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Maritime works – Part 5: Code of practice for dredging and land reclamation



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Foreword

Publishing information

This part of BS 6349 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 December 2016. It was prepared by Technical Committee CB/502, *Maritime works*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This part of BS 6349 supersedes BS 6459-5:1991, which is withdrawn.

Relationship with other publications

BS 6349 is published in the following parts:

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

This part of BS 6349 is related to prEN 16907-6, which is currently in preparation.

Information about this document

This is a full revision of the standard, and introduces the following principal changes:

- substantial changes to reflect scientific and technological advances since 1991;
- changes to take into account new and revised legislation;
- restructure of text to better facilitate use of the standard;
- changes for consistency with the updated suite of BS 6349 standards that have been revised to take account of Eurocodes.

Use of this document

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

Any user claiming compliance with this part of BS 6349 is expected to be able to justify any course of action that deviates from its recommendations.

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").

Contractual and legal considerations

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

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

1 Scope

This part of BS 6349 gives recommendations for dredging and land reclamation works.

In addition, this part of BS 6349 outlines environmental assessment procedures and criteria in relation to the UK that are considered illustrative of similar good practice in many international jurisdictions.

2 Normative references

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

Standards publications

ASTM D1586, *Standard test method for standard penetration test (SPT) and split-barrel sampling of soils*

ASTM D2167, *Standard test method for density and unit weight of soil in place by the rubber balloon method*

ASTM D2488, *Standard practice for description and identification of soils (visual-manual procedure)*

ASTM D4253, *Standard test methods for maximum index density and unit weight of soils using a vibratory table*

ASTM D4254, *Standard test methods for minimum index density and unit weight of soils and calculation of relative density*

ASTM D7382, *Standard test methods for determination of maximum dry unit weight and water content range for effective compaction of granular soils using a vibrating hammer*

BS 1377 (all parts), *Methods for test for soils for civil engineering purposes*

BS 5607, *Code of practice for the safe use of explosives in the construction industry*

BS 5930:2015, *Code of practice for ground investigations*

BS 6031, *Code of practice for earthworks*

BS 6349-1-1, *Maritime works – Part 1-1: General – Code of practice for planning and design for operations*¹⁾

BS EN 933-3, *Tests for geometrical properties of aggregates – Part 3: Determination of particle shape – Flakiness index*

BS EN 933-4, *Tests for geometrical properties of aggregates – Part 4: Determination of particle shape – Shape index*

BS EN 1997-1:2004+A1:2013, *Eurocode 7 – Geotechnical design – Part 1: General rules*

BS EN ISO 22476 (all parts), *Geotechnical investigation and testing – Field testing*

Other publications

[N1]PIANC MARCOM WORKING GROUP 144. *Classification of soils and rocks for the maritime dredging process*. PIANC Report No. 144. Brussels: PIANC, 2016.

¹⁾ This part of BS 6349 gives informative references to BS 6349-1-1:2013.

3 Terms and definitions

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

- 3.1 agitation dredging**
practice of moving sediment from the seabed and into suspension for dispersion by local currents
- 3.2 beneficial use**
use of dredged material for a useful purpose such as: engineering; environmental enhancement or compensation; agricultural purposes; or the manufacture of products
- 3.3 borrow area**
source of the excavated or dredged fill material
- 3.4 bucket capacity**
maximum volume of bucket when filled to the level of the cutting edge
- 3.5 bulking factor**
factor representing the increase in volume of dredged material relative to its in-situ volume before dredging
- 3.6 capital dredging**
excavation of bed material underwater from an area never previously dredged or not dredged for a very long period of time
- 3.7 capping (above water)**
use of a compacted fill layer to cover the surface of reclamation fill above water to protect against deterioration, erosion from flowing water and wind
- 3.8 capping (underwater)**
use of a clean dredged material as cover for contaminated bed material or dredged material placed underwater as a means of isolating the contaminated material from the marine/aquatic environment
- 3.9 competent person**
person suitably trained and qualified by knowledge and practical experience, and provided with the necessary instructions, to enable the required task(s) to be carried out correctly
- 3.10 confined disposal**
deposition of dredged material which cannot be used, at a site (below water or on land) which is constrained to prevent lateral displacement (escape) of the materials
- 3.11 confined disposal facility**
area for containing dredged sediments which prevents the material's lateral or vertical displacement (escape) either during or after the material's movement into the facility
- 3.12 dredged level/depth**
 - 3.12.1 design dredged level**
level defined by the designer to achieve the function of the works

- 3.12.2 maintained depth**
minimum depth targeted taking into account all factors related to the seabed including siltation, usually for navigational purposes
- 3.12.3 maximum dredged level**
maximum acceptable depth below design depth
- 3.12.4 minimum dredged level**
minimum acceptable depth above design depth
- 3.13 diffuser**
device placed at the outlet of a discharge pipeline to reduce the velocity of outflow and to reduce turbulence, by spreading or splitting the flow
- 3.14 displacement**
transport of dredged material at or near seabed level
- 3.15 disposal**
deposition of excess dredged material that cannot be reused for any other purpose
- 3.16 draught**
vertical distance from the vessel waterline to the deepest point on the keel
- 3.17 dredger**
plant used for excavating or moving rock or soil under water
- 3.18 dredging**
excavating or moving soil or rock underwater by dredger
- 3.19 fines**
silt and clay soil fraction with a particle size less than 0.063 mm
- 3.20 ground treatment**
enhancement of ground properties, principally by stiffening or strengthening processes and compaction or densification mechanisms to achieve a specific geotechnical performance
- 3.21 haul distance**
one way distance that a vessel has to travel from the dredging location to a placement area
- 3.22 hopper capacity**
maximum volume that the hopper, on hopper dredgers or hopper barges, can contain
- 3.23 in-situ density**
unit mass of bottom materials in their undredged undisturbed state
- 3.24 land reclamation**
process of creating new land from the sea, other masses of water, and areas subject to inundation, by the raising of land levels primarily using materials recovered by dredging processes
- 3.25 maintenance dredging**
dredging of a site which has previously been dredged to remove sediment deposits that have reduced the depth that existed previously

NOTE Maintenance dredging is most frequently undertaken for the purposes of maintaining an adequate water depth for safe navigation and also for maintaining water circulation and flow regimes in water bodies such as rivers, channels, lakes and at intakes.

3.26 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

[SOURCE: BS 6349-1-1:2013, 3.1.28]

3.27 nautical depth

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

[SOURCE: BS 6349-1-1:2013, 3.1.29]

3.28 over-dredging

dredging of material below the deeper tolerance limit on the design dredged level

3.29 placement

placing of dredged material in reclamation or deposition of dredged material

3.30 seabed

ground at the bottom of the water column in any mass of water

NOTE This includes the bed of harbours, estuaries, rivers, lakes and similar masses of water.

3.31 siltation

process of deposition of sediments onto the seabed under water

3.32 spud

vertically moveable post planted into the seabed for holding a vessel in position

3.33 vacuum consolidation

applying a vacuum to increase the effective stress of soil by reducing pore pressure to accelerate consolidation

3.34 water injection dredging

practice of applying water jets under pressure into bottom sediments to cause a dense fluid flow close to the bed as a density current

4 Planning of dredging works

COMMENTARY ON CLAUSE 4

Dredging schemes include:

- *maintenance dredging;*
- *capital dredging;*
- *dredging for seabed material;*
- *disposal of excess material;*
- *reclamation.*

Dredging for reclamation by hydraulic means is covered by prEN 16907-6.

4.1 Main components

COMMENTARY ON 4.1

The main operations in executing dredging works are:

- *excavation of bed material;*
- *transport of material;*
- *deposition of bed materials, either in land reclamation or for other beneficial use such as beach nourishment, or in disposing of excess/unsuitable material.*

When dredging works are formulated, the interrelation between these operations should be assessed in conjunction with the mass balance between the materials borrowed, dredged, deposited in placement areas and released into the water column or onto the sea bed through the whole cycle of excavation, transportation and deposition activities.

Planning and design should take into account that the main operations of execution (excavation, transport and deposition) are connected:

- maintenance dredging and capital dredging require areas for the placement of removed and excess materials;
- dredging for materials requires borrow areas and might also require areas for placement of unsuitable materials;
- phasing of the works might require use of temporary intermediate locations for temporary storage of excavated materials;
- dredging can be undertaken to provide adequate depths for access to reclamation sites, and can also be required to prepare (improve) sea bed conditions at reclamation sites in preparation for the placement of material;
- dredging equipment and support vessels require locations to moor, bunker and transfer personnel.

