sure that the method, equipment and quality control checks used are appropriate to the physical and environmental conditions at the survey location, taking into account the required accuracy.

When surveys are 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 [16].

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 likely to achieve higher depth accuracy. Transducer beam width has a significant effect on the accuracy and appearance of a recorded echo.

Acoustic energy at 33 kHz can penetrate 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 silt 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.

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 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. Full ensonification is typically required 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.

NOTE 2 Additional information including a description of MBES and interferometric sonar systems is given in the IHO Manual on hydrography [16].

NOTE 3 MBES mapping resolution is higher than SBES. However, this depends on the acoustic frequency. Typical frequencies of the MBES are given in the IHO Manual on hydrography [16].

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. It provides a general depictive map on both sides of the survey vessel's path, and is therefore useful in imaging sea floor features that would not otherwise be detected or recognised by using single beam echo sounders alone.

Side-scan surveys should be used when required to supplement SBES surveys in order to examine the entire seabed between sounding profiles and thus to identify features not otherwise detected, and to identify any requirement to run additional SBES profiles at significant changes in bathymetry.

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, obstructions 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.

NOTE 3 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 a horizontal bar fore and aft from the vessel, 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 typical speeds of 1 m/s to 1.5 m/s (2 knots to 3 knots) along the necessary course lines to make certain full sweep coverage of the area.

5.2.6 Reduction of soundings

Soundings of water depth should be reduced to an appropriate project or asset datum, taking into account the variation in water level during the survey (see 5.1.1). The datum to which the soundings are reduced should be noted on the drawing, chart or digital data description, together with its relationship with relevant land-based datum and astronomical tide levels.

5.2.7 Surveys for dredging

COMMENTARY ON 5.2.7

BS 6349-5 gives recommendations for capital and maintenance dredging and land reclamation works and notes that the choice of dredging plant, working times and safe navigation are all affected by seabed levels. Surveys carried out in connection with dredging work have particular objectives, including those relating to measurement of works done for payment and verification of contract terms, including determination of:

- *the volume of seabed material to be removed by the dredging process;*
- *bed levels prior to and on completion of dredging work and demonstration that the specified levels have been achieved; and*
- *the volume of seabed material actually removed by the dredging process.*

These matters inform contractual, engineering and environmental matters and are often required to achieve higher accuracies and resolution than is the case for IHO standards required to demonstrate compliance with navigation criteria.

Bathymetric surveys for dredging projects should be undertaken using one of the methods described in Clause 5 but are most likely to employ either:

- a) SBES, which can include a single or dual frequency transducer; or

b) MBES.

In most circumstances a MBES should be used to determine the bathymetry through the different stages of dredging projects. To show that the minimum design depth for navigation has been achieved, particularly when dredging in rock is involved, a MBES should be used at a survey line spacing that achieves complete coverage of the seafloor of the area in question. Where the risk exists of localised high points or objects on the seafloor that might not be resolved by the MBES, a side-scan sonar survey should also be used to supplement the MBES.

If the objective of the survey is to provide a basis for the measurement of quantities for the payment of a contractor, a MBES system should be used and data should be collected such that total coverage of the dredged area is achieved.

5.2.8 Surveys for navigation

Surveys which are principally required to establish depths for navigation purposes should meet the requirements of the appropriate harbour authority, hydrographic office or other body having jurisdiction over safety of navigation at the location, taking into account the types of shipping concerned.

NOTE Standards for hydrographic surveys [23] are typically used to specify the accuracy to which bathymetric data should be acquired for navigation purposes. The standards quote different survey requirements (e.g. recommended line spacing) and acceptable total horizontal and vertical uncertainties for different “orders” of survey. Examples of different areas that fall under each “order” are also provided.

5.2.9 Surveys for coastal bathymetry

Methods for coastal bathymetry surveys should be selected to effectively combine land topographic cross sections with water-based hydrographic surveys. 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 1 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.

NOTE 2 Topographic surveys may be undertaken as far into the water as possible, usually at low tide.

5.2.10 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 confirm 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 [16].

LiDAR observations are not as accurate as profile data obtained from traditional topographic and acoustic survey systems. Laser system is sensitive to suspended material and turbidity in the water column, with maximum operating depths of around 50 metres.

5.3 Topographic surveys

COMMENTARY ON 5.3

As defined by the IHO Manual on hydrography [16], a “Topographic Survey consists of a series of tasks carried out with the aim of determining the composition of those parts of the earth’s surface which emerge from the water. It includes the coastal relief and the location of permanent natural or artificial objects and features.”

Topography has implications for cargo equipment, shoreline or coastal infrastructure and their tie-in connections, port infrastructure, water intakes and drainage. Depending on the stage of the project lifecycle and the level of accuracy survey, methods and techniques might have to be selected. From the 1970s onwards, traditional land surveying methods were increasingly supplemented by electronic distance measurement (EDM) in order to electronically combine the angular distance measurement capability of theodolites with EDM to enable measurements to be processed into x, y, z coordinates to a prescribed datum, and then stored and shared digitally.

Global Navigation Satellite Systems (GNSS) are now widely adopted for surveying and mapping. For guidelines for use of GNSS in surveying, see RICS Guidelines for the use of GNSS in Surveying and Mapping¹²⁾ which includes descriptions of real time kinematic (RTK) methods making use of networks of continuously operating GNSS receivers (COGRs) to provide a source control for GNSS surveys equipment. COGR networks exist in many countries and in several countries, including the UK, network RTK service providers supply a real-time correction service to subscribers via the mobile phone network.

The Survey Association (TSA) provides¹³⁾ an overview of the types of equipment used for different situations and locations based on the availability of network RTK services in the UK. The range of useful guidance notes covers:

- how, in open areas of mostly natural or surface features detail, GNSS Network RTK can be supplemented by Radio RTK where there is no mobile phone signal in the area.*
- how, when surveying or working close to structures or buildings, when working under trees or other cover, or when high accuracy is required, a total station is likely to be needed to access and resolve the required spatial detail and to provide the accuracy required; and*
- where, for surveys requiring a high amount of complex detail and where the distance from the survey instrument and the detail is relatively short, a laser scanner (LiDAR) method might be used. Such surveys produce a large amount of data and filed work is therefore quick, however significant post-processing is required to extract the required information.*

Topographic survey requirements should be planned, scoped, and specified to define:

- a) the location and extent of the area to be surveyed;
- b) the detail required;
- c) the accuracy required;
- d) the scope, details and accuracy of any additional features to be surveyed such as buildings, structures, roads, paving, drainage and underground and overground utilities;
- e) the reference grid and datum or datums of the survey; and
- f) how the data is to be presented, stored and transferred.

The equipment and methods chosen for the survey should be capable of meeting the accuracy requirements for the particular survey and of operating in the particular survey location.

NOTE PAS 128 provides a specification for underground utility detection, verification and location for onshore areas.

5.4 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 either on or immediately below the bed, such as submarine pipelines and cables, wrecks, or unexploded shells, mines, or bombs. Specialist advice should be obtained to determine the scope and methods of surveys required to identify and locate such hazards. Where access is limited and/or restricted, such as underneath structures, the planning and survey should consider obstructions or buried elements that pose a hazard to the survey.

¹²⁾ Available at <https://www.rics.org/uk/upholding-professional-standards/sector-standards/land/guidelines-for-the-use-of-gnss-in-land-surveying-and-mapping/>

¹³⁾ Available at <https://www.tsa-uk.org.uk/downloads/>

NOTE BS 6349-5 provides advice in respect to 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 (see 5.4.2).

5.4.1 Sea bed conditions

The method of definition of the nature of the sea bed should be assessed according to the particular objectives of the survey and the nature and historical usage of the survey location.

NOTE 1 Some characteristics of sea bed condition, which might be important features to the project, can be measured remotely by instruments, such as side-scan sonar and echo sounder. Others require a visual inspection either directly by a diver or by using a remotely operated camera. An indication of the texture of the sea bed can be provided by side-scan sonar and in some cases with MBES. Side-scan sonar technology is best suited to indicate the presence of any upstanding rock outcrops, dune formations, ripples, pipelines, wrecks, or general debris.

NOTE 2 The mapping of areas of dense coral, algae, dense sea grass, etc. can be carried out using satellite imagery. This passive technique analyses the reflections of the sun's rays from the sea bed at depths from 3 m to 25 m, depending upon water clarity.