At the start of the planning phase, the function of the works should be clearly defined and appropriate performance criteria set, including environmental design and performance requirements, to ensure that:

- the dredging and reclamation works fulfil their intended function;
- environmental constraints and requirements are taken into account from the earliest stage of project planning and procurement.

NOTE Recommendations on operational considerations for planning and design of maritime works are included in BS 6349-1-1.

4.2 Project planning

NOTE 1 The lead time for planned dredging projects, particularly capital works, can be substantial.

The scheduling of a dredging project should typically go through the following phases:

- a) planning:
 - 1) define project function (use of the works), such as navigation channel, reclamation, coastal protection, port or shore approach for submarine pipeline or intake;
 - 2) identify licensing requirements, environmental requirements [e.g. environmental impact assessment (EIA)] and functional requirements such as water depth, load capacity and settlement criteria;

- 3) identify performance requirements:
 - i) engineering performance criteria;
 - ii) environmental performance criteria, that focus on sustainable designs and “win-win” solutions;

NOTE 2 Further information is given in the PIANC Position Paper Working with nature [1].

- 4) establish boundary and baseline conditions necessary for engineering design and environmental design and impact assessments:
 - i) metocean data;
 - ii) geotechnical conditions;
 - iii) ecosystems and other sensitive receptors;
 - iv) engage stakeholders;
 - v) risks and hazards;
 - vi) sediment transport assessment;
 - vii) potential effects on the shoreline evolution of the surrounding area;
- b) concept design:
 - 1) initial feasibility and concept design, looking for “win-wins” between infrastructure and the environment;
 - 2) final decision to execute based on the aspects below:
 - i) financial;
 - ii) technical;
 - iii) environmental;
- c) detailed design:
 - 1) detailed design and engineering including site-specific data acquisition and detailed planning for execution, in which the level of definition is sufficient for construction;
 - 2) finalize environmental design and complete EIA;
 - 3) obtain pre-construction final consents and approvals;
- d) execution:
 - 1) implementation and construction of dredging or reclamation project;
- e) operation and maintenance:
 - 1) operational use of the completed maritime works by user, operator or owner, and planned and unplanned inspection, and maintenance, including maintenance dredging.

The design should be developed cyclically in progressive detail by repeating phases a) to c) until a feasible project is developed.

The process for obtaining consents and approvals should be commenced as soon as the scheme is sufficiently defined, so that as far as possible all permissions are obtained prior to construction. The responsibility for obtaining consents and approvals should be clearly defined and should be allocated to the party most capable of obtaining the consent, taking into account the project timetable.

During the project development, data collection and field investigations should be carried out for both the environmental and the engineering assessments. The extent and need for such investigation should be determined as early in the process as possible, and an appropriate schedule established so that the project timescale can be identified and the consequences understood.

Field work timing and durations should take account of seasonal restrictions including:

- weather windows;
- seasonal sea conditions, particularly during winter field work;
- ecological concerns:
 - migration patterns;
 - breeding seasons;
- leisure activities:
 - bathing water season;
 - boating;
- commercial restrictions:
 - fishing seasons.

For capital works, an EIA is generally required and sometimes for non-routine maintenance dredging. The time taken for the EIA process and public and stakeholder consultation should be included in the project programme and can be a cause of considerable delay, even when undertaken diligently.

NOTE 3 On major projects the overall lead in time can exceed a year or more.

To minimize the risk and uncertainty the procedures described above should be completed as far as practical before inviting tenders for the work, and particularly before the commencement of the works, noting that the final design can be the responsibility of the contractor under certain forms of contract.

NOTE 4 The more tenderers understand the scope and physical constraints, the lower the risk.

4.3 Procurement of services

Dredging is a specialist activity, and specialist advice should be sought when procuring dredging and reclamation services. Contracts, specifications and methods of measurement should each be carefully drafted by an appropriately experienced person.

Procurement documents should include as a minimum:

- a description of the project to be carried out, as well as a clear definition of the scope of the required services;
- the functional requirements of the end product, e.g. airport, port, housing;
- a definition of horizontal and vertical site datums, and respective survey grid;
- a coordinated plan of works area, and site boundaries both on land and at sea;
- the performance requirements, e.g. dredge (depth) tolerances in the case of capital and maintenance dredging, and particle size distribution in the case of aggregate dredging (many other potential criteria also exist; see 4.4);
- responsibility for and scope of final design;

- the time frame in which the project is to be delivered, with milestones as required;
- the likelihood of changes in requirements or externally enforced changes;
- any constraints, conditions, boundaries or responsibilities relating to the works in question (e.g. in relation to licences and permissions, navigation, safety);
- the allocation of risk (e.g. delays, unforeseen events) between the contracting parties, together with associated conditions of contract;
- a measurement system that reliably and transparently shows how much work has been done and what payment is due;
- the course of action to be followed in the event of problems arising;
- definition of payment terms and other relevant financial matters;
- information required for the management of environmental impact and safety during the project, including the need for method statements and a hazard identification (HAZID) workshop.

The measurement and payment system should take great care to define the design level, such that the design dredged level is properly differentiated from the maintained and nautical depths, taking account of the expected dredging tolerances. This is particularly important where a thin layer of material has to be removed to achieve a navigational depth, such that the over-dredged volume risks being a very large proportion of the net dredged volume.

NOTE Engineering performance criteria are addressed in 4.4 and environmental issues in Clause 5.

4.4 Engineering performance criteria

COMMENTARY ON 4.4

This subclause identifies the typical performance criteria for dredging and reclamation projects based on the requirements for anticipated use.

Environmental performance criteria are covered in Clause 5.

4.4.1 General

The engineering performance criteria should be set to ensure that when achieved the dredging scheme is suitable for the intended function.

The performance criteria depend upon the actual nature of the site and the requirements of each project and so the guidelines provided here should be taken as indicative and not exhaustive.

4.4.2 Maintenance dredging

Maintenance dredging should be undertaken to restore the bed to the original design level required to meet the performance criteria for the original project, or such other criteria that fulfil the current function of the project, as given in 4.4.3 to 4.4.6.

NOTE The general performance criteria for maintenance dredging are given in Table 1.

Table 1 Maintenance dredging – General performance criteria

Parameters	Performance criteria
Extent of works	Define the limits and extent of works areas required to re-establish depth to fulfil current requirements
Extent of dredged area	Define area where to re-establish depth required to fulfil function and to extent required
Minimum dredged level	Re-establish depth or lesser depth required to fulfil function required
Maximum dredge level	Maintain acceptable long term stability of side slope and/or edges
Maximum over-dredge deeper than tolerance	Limit to ensure stable slope and edge structure stability and to avoid excessive over-dredging
Over-dredge rectification	Identify rectification measures-to restore stable slopes and bed levels if needed
Vessel impact protection	Maintain safe navigational distance to protect structures (such as quay walls and jetties) from vessel impact
Structural stability	Maintain safe depth to protect structures (such as quay walls and jetties) from undermining
Side slopes angle	Ensure stable side slopes Limit erosion Design for material and seismic/non-seismic conditions

4.4.3 Capital dredging

The performance criteria for capital dredging vary with the function of the project. The typical performance criteria given in the relevant table for the following types of capital dredging project should be taken into account when identifying the performance requirements of a specific project:

- general dredging (Table 2);
- navigation depths and channels (Table 3);
- foundations (Table 4);
- pipe trenches (Table 5).

Table 2 General capital dredging – General performance criteria

Parameters	Performance criteria
Extent of works	Define the limits and extent of areas required for the works
Extent of dredged area	See specific criteria in Table 3 to Table 5
Minimum dredged level	Set to achieve design dredged level
Maximum dredge level	Maintain acceptable long term stability of side slope and/or edges
Maximum over-dredge deeper than tolerance	Limit to ensure stable slope and edge structure stability and to avoid excessive over-dredging
Vessel impact protection	Maintain safe navigational distance to protect structures (such as quay walls and jetties) from vessel impact
Structural stability	Maintain safe depth to protect structures (such as quay walls and jetties) from undermining
Side slopes angle	Ensure stable side slopes Limit erosion Design for material and seismic/non-seismic conditions
Contaminated materials	Apply environmental performance criteria
Unexploded ordnance (UXO)	Prescribe safety procedures

Table 3 Capital dredging for navigation – Performance criteria

Parameters	Performance criteria
As in Table 2	General dredging criteria remain relevant
Alignment, width	Align to meet marine traffic requirements
Minimum dredged level	Sufficient for under keel clearance (UKC ^{A)}) required, taking into account vessel movements and wave conditions. Navigable depth principle ^{B)} Sedimentation infill allowance
Maximum dredge level	Limit to control rates of siltation and infill

^{A)} See the PIANC report *Harbour approach channels design guidelines* [2].