5.4.2 Marine magnetometer profiling

COMMENTARY ON 5.4.2

The marine magnetometer detects and records the total magnetic field of the earth near the sea bed. Ferrous metal objects on or just below the sea bed results in a deviation of the earth's magnetic field and cause magnetic anomalies, which the magnetometer can detect. Magnetic anomalies can be caused by iron-rich dykes and similar geological features, however anomalies that are of interest during near shore marine surveys are more commonly associated with man-made objects such as pipelines, shipwrecks, cables, and other civil and military debris.

The magnitude of a magnetic anomaly decreases as the distance increases from the ferromagnetic object which is giving rise to that anomaly. It therefore follows that there comes a point where a magnetometer is sufficiently far from a ferromagnetic object (this distance varies with the size of the object) that the magnetometer can no longer detect the anomaly produced by that object.

Surveys that incorporate the collection of magnetometer data include "reconnaissance" type surveys, utility inspection surveys and surveys conducted principally for the purposes of identifying unexploded ordnance (UXO).

In the case of reconnaissance surveys, magnetometer data should be collected in conjunction with bathymetric, side-scan sonar, and sub-bottom profiler datasets. The minimum line spacing should be assessed based on the nature of the hazard or utility under investigation.

NOTE 1 In a reconnaissance survey, line spacing is typically of the order of several 10 s of metres and the magnetometer dataset is typically not the primary dataset of interest. In some cases, there could be a specific utility which is known to exist within the survey area (e.g. a live fibre-optic cable buried beneath the seafloor) which the magnetometer is best suited to identifying and the spacing can be selected accordingly.

In the case of a survey to identify a specific linear utility feature, the magnetometer should be towed sufficiently close to the seabed such that the anomaly produced by the utility is detectable. Marine magnetometers towed astern of a survey vessel should be towed a sufficient distance from the vessel such that the anomaly caused by the vessel itself is not detected by the magnetometer.

In the case of a UXO survey, magnetometer data should be acquired at a much denser line spacing than is typically carried out for a reconnaissance survey. The exact line spacing should be determined by a specialist assessment as part of a UXO risk assessment study for the survey/project area.

NOTE 2 UXO surveys, risk assessments, and assessment as part of requirements for such surveys are typically carried out by specialised UXO consultants with specialist personnel who have demonstrable competence in managing the applicable risks.

The scope of the UXO risk assessment study should include the assessment of the likelihood of the existence of any items of ordnance within the project site. If there is sufficient probability that such items are present, then the scope of the required UXO survey

should be assessed. The line spacing and maximum altitude above the seafloor that the magnetometer tow fish (if used) would be towed at should also be specified based on the minimum size of ordnance that the UXO survey is required to detect.

NOTE 3 Line spacings and altitudes of approximately 5 m are typical for UXO surveys. The actual spacing of lines sailed by the survey vessel is sometimes increased by towing a spread of magnetometers (typically two to four) from the survey vessel.

Data collected during a UXO survey, typically acquired and processed by a survey contractor, should be reviewed by the specialists that carried out the risk and survey scope assessment.

NOTE 4 CIRIA 754 Assessment and management of unexploded ordnance (UXO) risk in the marine environment¹⁴⁾, provides a method of assessing and managing the risks for UXOs in the marine environment.

5.5 Surveys using autonomous and remotely operated vehicles

COMMENTARY ON 5.5

Advances in technology have resulted in rapid increase in the capability and usage of remotely operated surveying equipment and methods. This includes unmanned aerial vehicles (UAV, also referred to as drones) with a variety of aerial platforms, sensors and scanning technologies. For underwater surveys, autonomous underwater vehicles (AUV) and remotely operated vehicles (ROV) operating underwater or on the water surface (and sometimes also referred to as surface drones) and can also be used to carry out surveys and inspections using imaging and sensor systems.

The technology available for use alongside remote and autonomous survey and scanning continues to develop. An overview of drone technology, application and regulatory constraints affecting operation of the equipment is given in RICS insight paper Drones: applications and compliance for surveyors.¹⁵⁾

The use of different sensors and data capture methods has created opportunities to generate significant additional dimensions for surveys of landscapes and existing built assets compared to conventional survey techniques, including the use of:

- *digital photographic imaging to document assets and create three-dimensional (3D) point clouds by photogrammetric methods;*
- *infrared imaging to potentially identify structural defects such as delamination of reinforced concrete;*
- *hyperspectral imaging to identify contaminated land or particular types of vegetation; and*
- *LiDAR to create 3D point clouds.*

CIRIA 783, Unmanned aerial vehicles for managing assets [17] provides a comprehensive guide to the use of UAVs for surveys supporting asset management, including regulations concerning aviation safety when operating in UK airspace.

Where remote data collection using UAVs, ROVs or other similar systems is proposed as a method of data acquisition of terrain or existing assets, the following requirements should be established as a minimum:

- a) the type of sensor and usage of data required (e.g. imaging, LiDAR);
- b) the level of accuracy, calibration, and quality control;
- c) data processing, storage and other requirements (including for into BIM systems); and
- d) safety and data security requirements.

For an aerial based topographical survey method, such as the use of drones, either Ground Control points (GCP) or connection to RTK network should be used to make sure the accuracy is as expected.

¹⁴⁾ Available at https://www.ciria.org/CIRIA/CIRIA/Item_Detail.aspx?iProductcode=C754&Category=BOOK

¹⁵⁾ Available at <https://www.rics.org/globalassets/rics-website/media/knowledge/research/insights/drones-applications-and-compliance-for-surveyors-rics.pdf>

5.6 Digital data acquisition and processing

COMMENTARY ON 5.6

Increasing survey data is acquired and processed digitally and integrated into other systems used for design and asset management, including through use of BIM as set out in subclause 23.5. If the owner or operator proposes to adopt an AIM, it is important that requirements are defined at the earliest stages of the asset lifecycle so that digital information, including survey data, can be captured, stored, and accessed throughout the asset lifecycle. So-called point cloud data is the geometric survey data acquired by LiDAR scanning or by photogrammetric surveying used for digital surface modelling (DSM), information modelling (BIM), digital elevation (DEM) and digital terrain modelling (DTM).

Where BIM is adopted, digital survey data forming part of project and asset information requirements should be compatible with asset information model (AIM) or asset information management systems (AIMS). Raw survey data should be processed and stored according to prescribed data standards and, where appropriate, integrated with other data to create information in a suitable form for the AIM.

NOTE Organisations such as the Environment Agency in the UK have developed DEMs and developed a LiDAR Composite DTM (Digital Terrain Model)¹⁶ which is, as a raster elevation model, covering areas of England at 500 mm spatial resolution.

6 Meteorological and oceanographic data acquisition

6.1 General

COMMENTARY ON 6.1

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, operations, and decommissioning. During construction, maritime works are particularly sensitive to adverse weather conditions, which can hinder access to the works, prevent the use of floating plants and cause damage to works both above and below high water level. Weather conditions can limit construction activity to certain seasons or “weather windows” and can affect various transient load conditions such as towing, sinking and grounding of floating elements.

The information required can range from the persistence of relatively calm intervals for the operation of construction plants or safe vessel operations, to seasonal variations in the general characteristics for operational purposes, to predictions of normal and extreme environmental load events which structures need to be able to withstand during their design life. In nearly all cases, the availability of long-term wave information (over several decades) is required.

Wave data (measured or estimated), as discussed in Clause 11, is generally more readily available at offshore (deep water) locations than at nearshore sites. For maritime works in the coastal zone, it is therefore almost always necessary to transform offshore wave conditions to nearshore locations, taking account of transitional and shallow water effects, as discussed in Clause 13. It is desirable and in some cases essential to validate the transformation with short-term measured data and/or site observations at the site of interest. Water level data is generally more readily available at inshore locations and thus the coincident timing of wave conditions and water levels at the location of interest needs to be borne in mind (relative to the original measured location and any transformation process).

Considerations in respect of water quality and chemistry (including salinity, dissolved oxygen content, temperature, turbidity, and suspended sediment) and marine life are described in Clause 14.

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 15.