^{B)} In muddy areas the seabed level is difficult to determine, with the soil density gradually increasing in density from fluid to solid mud at deeper levels. The “navigational depth”, “nautical bottom”, should be carefully defined in relation to the thickness and density of fluid muds acceptable for navigation; along with the method for proving that this depth is achieved. This allows more economic capital dredging and reduces the need for later maintenance dredging.

Table 4 Capital dredging for foundations – Performance criteria

Parameters	Performance criteria
As in Table 2	General dredging criteria remain relevant
Bearing capacity	Material with insufficient strength should be removed/improved
Settlement	Material prone to settlement should be removed/replaced/improved
Differential settlement	Material prone to variable settlement should be removed/replaced/improved
Hard material	Hard material should be removed that could: • overstress the structure • obstruct installation
Line and level	The dredging formation should be trimmed to the specified tolerances to spread the foundation load and avoid overstressing the structure

Table 5 Capital dredging for pipe trenches – Performance criteria

Parameters	Performance criteria
As in Table 2	General dredging criteria remain relevant
As in Table 3	Same as for navigation depth and channels
As in Table 4	Foundation criteria remain relevant
Trench alignment	The trench alignment should match the permissible pipe bending radii: • achievable by the pipe installation method • required for structural integrity
The trench profile	The trench profile should match the radii: • achievable by the pipe installation method • required for structural integrity
Trench depth	The trench depth should provide sufficient depth below seabed to: • protect the pipeline • allow for sediment movement and infill • allow for bedding backfill, anchor and scour protection if needed
Trench width	The trench width should be wide enough to allow: • installation tolerances • installation machinery and equipment • backfill and protection

4.4.4 Dredging for seabed material

The typical material properties criteria given in Table 6 should be taken into account when identifying the performance requirements for winning seabed material by dredging, typically for use as aggregates or fill.

Table 6 Dredging for seabed materials – Performance criteria

Material property	Performance criteria
Extent of works	Define the limits and extent of areas required for the works
Extent of dredged area	Define the limits and extent of areas permitted and required for extraction of materials
Maximum dredged level	Set the depth limit permitted and required for extraction of materials
Dredging rates and volumes	Define any limitations on rate and volume of material extracted
Dredging plant	Define any limitations on type and use of dredging plant
Soil type	Ensure suitable for planned use of dredged material
Mineralogy	Ensure suitable for planned use of dredged material
Chemical characteristics	Limit: • sulfates • salt • gypsum • carbonate • solubility
Grading distribution	Limit: • fines content • maximum particle size
Particle density	Limit low specific gravity
Seashell material	Set limit
Contamination	Set limit

4.4.5 Disposal of excess materials

The typical performance criteria given in Table 7 should be taken into account when identifying the performance requirements for disposal of excess materials.

NOTE The disposal of excess materials is discussed further in Clause 12.

Table 7 Disposal of excess materials – Performance criteria

Parameters	Performance criteria
Location and geometry	Shortest haul distance to dredging site Large enough to receive volumes
Minimum water depth	Safe navigation depth
Maximum elevation	Safe navigation depth
Form/type of material	Suitable for containment or dispersal
Containment	Ensure containment effective if required
Dispersal	Ensure fate of dispersed material understood
Release of fine materials	To meet environmental criteria
Release of contaminants – particles/solutes	To meet environmental criteria
Licensed disposal area	To meet license criteria

4.4.6 Reclamation

The typical performance criteria given in Table 8 should be taken into account when identifying the performance requirements for reclamation.

NOTE 1 Reclamation is discussed further in Clause 13.

NOTE 2 Reclamation with dredged hydraulic fill is covered in prEN 16907-6.

Table 8 Reclamation – Performance criteria

Parameters	Performance criteria
As in Table 4	Formation to meet foundation performance criteria
Fill material properties	Select suitable material (see Table 6)
Fill mass properties	Extract, place and treat material to achieve required properties
Total settlements	Limit over design life
Differential settlements	Limit over design life
Earthquake induced settlements	Limit within acceptable return period
Liquefaction	Ensure adequate resistance
Bearing capacity	Sufficient for loading
Edge structure slope stability	Adequate for loading, and retention of reclamation
Lateral movements	Limit over design life
Drainage	Ensure sufficient to maintain soil strength
Permeability	Ensure sufficient to maintain soil strength
Ground water level	Prevent soil strength reduction due to excessive rise in level

Ground treatment should be adopted as necessary to improve the reclamation properties where the performance criteria cannot be achieved, as described in Clause 14.

4.4.7 Dredging tolerances

When setting the design dredged level the designer should consider the tolerance achievable with the proposed plant and method and the resultant nature of the dredged surface. As the dredged surface can be variable in nature and consistency, the following factors should be taken into account when determining the accuracy of the dredged formation that can be achieved:

- the height, length, direction and frequency of the prevailing waves and swell;
- the type and properties of the soil, e.g. strength, compaction, cementation, cohesion and variability;
- the type and size of the dredging equipment;
- the experience of the operating personnel;
- the depth of dredging and type of depth-indicating instrumentation on board the dredger;
- the rate of change of tidal level;
- the strength of tidal or river currents;
- the extent of automated control of the dredging.

The range of vertical accuracies that are normally achieved by different types of dredging plant under varying site conditions is given in Table 9.

Table 9 Typical working vertical accuracy for dredging plant under various site conditions

Site conditions	Light trailer <10 000 m ³ mm	Standard trailer >10 000 m ³ mm	Cutter suction mm	Grab hopper mm	Grab pontoon mm	Backhoe mm
Bed material						
Loose silt	250	200	200	250	250	200
Cohesive silt	250	250	150	250	250	150
Fine sand	250	200	150	200	200	150
Medium sand	200	150	150	200	200	150
Gravel	200	150	150	200	200	150
Soft clay	300	250	150	300	250	150
Medium clay	300	250	150	300	250	150
Stiff clay	250	200	150	250	250	150
Very weak rock	N ^a	300	300	N	300	300
Weak rock	N	N	300	N	350	350
Moderately weak rock	N	N	300	N	N	350
Pre-treated rock	N	350	350	350	350	300
Sea conditions						
Sheltered water						
Small plant	100	100	150	150	150	100
Medium plant	100	75	125	125	125	75
Large plant	75	50	100	125	125	50
Exposed water						
Small plant	300	250	N	400	N	N
Medium plant	250	200	300	350	350	250
Large plant	250	150	250	300	250	200
Currents						
Moderate (0.5 m/s)	0	0	0	100	100	0
Strong (1.0 m/s)	100	100	50	200	200	0

NOTE 1 Accuracies are plus or minus.

NOTE 2 Sea and current condition adjustments should be added to "bed material" figures.

NOTE 3 None of the figures are absolute limits, but are reasonable expectations on most work. Difficulties might arise where lower limits are specified.

N = Not appropriate. N^a = Not usually appropriate.

The design should identify the minimum depth required and the maximum allowable dredged level, and set the design dredged level accordingly.

NOTE The design dredged level in navigation areas is sometimes set with a zero upward vertical tolerance and a relaxed downward tolerance in the order of –0.5 m to –1.0 m. In this case, the net dredged volume can be calculated as that above the design dredged level, thereby excluding the volume below, which varies with plant, method and sea and soil conditions.

For simplicity, the volume of dredging in navigation areas should be calculated as the in-situ volume of the material above the design dredged level; however, this requires the operator of the dredger to make an allowance for the volume within the tolerance and any possible over-dredging outside the tolerance. The resultant unmeasured volume can be considerable, especially where thin layers of material are to be removed, and the resultant implications for the dredging and disposal of the total volume should be carefully evaluated.

5 Dredging environmental design

COMMENTARY ON CLAUSE 5

Dredging and land reclamation have the potential to change the coastal and marine environment positively or negatively over both spatial and temporal scales.

The environmental design requirements relating to dredging scheme licences and permits are continually changing due to:

- *new and amended legislation;*
- *re-organization of government departments and authorities;*
- *changes in responsibility for enacting legislation;*
- *changes in application procedures;*
- *changes in the environmental criteria.*

Guidance is available from the appropriate government organization(s) – currently the Marine Management Organisation (MMO) in England, Natural Resources Wales in Wales, Marine Scotland in Scotland and Department of Environment, Northern Ireland.

General guidance is given in Environmental aspects of dredging [3].

5.1 General

Potential environmental impacts should be identified and their resolution addressed at the planning phase, prior to the design and execution of dredging and reclamation works, to allow the design to accommodate the environmental criteria, mitigation measures and monitoring required to achieve environmentally acceptable and compliant projects (see 4.2).

The extent and scope of environmental impact assessment should be commensurate with the magnitude of the dredging scheme and the sensitivity of the area.

NOTE Environmental impact assessment follows a similar process regardless of the actual type and form of the dredging and reclamation process. The best-practice approach is to work with nature as part of design.

Responsibility for environmental permitting should be carefully defined to ensure that the required mitigation and/or monitoring actions are planned in a coherent and transparent manner.

5.2 Sustainable development

COMMENTARY ON 5.2

From a permitting and planning perspective, there is a general presumption to decide in favour of development unless the adverse environmental impacts would significantly and demonstrably outweigh the development's benefits, when assessed against environmental laws, policies and criteria (i.e. such that the development could be considered unsustainable). Accordingly, the acceptability of environmental impacts is partly a permitting and/or planning decision that needs to account for environmental and social factors in addition to economic or strategic factors, to determine whether development is sustainable.

5.2.1 General

Dredging and reclamation projects should be undertaken within the principles underpinning sustainable development, and hence the following matters should be balanced:

- the economic or strategic return on the investment should justify the implementation;

- the environmental impact should be acceptable or beneficial and meet compliance criteria.

In terms of dredging and reclamation projects, permitting and planning decisions necessarily require that a balance is struck between safeguarding the environment and achieving the development's objectives. Therefore, an environmental scheme design approach should be adopted at the conception of a project and environmental criteria should be integrated into the project's objectives. Objectives should be provided in terms of what the critical success factors are and where there is flexibility such that the project can be accomplished efficiently without unacceptably impacting on the environment and society.

The judgement on the economic or strategic return on the investment is best made by the scheme proponent, who should usually be responsible for demonstrating either that the scheme is environmentally beneficial or that any adverse environmental impact does not outweigh the benefits.

NOTE 1 Dredging schemes change both the physical environment and ecology in the area of impact.

The acceptability of the changes should be judged against environmental criteria developed on the basis of scientific evaluation, with a precautionary approach taken where the science is not definitive.

NOTE 2 In the UK a substantial framework of legislation and regulation has been established to judge the environmental acceptability of dredging schemes.

5.2.2 Stakeholder engagement

The relevant regulatory authorities and stakeholders should be identified at the outset and should be approached as soon as the scheme is sufficiently developed for useful review and comment. A wide range of such stakeholders should be addressed so that objections can be addressed before the scheme is fully developed and committed.

The stakeholders that should be approached can include:

- the government and regulatory authorities;
- local and municipal government;
- landowners, especially Crown Estates;
- port, harbour, river and navigation authorities;
- utility and service providers;
- industrial interests such as outfall and intake operators;
- commercial interests – fisheries and shellfisheries;
- groups concerned with:
 - marine ecology;
 - migratory fish;
 - marine mammals;
 - seabirds waterfowl and birdlife;
 - archaeology;
 - recreation – watersports;
 - leisure – beaches and seaside facilities.

Engagement with stakeholders should be undertaken early in the process.

NOTE This might be limited to regulatory stakeholders, in a commercially confidential project, as environmental scoping opinions can be sought that can provide efficiency in prioritizing sustainability.

Consultation with regulators and other stakeholders should be undertaken and specialist advice should be obtained when planning any marine ecology investigations, to provide insights and information to the process, which enhances environmental design intelligence.

5.3 Potential impacts

COMMENTARY ON 5.3

Dredging and reclamation projects can cause various impacts (i.e. changes) to the physical, chemical, biological and socio-cultural environment at and around project sites.

The scope for potential impacts relates to how specific dredging and reclamation activities interact with the affected environmental parameters and their sensitivity and vulnerability to change. The key activities associated with dredging and reclamation can include substrate removal and burial, sediment releases and underwater noise emissions.

Physical, chemical, biological and socio-cultural environmental parameters have the potential to be impacted by dredging and reclamation.

Potential impacts should be identified and assessed to determine whether they can be accommodated by the environmental design process, to ensure that dredging and reclamation is acceptable in relation to the applicable environmental criteria (see 5.2), and whether mitigation and/or compensation measures are required (see 5.6).

5.4 Environmental design process

5.4.1 General

The environmental design process for dredging and reclamation should investigate solutions for the key adverse environmental impacts (e.g. identified by an EIA or other assessments) and opportunities for embedding and implementing mitigation measures into dredging and reclamation activities.

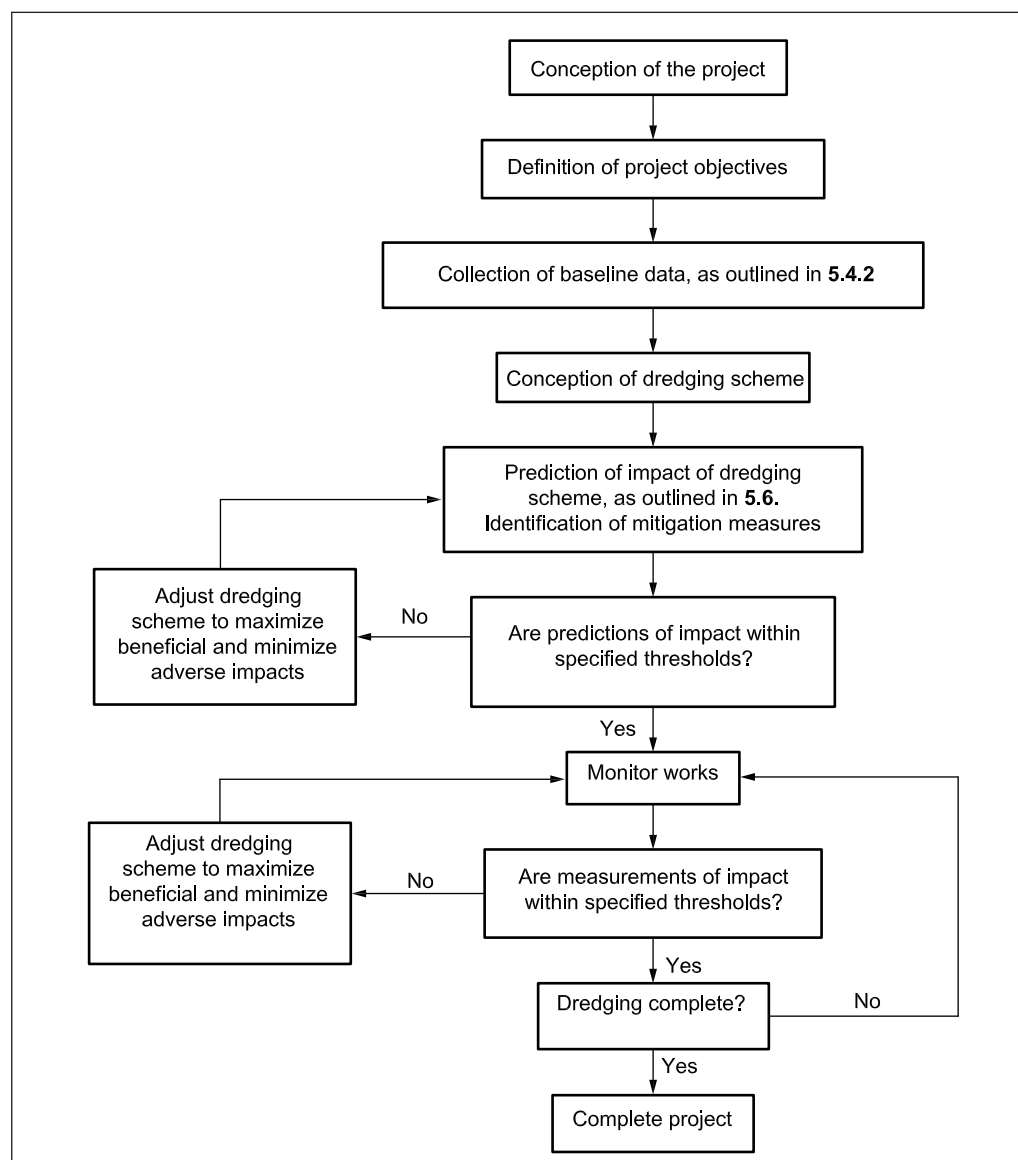
Investigations should involve some form of written and/or illustrative representation of the relationships between the sources (i.e. dredging and reclamation activities) and receptors (i.e. the environment) of environmental impacts, and the pathways that connect them (e.g. transport mechanisms or exposure pathways).