Metocean data suitable for preliminary planning purposes and obtainable for the UK include:

- *National Oceanographic Centre (in particular the British Oceanography Data Centre – BODC);*
- *Centre for Environment Fisheries and Aquaculture Science (CEFAS); and*
- *UK Meteorological Office.*

¹⁶) Available at <https://environment.data.gov.uk/dataset/668881ad-4f8f-42bd-b835-89acf0269496>

Other commercial service providers can also provide metocean data, and port authorities and national and local government agencies often hold relevant record information. Background information is also provided in the Admiralty Pilot series of publications [24]. This information is, however, not usually sufficient for design purposes.

Refer to Annex F for complementary guidance on issues that are relevant to planning metocean data acquisition activities for planning, design, execution and operation of maritime works, including further consideration for projects outside the UK.

Requirements for site- and location-specific data acquisition or predictive modelling studies, 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:

- a) review of publicly available data;
- b) data purchase or exchange;
- c) field data collection;
- d) satellite data acquisition or purchase; and
- e) hindcast and other modelling studies.

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

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

Interpretation and analysis of measured metocean data for the purpose of assessing operational factors and infrastructure design criteria should take into account the most up to date predictions of the effects of future climate change over the design life. When analysing long-term series datasets, adjustment for non-stationarity should be made to account for features such as past climate change.

6.2 Survey scope and metocean variability

Where a site-specific survey or data collection campaign is planned, general conditions should be assessed and 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:

- a) 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;
- b) rapidly varying conditions such as squalls and storms which might or might not occur in the survey period;
- c) infrequent conditions such as extreme storms that are unlikely to occur in a typical survey period;
- d) seasonal variations in metocean conditions;

- e) seasonal or other variations in topography or bathymetry or other physical changes that can indirectly affect surveyed conditions;
- f) long-term oscillations and inter-annual variability that are not characterized in a typical survey period; and
- g) 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.

6.3 Meteorological data acquisition

6.3.1 Wind

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

- a) wind sensors should be sited in clear air and mounted in a way that is not shielded or impacted by turbulence from near-by structures;
- b) wind sensors should be mounted at a height high enough to avoid turbulence from the ground or sea surface;
- c) the height of the wind sensor above sea or land height should be recorded;
- d) where marine icing is possible, heated sensors should be used; and
- e) 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:

- 1) adjust speed values to a standard elevation of 10 m above mean sea level with a specified averaging time of 1 h or other interval according to usage;
- 2) calculate averages, maxima and percentage frequency tables;
- 3) prepare wind roses showing the frequency distribution of wind speed and direction;
- 4) calculate extreme wind speed values for different time averaging periods; and
- 5) calculate wind persistence to show the expected duration and number of occurrences that exceed or are 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.

6.3.2 Precipitation

When measuring precipitation, the following factors should be taken into account:

- a) sensors should be sited to avoid shielding by buildings or other obstacles;
- b) sensors should be sited to avoid contamination such as leaves or other items being blown into the funnel and blocking the sensor; and
- c) rainfall should be continuously measured over 5 min periods and each 5 min average value should be recorded.

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

NOTE Different measuring periods and averaging times may be utilized depending on specific applications and user requirements. Typically 5 min averages are used for surface water drainage assessment but some end users such as the Environment Agency in England use 15 min for flooding assessment.

6.3.3 Temperature and humidity

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

- a) sensors should be sited in clear air away from sources of airborne contamination, exhaust or vents;
- b) 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;
- c) proximity to the sea can have a significant 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; and
- d) 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:

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

6.3.4 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:

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

6.3.5 Atmospheric pressure

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

- a) sensors should be sited in clear air, away from large structures or anywhere that could act to funnel winds and increase velocities, as this changes the measured pressure in accordance with Bernoulli's principle;
- b) sensors should be mounted with a static pressure head, to minimize errors due to variations of wind speed and direction;
- c) where sensors are housed within a building, a clear path by an airtight tube should be made to measure the pressure outside the building in open air;
- d) atmospheric pressure changes with height above sea level and should normally be converted to a mean sea level pressure; and
- e) atmospheric pressure should be continuously measured over 10 min periods and each 10 min average value should be 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 [25].