NOTE This investigative approach can take the form of a conceptual model that represents the environmental impacts and their consequences.

If a conceptual model is adopted this should be used as an iterative tool that is developed and refined throughout the environmental design process as new information becomes available (e.g. new baseline environmental data, updated dredging methodology). A conceptual model's detail should be proportionate to the sensitivity, vulnerability and/or value of the environmental conditions and the complexity and/or scale of dredging and reclamation activities.

The scheme design should follow an iterative process, as illustrated in Figure 1.

Figure 1 Scheme environmental design process



5.4.2 Baseline data establishment

Baseline data should be collected and used to inform an environmental design for dredging and reclamation projects. Baseline data collection should comprise at least a two- to three-staged process involving:

- desk study, using available and accessible data sources to determine the scope of surveys (if required) including any seasonal restrictions;
- site survey, using appropriate and relevant methodologies and equipment;
- ground-truthing or verification, to plug data gaps or address data uncertainties.

Baseline data collection should be designed to accommodate requirements for environmental impact assessment, longer term environmental monitoring, statistical analyses and/or numerical modelling requirements, and engineering/design information.

NOTE Further guidance on data collection is given in Clause 6. Further guidance on environmental monitoring design is given in 5.7.

Once the results of baseline data collection are available, the dredging scheme design should be adjusted to address potential environmental constraints and/or potential significant impacts. The baseline data should be used to inform environmental impact assessment and other environmental assessments. The outcomes of these assessments should be used to inform the dredging scheme design in one or more of the following ways:

- develop pragmatic and robust mitigation measures;
- develop trigger levels with statistical robustness where required;
- develop an appropriate monitoring programme (see 5.7);
- identify potential beneficial uses of materials unsuitable for incorporation in the works;
- develop compensation measures if required.

5.5 Use of numerical models for impact prediction

COMMENTARY ON 5.5

Numerical models can be used to simulate the physical effects of dredging operations on the environment. The appropriate choice of numerical model (if any is used) is dictated by the objective of the modelling, the parameter that is to be modelled and the resolution and scale (both temporal and spatial) relevant to the dredging activity and environment within which the dredging activity will occur. Key parameters that can be modelled include: water levels and currents; wave conditions; sediment transport (both fine and coarse fractions); sediment plume dispersion (near-field and far-field dispersion); and sound.

The numerical modelling software chosen to simulate the effects of dredging operations on the environment should accurately represent the physical processes of relevance. The model domain should be sufficiently large to prevent “edge” or boundary effects influencing model results in key areas. Quality assured input data should be used to construct the model; this typically includes the use of bathymetric and topographic data. Boundary conditions should be obtained from observations, other models or synthesised. The model should be appropriately resolved to represent both spatial and temporal scales relevant to the parameter of interest.

NOTE 1 This requires skilled judgement by an appropriately qualified person – excess temporal or spatial resolution can significantly increase numerical model simulation times and lead to excessive data storage requirements. Insufficient resolution means that the required output accuracy might not be achieved or might lead to instabilities in the model.

The numerical model should be calibrated and validated.

Calibration or “tuning” of the model should be undertaken to ensure that the key model parameters are influencing the model correctly, e.g. correct representation of friction, correct lag function, and appropriate settling velocity and critical shear stress for erosion and deposition. The mass balance should also be checked to demonstrate that the model is reasonably representative. Where data to inform the values of these parameters is not available, standard values should be obtained from appropriate texts.

NOTE 2 Examples of appropriate texts include Dynamics of marine sands [4] and Dynamics of estuarine muds [5].

Validation should be undertaken to provide confidence in the numerical models’ ability to simulate or predict. The process of validation should involve comparison of specific model outputs with site specific measured values.

NOTE 3 The validation process is relatively straightforward for hydrodynamics and acoustics (e.g. comparison of water-levels, flow speeds and acoustic transmission losses); however, where it is required to be performed, the process is more complex for sediment transport models as, typically, only the excess (additional) sediment load generated by the dredging activity is simulated.

Accurate validation of sediment transport should use high quality field data and should distinguish between background and dredging induced sediment load.

Interpretation of numerical outputs should be performed by a competent person.

NOTE 4 Verified results of numerical modelling can be used to plan future dredging operations as well as part of an adaptive management programme.

5.6 Minimizing environmental impact

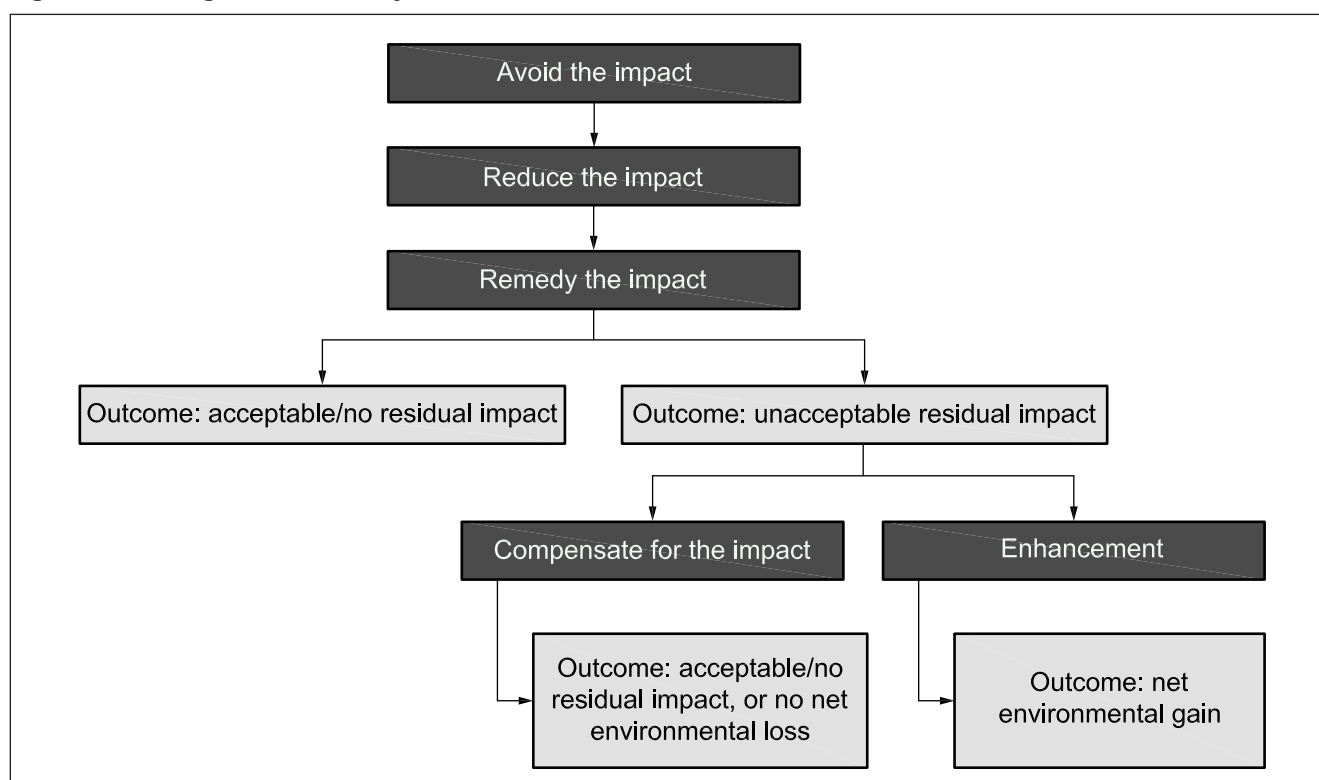
Mitigation measures should be applied to dredging and reclamation projects to negate and/or minimize adverse environmental impacts. Mitigation measures should contribute to achieving environmentally acceptable dredging and reclamation projects that meet the relevant environmental criteria.

5.6.1 Mitigation hierarchy

Mitigation should be addressed through a hierarchical, stepped approach of avoiding, reducing and, if possible, remedying environmental impacts, such that the residual impacts meet the relevant environmental criteria.

NOTE 1 A typical mitigation hierarchy is shown in Figure 2.

Figure 2 Mitigation hierarchy



The hierarchy should be applied as follows.

- a) Mitigation measures that avoid impacts should be preferred over reduction and remediation measures because they prevent impacts and, therefore, can be the most effective.

NOTE 2 Avoidance measures are more likely to relate to the earlier (i.e. planning) stages of the project lifecycle.

- b) Mitigation measures that reduce impacts should be preferred over remediation measures as both the impact and the consequent remediation are reduced.

NOTE 3 Reduction measures are more likely to relate to the progressive (i.e. implementation) stages of the project lifecycle.

- c) Mitigation measures that remedy impacts should be adopted that correct or restore impacts that cannot be avoided or reduced.

NOTE 4 Remediation measures are more likely to relate to the later (i.e. completion) stages of the project lifecycles.

The residual impacts remaining after mitigation should be environmentally acceptable.

5.6.2 Mitigation measures

While many measures are available to mitigate the impacts associated with dredging and reclamation projects, they should be selected carefully to ensure that they are environmentally effective and socially and economically acceptable.

Mitigation should be identified from the outset of project lifecycles.

NOTE This approach allows for mitigation to be taken into account during concept, feasibility, planning and design phases, and thereby facilitates the early selection of effective measures that are higher up the mitigation hierarchy and can be integrated and embedded into projects.

5.6.3 Compensation and enhancement measures

Compensation and enhancement measures should be applied to residual impacts remaining when mitigation measures have been applied but cannot achieve environmental acceptability.

NOTE 1 These measures are lower down the mitigation hierarchy because there is an inherent risk associated with their effectiveness; for example, artificially created compensatory habitats might not be successful and/or fulfil the ecological functions of impacted natural habitats.

Compensation measures should be applied to dredging and reclamation projects where residual impacts are environmentally unacceptable and/or positions of no net environmental loss are required, but cannot be achieved through mitigation alone.

NOTE 2 Compensation is distinguished from mitigation as compensation involves measures to replace or offset unavoidably adversely impacted or lost environments.

Enhancement measures should be applied to dredging and reclamation projects where positions of net environmental gain are required.

NOTE 3 Enhancement can be applied on and off dredging and reclamation sites. In relation to dredging and reclamation projects, enhancement measures typically relate to the natural environment and include, for example, improvement measures such as extending and restoring habitats.

5.6.4 Mitigation and compensation implementation

COMMENTARY ON 5.6.4

Mitigation and/or compensation measures can be required by environmental legislation (e.g. environmental quality standards), permit/licence/consent conditions, con-tract/specifications, and/or for best practice and environmental gain objectives.

Mitigation and/or compensation measures should be implemented through a planned framework of activities relating to dredging and reclamation activities. This framework should take the form of a management plan, such as a construction environment management plan or a dredge environmental management plan. A management plan should cover the following aspects:

- overarching management framework, identifying how the environmental management plan integrates with a project's wider management framework;
- Context, identifying how dredging and reclamation relates to the local environment, including a history of dredging and reclamation at the site;
- project description, providing information on dredging and reclamation, including the location, timing, methodologies, etc. of activities;
- permit/licence/consent conditions, including details of relevant environmental conditions and any other statutory requirements for legislative compliance;
- baseline environment description, characterizing the environmental parameters of the dredging and reclamation sites and adjacent areas;
- impact description, covering potential environmental impacts (and any uncertainties) associated with dredging and reclamation;
- environmental management, describing the strategies and actions to mitigate and/or compensate for impacts, including specific and auditable measures, performance indicators, monitoring requirements, corrective actions, responsibilities and a programme for management and monitoring activities;
- contingency arrangements, identifying corrective actions and contingency plans to be implemented in the event that unacceptable or unforeseen impacts occur (i.e. non-compliance);
- auditing requirements and reporting, setting out reporting and documentation standards, timing, and responsibility of any auditing or reporting;
- management plan reviews, making provisions for regular reviewing and updating of the management plan if considered necessary to achieve the dredging and reclamation objectives and to allow for continuous improvement.

5.7 Environmental monitoring design

5.7.1 Monitoring philosophy

COMMENTARY ON 5.7.1

Monitoring can be focussed on one or more specific environmental parameters, depending on the sensitivity of the local environment and the potential impacts of the dredging and/or reclamation.

Depending on the scope of monitoring required, the monitoring strategy can be implemented to characterize the baseline environmental conditions and, subsequently, detect and quantify changes to those conditions (i.e. environmental impacts) during dredging and reclamation.

Monitoring should involve the detection and evaluation of actual environmental changes against the baseline conditions (see 5.7.2) and predicted impacts and/or the compliance criteria established by the permitting process (e.g. environmental quality standards). Accordingly, monitoring should be used to inform decision-making before, during and after dredging and reclamation works and, in particular, it should be used to inform the need to adapt working practices and methods to achieve environmental objectives and avoid non-compliance.

5.7.2 Why and when to monitor

Monitoring should be undertaken to achieve one or more of the following outcomes in relation to the project cycle:

- baseline monitoring (pre-dredging and reclamation works) to obtain baseline data on:
 - the initial site conditions, to inform design and engineering investigations;
 - the initial environmental conditions, to inform design and environmental assessment investigations;
- surveillance monitoring for any areas likely to be impacted (during dredging and reclamation works) to detect and evaluate environmental change and performance in relation to environmental requirements and compliance criteria, thereby providing a feedback mechanism to inform an adaptive management approach to enable appropriate environmental mitigation and protection measures;
- surveillance monitoring (during and/or post-dredging and reclamation works) to inform comparisons between predicted environmental impacts and realized environmental impacts, thereby improving the effectiveness of future impact assessments and the implementation of mitigation measures;
- compliance monitoring (during and/or post-dredging and reclamation works) to provide evidence to demonstrate environmental performance against licence and permit conditions, and relevant environmental quality standards.

5.7.3 Monitoring design

Monitoring design should be:

- tailored to the particular environmental parameters associated with the potential environmental impacts of a particular dredging and reclamation project (i.e. physical, chemical, biological and/or social-culture parameters, as identified in 5.3);
- informed by consultation and consensus with relevant regulators and stakeholders;
- commensurate with the scope and magnitude of the project;
- should accord with the principle of using specific, measureable, achievable, relevant and time-related (SMART) criteria.

Where significant impacts could occur, a conceptual model should be used to assess the transport, fate pathways, and environmental receptors affected by the dredging and reclamation operations (see 5.4).

The assessment should generate information and/or data that can be recorded and assessed against environmental performance and/or compliance requirements to demonstrate the acceptability or unacceptability of the dredging and reclamation works.

Environmental monitoring resources should be deployed efficiently, focussing on major parameters with high potential impact to ensure maximum effectiveness.

NOTE 1 This approach can facilitate the design of a monitoring scheme that balances environmental protection and compliance requirements, technically sound monitoring methods and data generation, and proportional cost-effectiveness.

Given the scale of dredging and reclamation projects, it is unlikely that a single monitoring point/sample or occasion will be sufficient to represent the affected environment either temporally and/or spatially. Therefore, monitoring design should identify the need for sufficient multiple monitoring points/samples (i.e. replication to cover spatial scales) and occasions (i.e. repetition to cover temporal scales) to accommodate data confidence and, if necessary, statistical assessment.

Where relevant, controls and reference points should be used to record the environmental changes that occur without being affected by dredging and reclamation works, so that natural variability can be recorded and factored into the monitoring results. Care should be taken to ensure that controls and reference points are suitably comparable to the monitoring points within the influence of the dredging and reclamation works, and are not subject to alternative anthropogenic effects that could compromise their use as a control or point of reference.

Monitoring design should take into account the relevant temporal and spatial scales. In terms of temporal scales, monitoring should adequately cover the period of potential environmental impacts, so it can be appropriate to design monitoring to account for the temporal variability of the sources (e.g. continuous or sporadic dredging works), pathways (e.g. tide and current patterns, diurnal and seasonal weather conditions) and/or receptors (e.g. fish migration, bathing water seasons).

NOTE 2 These variations can affect the duration of the monitoring and the frequency and intensity of monitoring over that duration.

In terms of spatial scales, monitoring design should be informed by the positions and extents of sources, pathways and receptors and whether or not validated model predictions exist (these can help to reduce monitoring requirements). In addition, for some environmental parameters the spatial extent of monitoring should accommodate additional controls or reference points that are situated beyond the area of potential environmental impacts.

NOTE 3 For some environmental parameters, such as physico-chemical water quality (e.g. dissolved oxygen, suspended solids), it can be appropriate for monitoring to generate real-time data to detect adverse impacts and enable rapid adaptive management decisions (e.g. changing the dredging activity, reducing the production rate or overflow, or ceasing operations until the impact level is reduced). Real-time monitoring systems can be connected to alarm systems that signal when the works are approaching and/or breaching the environmental limits. For other environmental parameters (e.g. marine mammals, archaeology), it can be appropriate to have dedicated, trained personnel in place to provide in-situ monitoring (e.g. marine mammal observers, archaeological watching briefs) to generate continuous recording of environmental encounters as they occur.