Atmospheric pressure records should be processed and presented to:

- 1) calculate averages, maxima, minima and percentage frequency tables;

- 2) calculate the maximum rate of change of atmospheric pressure in a certain period (e.g. 24 h); and
- 3) calculate pressure persistence to show the expected duration and number of occurrences that are below a particular atmospheric pressure threshold.

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

6.3.6 Solar radiation

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

- 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.

6.4 Oceanographic data acquisition

6.4.1 Water levels

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

- a) gauge should be able to filter out short period level fluctuations due to wind or wash waves;
- b) 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;
- c) location and mountings should confirm that the gauge remains stable and fixed in position and elevation for the duration of observations;
- d) where derivation of astronomical harmonic constituents is required, the duration of measurements should not be fewer than 30 days; and
- e) 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 not be less than 1 year.

NOTE Data on sea levels in the UK can be obtained from the National Tidal and Sea Level Facility¹⁷. The United Kingdom Hydrographic Office (UKHO) also provides information relating to astronomical tide levels, tide predictions and water-level measurements both in the UK and globally. Operating authorities such as EA, SEPA and NRW in mainland UK and more generally port authorities also record tidal levels at many locations around the coastline. A further source is the British Oceanographic Data Centre (BODC) which provides access to water-level measurements from a range of sites across the globe based on the Global Sea Level Observing System (GLOSS).

6.4.2 Currents

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

- a) current speed and direction should be measured using direct measurements of water velocity at fixed points using current meters or acoustic doppler systems.
- b) current speed and direction should be measured indirectly by tracking of currents. This should be conducted with the use of a float or dye to supplement direct measurement and to map circulation patterns over a wide area.
- c) at coastal and port locations, currents frequently exhibit spatial variability. 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

¹⁷ Available at <https://ntslf.org/>

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.

- d) Where derivation of astronomical harmonic constituents of tidal currents is required, the duration of measurements per location should not be less than 30 days.
- e) 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 not be less than 1 year.

6.4.3 Waves

When measuring waves, the following should be taken into account:

- The scope, extent and timing of measurements for the full range of considerations relating to functional, construction, environmental and operational aspects of planning and design set out in Clause 10.
- Wave data collected over a sufficient length of time to characterize the wave climate allowing for seasonal variation.

Sources of wave data should be assessed to verify whether or not they are representative of the 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.

NOTE 1 Wave conditions for planning and design can be derived from a number of sources including by transforming offshore wave data to the nearshore location of interest. Offshore data sources include measured data, synthetic wave data (hindcast from recorded wind data or more commonly from large scale numerical models such as WaveWatch III). For the UK, the CEFAS strategic wave monitoring network is a source of real-time wave data from a network of wave buoys located in areas at risk from flooding (refer to Cefas – WaveNet interactive map¹⁸). Visually observed wave data from ships (VOS) have also been used for preliminary purposes although such data suffer from a degree of subjectivity and VOS data is now seldom used.

NOTE 2 Clause 11 has further guidance on assessment of offshore wave climate. Annex F.3 includes information on types of wave recording devices.

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; and
- 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 on structures should be assessed in accordance with BS 6349-1-2 to include loading from:

¹⁸) Available at <https://wavenet.cefas.co.uk/map>

- a) wind acting directly on the structure; and
- b) wind acting indirectly through mooring systems of moored vessels or other floating facilities.

In addition to structural loading, wind should be assessed in planning and design for execution and safe operations, including:

- 1) environmental operating limits for vessel arrival, departure, berthing and cargo transfer;
- 2) environmental operating limits for floating and other construction equipment; and
- 3) environmental operating limits for safe access to exposed waterfront facilities and spaces with personnel or public access.

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 also affect vessel and cargo transfer operations and should be assessed.

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 10 min or 1 h, depending upon usage.

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 detailed or local information on the relationship between mean hourly wind speeds (U_{3600}) and gust values, the following relationship should be used, where t is the time interval of the measurement measured in seconds:

$$U(t) = U_{3600} \left\{ 1.277 + 0.296 \tanh \left[0.9 \log_{10} (45/t) \right] \right\}$$

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.

NOTE 1 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. For drainage design 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.

NOTE 2 The relationship between intensity, frequency and duration can vary markedly for different regions and is important for drainage, loading and flood risk 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.