5.7.4 What and how to monitor

COMMENTARY ON 5.7.4

As identified in 5.7.3, monitoring needs to be tailored to the particular environmental parameters, potential environmental impacts, the dredging and reclamation project, and the monitoring objectives. For this reason, there is not a set list of parameters to be monitored for each and every dredging and reclamation project.

Monitoring should incorporate appropriate methodologies, standards, best practice and relevant guidance, and use appropriate equipment and technologies.

Monitoring equipment (e.g. vessels, side-scan sonars, turbidity meters, dissolved oxygen meters, acoustic Doppler current profilers, sound pressure level meters, water samplers, grab samplers, beam trawls, underwater cameras, remotely operated underwater vehicles, laboratory equipment, data loggers) and data interpretation equipment (e.g. geographical information systems, mapping software, numerical modelling software, statistical analysis software) should be appropriate, fully functional and, if relevant, calibrated to the local site conditions.

Monitoring personnel should be appropriately qualified and experienced to undertake the tasks required (e.g. as field scientists, laboratory technicians, marine mammal observers or fishery liaison officers).

Monitoring activities and services should be undertaken in accordance with a recognized quality assurance and/or management system.

Monitoring activities and services should be planned and executed in accordance with an environmental management and/or monitoring plan or programme. A plan should provide a transparent delivery mechanism for the monitoring scheme. A plan should define the responsibilities of the monitoring team (e.g. project proponents, contractors, monitoring personnel), and provide the means for communicating the monitoring requirements (e.g. locations, methods, equipment) and parameters (e.g. specified contaminants, sound levels, species). In addition, a plan should include an evaluation system by which monitoring can be improved if required, and by which the project's environmental performance and compliance can be assessed and reported.

5.7.5 Environmental management plan

If appropriate, an environmental management plan should be established to define a monitoring strategy to be undertaken to assess compliance with environmental legislation, permit/licence/consent conditions, and/or contract/specification requirements.

The environmental management plan should identify the monitoring to be undertaken at spatial and/or temporal scales, as appropriate, for the affected environmental parameters. The results of monitoring should feed into a management plan and be used to inform decision-making during dredging and reclamation, including the need for corrective actions and adaptive management to achieve environmental acceptability and avoid non-compliance.

6 Site investigation and data collection

COMMENTARY ON CLAUSE 6

This clause describes the various stages of a site investigation. It shows the diversity of techniques and the necessity to combine them in an optimal way in order to obtain meaningful and representative results. This clause does not constitute a handbook for site investigation, nor does it provide guidelines for the setting up of a correct site investigation programme. There is abundant literature available on site investigation techniques. For dredging and land reclamation in particular, guidance is given in the following publications:

- *PIANC PTC2 Report WG23 [6];*
- *Geotechnical and geophysical investigations for offshore and nearshore developments [7];*
- *Facts about site investigation [8];*
- *PIANC Report No. 144 [N1].*

6.1 General

Site investigation should be undertaken for all major land and marine construction projects.

NOTE 1 For large projects in particular, site investigation is a complex sequence of operations involving many different techniques. Site investigation consists of collecting all the site-specific information required to design, plan and realize a construction project. In general, it encompasses meteorological, ecological, water column, seabed and ground data.

NOTE 2 Reclamation with dredged hydraulic fill is covered in prEN 16907-6. General recommendations for site investigation are given in BS 6349-1-3.

The scope of work for desktop studies, geophysical and geotechnical investigations, and any other relevant data collection should be integrated to ensure consistency and avoid duplication.

All persons planning any dredging or reclamation work should have suitable and sufficient knowledge of the site conditions. If information exists as a result of earlier work on or in the vicinity of the site, this should be evaluated by means of a desk study and, where possible, interviews with local specialists.

The identified data gaps should be filled by further from the site investigation.

The site bathymetry and soil conditions should be determined, and checks should be made for:

- excessive debris or foreign matter;
- services;
- munitions and unexploded ordnance (UXO);
- sensitive structures or installations;
- possible draught, air draught, width restrictions or traffic limitations to the passage of dredging or ancillary plant;
- as an extension of the soils investigation, the possible presence of boulders, which might have an excessively disruptive effect on dredging operations;
- other environmental factors such as prevailing weather conditions, tidal and river currents, and the presence of restricted areas due to environmental designations;
- working time restrictions, e.g. for the purposes of wildlife conservation, water depth, limitations owing to tides or reduction of noise close to populated areas.

A site investigation should typically comprise the following steps:

- preliminary activities, such as desk studies, selection of techniques and planning;
- fieldwork, such as hydrographic surveys, geophysical surveys and in-situ geological and geotechnical works;
- laboratory testing;
- interpretation and reporting.

Offshore site investigation is a highly specialized and constantly evolving field. Setting up, realizing and interpreting a site investigation campaign should be undertaken with advice from professionals with adequate multidisciplinary knowledge, training and experience. Geophysical techniques should be adopted as necessary to establish the likely geology over a large area, to help plan a borehole grid pattern and subsequently to “fill in” details between borings and drillings. Interpretation of the site investigation data plays an important role in providing a usable model of the sub-surface conditions. Interpretation should be carried out by experienced and competent individuals, based on the reports provided by the specialist site investigation contractor(s).

Factual field data and laboratory results should be reported separately from any interpretation of that data. The contents of the ground investigation report should follow the guidelines in BS EN 1997-1:2004+A1, 3.4. The contents of the geotechnical design report should follow the guidelines in BS EN 1997-1:2004+A1, 2.8.

NOTE 3 The separation between factual and interpretive reports is required to avoid constant revisions of the field data reports when the interpretation is refined or developed to cover different aspects, noting that designers focus on the permanent works design and contractors on dredgeability.

Similarly the responsibility for collecting the factual and interpretative data should be clearly defined.

For some projects the complexity of the geology, or other special circumstance, might warrant the use of test dredging. Experience from previous dredging contracts should be used where relevant and available. In all cases, details of all relevant and available information should be provided, both quantitative and qualitative. Care should be taken to obtain reliable information and to interpret this correctly.

Field investigations for capital dredging in particular should be performed in stages, e.g. preliminary and detailed. Investigative work should be performed at coarser spacing to begin with, and this should be refined as results (both field and laboratory) are obtained and geological conditions are understood.

NOTE 4 It might be necessary, especially for larger projects, to separate mobilizations for the stages in order to assimilate and understand the generated data and adequately plan the following stage. While site investigations often do not proceed this way due to time and/or budget constraints, staged investigations result in a higher quality of information and less risk to both employer and contractor.

6.2 Geotechnical investigations

6.2.1 General

The geotechnical properties of the ground to be dredged fundamentally affect the performance of all dredging plant. These properties should therefore be defined in advance of dredging works in accordance with PIANC Report No. 144 [N1].

NOTE 1 Recommendations for geotechnical design are given in BS 6349-1-3.

NOTE 2 Further guidance on undertaking ground investigations can be found in BS 5930:2015, for investigations over water in BS 6349-1-3, and BS EN ISO 19901-8.

The ground conditions are important to a wide range of parties and the following factors should be taken into account throughout the life cycle of a project.

- Ground conditions constitute a major consideration at the construction design stage.
- Ground conditions have a major impact on the timing and costing of the works (selection of equipment, production rate, wear and tear, etc.).

- The high mobilization and capital cost of dredging equipment means that an incorrect or incomplete assessment of the dredgeability of the seabed materials might result in major cost or schedule overruns.
- The majority of disputes and claims related to dredging works are related to unexpected ground conditions.
- Site characteristics, particularly soil type, have a significant influence on the environmental impact of the dredging and placement process.

NOTE 3 In most cases, where dredging is required, the depth of ground to be removed is limited to a few metres. In these instances, subject to ground conditions, a relatively simple method of ground investigation, such as vibrocoring, might be adequate. In contrast, where difficult materials such as rock have to be removed by dredging there is no alternative to obtaining samples by drilling from a floating or fixed structure. Where vibrocoring is employed in mixed granular soils, such as sand, gravel and cobbles, it is important to recognize and to highlight the fact that the results can be skewed towards the finer fraction of the size distribution, due to the tendency of the vibrocore to deflect from larger sizes and not sample sizes larger or close to the core diameter.