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;
- flood risk assessment using depth duration frequency (DDF) models;
- imposed snow and ice loading: the accretion of snow or ice exerts load on a structure. Ice forms due to freezing of old wet snow, freezing sea spray or freezing rain. Structural icing affects 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 necessitates special protection for buildings; and
- construction delays: frequent rain increases construction time substantially, especially earth-moving operations.

NOTE 3 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.

- a) 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.*
- b) 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 presents a significant hazard to navigation for 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; and*
- *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 should 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. However, at coastal stations of the UK Meteorological Office, 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 1 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.¹⁹⁾

NOTE 2 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:

- estimating the cooling capacity of an area of water and the potential evaporation in thermal balance equations;
- calculating the size and capability design of solar power systems (photovoltaic or solar thermal systems);
- calculating the mortality of bacteria released to the sea in sea outfall design for effluents such as domestic sewage; and
- assessing 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 wavelengths. 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 and the Coriolis effect. 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 typically often less than 1 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 known as storm surges. A sustained strong wind blowing on shore can, on its own, “pile up” water against the coast, resulting in a water level higher than the predicted tidal height and referred to as wind set-up. This may be particularly significant in terms of seasonal water level changes and are also experienced in some large lakes or partially enclosed seas where the wind is mono-directional during extended periods of time (e.g. the Red Sea).

Differences between predicted and actual times of high and low water are caused mainly by the wind.

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 (also referred to as a bound infragravity 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 than might otherwise be expected.

The water level at the site of interest can be influenced by other factors including fluvial/estuarial influences, seiches and in the long term by climate change effects. Some large, enclosed water bodies and lakes may experience long-term lowering of water levels due to the effect of climate change and water abstraction.

Geological factors may also affect local mean sea level relative to geodetic datums. For example, this may be the result of isostatic effects (e.g. the British Isles to experience a net post glacial rebound in the north and a lowering

¹⁹⁾ 1 mbar = 100 N/m² = 100 Pa, 1 000 mbar = 29.5 inHg

in the south). Earthquakes may also cause changes in the elevation of coastal land mass relative to sea level and extraction of oil and gas or other subsurface minerals at or close to the coastline may also cause subsidence.

8.1 General

The effects of water level variations and changes due to the following influences should be assessed:

- astronomical tides;
- atmospheric pressure;
- wind and wave effects;
- seiches;
- infragravity waves;
- surface water run-off including river flows and any seasonal or long-term variations in these; and
- long-term sea-level trends including the effect of climate change and isostatic effect.

The scope of data collection, statistical analysis and modelling studies should be adequate to provide a reliable basis for design, execution and operational planning.

8.2 Astronomical tides

Long-term water-level measurements suitable for the site of interest should be used to inform planning and design of maritime works for which reliable tidal elevations are required for design and operations. Such records should be carefully reviewed for quality and continuity, and an assessment should be made of the need to separate tide and surge components and to account for non-stationarity in any long-term records in particular past sea level rise to better define water-level characteristics at the site.

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. 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.

8.3 Storm surge

Storm surges raise or lower the water level significantly above or below astronomical tide levels and the designer should assess the magnitude of storm surge likely under a range of design event probabilities (return periods).

NOTE In locations where a large tidal range and minimal surge is encountered, the design is unlikely to be sensitive to the effect of storm surges.

8.4 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.

8.5 Infragravity waves

Coastal locations exposed to long period waves caused by remote offshore oceanic storm events should be assessed to establish the potential for amplification of infragravity wave energy into damaging tsunami-like conditions with potential for exceptional coastal flooding and erosion.

NOTE The phenomenon of so-called meteo-tsunamis has been identified to refer to potentially damaging long period wave conditions caused by severe offshore oceanic storms and having similar characteristics to tsunamis in that they have potential to cause exceptional run up, flooding and erosion at shorelines because of amplification by interaction with coastal features including the continental shelf bathymetry, bay, or other feature.

8.6 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.

8.7 Long-term sea level trends

Changes in mean sea-level relative to land levels over the design working life, and through decommissioning where required, should be assessed using the most up to date region-specific guidance.

For extreme value analysis utilising long time series of water levels consideration should be given to past mean sea level rise and the record adjusted to account for the non-stationarity in the assessment.

NOTE 1 The IPCC provides an updated assessment every five to seven years, on which many regional authorities base local guidance. In the UK, local guidance is provided in the UK Climate Projections (UKCP). In order to model and predict future climate it is necessary to make assumptions about the economic, social and physical changes to the environment that influence future climate change. Future trends in global carbon emissions are uncertain and depend on nature and speed of implementation of carbon reduction measures globally.

NOTE 2 UKCP18²⁰ notes that, in addition to a direct increase in both low and high waters, there is also a potential for sea level change to have a more spatially complex effect on both the local tidal range and the extent of storm surges above the high tide. This is because the propagation of tide and surge is dependent on water depth.

9 Currents and water movement

COMMENTARY ON CLAUSE 9

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 heat 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 [24].

Local currents (both speed and direction) are a combination of tidal forcing, which is predictable, and residual effects, which are not predictable. They are usually the result of permanent ocean currents, tidal currents, direct or indirect atmospheric forcing and local effects such as river (fluvial) flows or density driven. In the coastal zone with a significant tidal range, tidal currents are strong and they normally dominate residual current. In areas with low tidal range and in open ocean (where the tidal range is less than 1 m) tidal currents are low and residual currents dominate the current regime. In estuarial environments, the effect of river flows is significant and the interaction with tides can give rise to phenomena such as tidal bores.

Local current flow patterns can be complex due to natural features of the seabed and coastline and man-made structures. Current velocities vary with depth and time at any location and proposed maritime works can have a significant effect on the current regime. Local currents can also be generated by density differences and by breaking waves and wave run-up at the shoreline.

The assessment of currents should take into account the following effects:

- a) astronomical tides;
- b) residual currents due to:

²⁰) Available at <https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-overview-slidepack-march21.pdf>

- 1) ocean currents;
 - 2) meteorological effects;
 - 3) river flows including seasonal variations; and
 - 4) density currents.
- c) wave and current interaction with coastal or nearshore structures or features (including breaking and run-up).

The scope of data collection, statistical analysis and modelling studies should be adequate to provide a reliable basis for design, execution, and operational planning.

Where proposed maritime works are assessed to have a significant effect on the existing current regime modelling should be used to assess any change in currents caused by the works. Such assessments should be appropriate in scope and methodology for the intended use in design including 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. The effects of marine growth should be taken into account.

When assessing current effects on structures and 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 ISO 21650:2007, Annex C provides typical empirical relationships for current velocity with depth. Mooring Equipment Guidelines (MEG4) provides a calculation method for tankers for determining the average current velocity where the velocity profile is not known.

10 Waves

COMMENTARY ON CLAUSE 10

The characterisation of wave conditions for planning and design requires some form of simplification of real sea conditions in which the sea is often a complex and irregular surface which can be described as many waves with different heights, periods and directions superimposed on one another.

In design situations, waves are sometimes described using a single representative wave height, period, and direction (in a particular water depth). For example, design approaches for some structure types require the maximum wave height as an input parameter, and generally rely on a simplified ratio between significant and maximum wave height based around an assumed statistical distribution.

In most cases a more comprehensive approach to the characterisation of wave conditions is required for design. Representative (statistical or spectral) wave parameters for a particular event (or group of events) can be estimated using a variety of techniques, as described in Clause 11 and Clause 13. Alternatively wave parameters can be derived directly from measured wave data. Parameters such as significant wave height (H_s) ($=H_{1/3}$), mean period (T_m), are derived from a statistical approach and spectral significant wave height (H_{m0}), peak wave period T_p from a spectral approach. CIRIA publication C683 [26] provides an introduction to the concepts of statistically described wave conditions (4.2.4.4) and spectral descriptions (4.2.4.5). Design approaches based on these parameters are commonly used in design. It is sometimes necessary to convert one set of parameters to another. Guidance on this can be found in CIRIA publication C683 [26], 4.2.4.5.

10.1 General

The assessment of wave conditions should be performed based upon methods of simplifying or representing the real wave conditions which are appropriate to the situation being assessed and the stage and of design. The method used should take into account:

- spectral shape;
- wave form of the sea state;