The investigation should be made within the planned areas of dredging. It is not normally sufficient to rely upon other investigations outside the proposed dredging areas, although the results of such investigations should be examined and made available where relevant.

NOTE 4 The geology of the coastal margins is almost invariably complex. The apparent economic savings that might result from a cursory ground investigation are in many cases outweighed by the increased costs arising from disruption of the works due to unforeseen ground conditions.

6.2.2 Geotechnical survey and site investigation methods

A suitable sampling and investigation procedure should be chosen for marine investigations.

NOTE 1 Many of the methods and tools widely employed in the investigation of ground on land can be adapted to marine applications. Ground investigation practice is described in detail in BS 5930:2015. Table 10 gives details of some common procedures.

Site investigations should be planned and carried out by a competent person. The work should be supervised by well-qualified and experienced geotechnical engineers or engineering geologists, and appropriate health and safety procedures should be followed.

Geotechnical specification and execution should where practical collect relevant data for other processes that might affect dredging performance, such as coastal or sediment transport processes and equipment suitability.

NOTE 2 Investigations for dredging projects normally involve work over water, and engineers and drillers who might be experienced on land-based operations do not always adapt to operations from floating craft with its many additional hazards.

As much information as possible should be obtained on the levels and the configuration of the deposits and on their origin.

NOTE 3 Deposits of complex structure need more detailed investigations than deposits having very regular profiles and structures. The scope of investigations depends on the size of the area to be dredged.

For dredging in in-situ material, test borings should extend a sufficient distance below the proposed design dredged level, particularly for capital dredging, to examine the material within the tolerance over-dredge depth range. Deeper borings should be undertaken where necessary to gain an understanding of the general geology, especially where relevant to slope and edge structure stability during dredging.

Table 10 Sampling and investigation methods for dredging purposes

Rock or soil type	Rotary drilling ^{A)}	Shell and auger boring	Underwater (sea bed) devices	Undisturbed sampling	Disturbed representative samples	Cone penetration tests (CPT) ^{B)}	Standard penetration tests (SPT)	In-situ vane testing
Rock and some very stiff/hard materials	Best method of obtaining core samples of intact rocks in in-situ condition for examination and test	NA ^{C)}	Useful for obtaining core samples of limited penetration	Cores represent undisturbed samples of intrinsic rock	Cuttings in drill fluid can be used for identification of non-recovered layers	NA	NA	NA
Boulders	Can be used to penetrate and obtain core samples	Chiselling required to penetrate strata	NA	Individual cobbles can be retained	NA	NA	NA	NA
Cobbles								
Gravels	NA		NA	Not practicable to retain gravel as an undisturbed sample unless in cemented condition		Very difficult to penetrate coarse gravel	Very difficult to penetrate coarse gravel	NA
Sands	NA	Method employed for site investigation in order to obtain representative and undisturbed samples and to carry out field (in-situ) tests		Patent samplers available, difficult to sample in undisturbed condition	Obtained from borings in tins or bags. Have to be "representative" (i.e. only from a single horizon or stratum). Essential for identification of various strata	Useful method for determining in-situ properties and "hard" strata levels. In areas with very wide soil variation can be useful to supplement borehole information	Useful method for determining in-situ properties, disturbed samples and "hard" strata levels in areas with very wide soil variation	Used for estimate of shear strength but great care needed in interpretation
Silts	NA		Various devices are available to obtain representative samples, but are generally of limited penetration	If cohesive in nature can use undisturbed core samplers for clay, otherwise see Sands				Used for estimate of shear strength but great care needed in interpretation
Clays	NA			Variety of undisturbed core samplers available				Very useful for shear strength evaluation in alluvial clays
Peats, etc.	NA			Variety of undisturbed core samplers available				Used for estimate of shear strength but great care needed in interpretation

NOTE For guidance on rock and soil type, see *PIANC Report No. 144 [N1]*.

^{A)} Normally 55 mm maximum (or equivalent) core size is commonly used in massive rocks and a minimum of 70 mm is normally recommended for weak, weathered or fractured rocks. However, it is suggested that 100 mm to 150 mm will give improved results.

^{B)} CPTu is generally preferred, with cone, sleeve and pore pressure measurement.

^{C)} NA = Not applicable.

In sand searches (e.g. for aggregate and reclamation purposes), borings should penetrate to adequate depths to identify the nature, volume and extent of the available in-situ material.

NOTE 4 Most site investigations for dredging work are necessarily carried out from pontoons or vessels. However, the use of a self-elevating platform permits work to be carried out in a similar way to that for a land-based investigation and considerably improves the quality of the information, particularly in exposed sea conditions.

In projects where the complexity of the geology or other special circumstances warrants, the use of test dredging might be essential. In any case the results of previous dredging contracts should be reviewed if available. In all cases, details of all relevant circumstances should be obtained, including quantitative and qualitative information on the spoil and where appropriate a description of the dredger(s) previously used.

Care should be taken in handling and preserving samples. Where possible, samples of rock should be retained in conditions approximating to the in-situ state. Undisturbed and disturbed samples of soil, particularly core samples of cohesive materials, should be protected from loss of natural moisture. Samples should be clearly labelled as described in BS 5930:2015, 25.11.2.

6.2.3 Soil classification

NOTE Soil classification is the arrangement of soils into groups that have similar properties. All soil classifications have their merits and particular applications.

Soil should be classified in accordance with PIANC Report No. 144 [N1], supplemented by BS 5930:2015. When describing soil samples, it should be made clear which classification system has been used.

6.2.4 Laboratory and in-situ tests for soils

The testing of soils should be in accordance with BS 1377. Laboratory testing should be undertaken on fresh samples and great care should be taken that samples are fully representative.

6.2.5 Laboratory and in-situ tests for rock

6.2.5.1 General

Owing to the many properties of rock that affect how it might be drilled, blasted or dredged, rock should be classified and tests should be carried out to identify the properties.

6.2.5.2 Laboratory tests

The following rock properties should be determined to provide the information necessary to assess whether, or how, rock can be dredged, with or without pre-treatment:

- compressive strength;
- tensile strength;
- quality (fracture spacing and openness);
- density;
- hardness;
- abrasiveness;
- porosity.

These properties should be tested in accordance with the appropriate parts of BS 1377, BS 5930:2015 or BS EN ISO 22476. Specialist geotechnical advice should be sought on which tests are most appropriate for providing information for dredging projects and how this information should be interpreted.

6.2.5.3 Field tests and descriptions

When the dredging of rock, with or without pre-treatment, is intended, an accurate assessment and description should be made of the condition of rock in relation to fracture state and rock quality. In-field assessments should be made, particularly in sedimentary rocks, to assess strength or resistance to cutting.

NOTE 1 These can include the following:

- *borehole logging;*
- *point load index tests;*
- *fracture state;*
- *fracture frequency;*
- *solid core recovery (SCR);*
- *total core recovery (TCR);*
- *rock quality designation (RQD);*
- *drillability;*
- *velocity of propagation of sound;*
- *standard penetration tests.*

The rock strength, quality and degree of fracturing should be taken into account when determining the need to use heavier or more powerful plant than normal, or whether to drill and blast.

NOTE 2 The purpose of any tests undertaken is to determine the effect of the type and condition of the rock on drilling and dredging. If fracturing is sufficiently close and open, pre-treatment might not be necessary. If pre-treatment is necessary, fractured rock might impede drilling by causing the drill to jam. Rock strength affects the energy required to achieve removal and abrasiveness affects the rate of wear of dredger components.

6.3 Geophysical investigations

COMMENTARY ON 6.3

Geophysical investigations are used to remotely ascertain sub-surface properties of the seabed materials, and are often supported and verified by the geotechnical techniques described in 6.2. Subject to sea conditions, geophysical investigations can be carried out rapidly over large areas at modest cost relative to intrusive investigation by boreholes or other methods described in 6.2.

Seismic profiling techniques are described in Annex A.

For major projects, geophysical investigations should be carried out to cross-correlate the site investigation data, boreholes, probing and sampling over the whole site area.

The interpretation of sub-bottom profiler data should be undertaken in conjunction with the results of geotechnical investigations performed over the survey area.

However, such methods require careful interpretation, and are very useful where relatively simple soil/rock conditions exist (i.e. soft alluvium over rock). Where only slight changes in strata density occur (i.e. in fine sediments), great care should be paid to the interpretation of the geophysical record.

The geophysical and geotechnical data should be integrated to produce a ground-truthed model of the sub-surface where necessary.

6.4 Unexploded ordnance (UXO) investigations

For dredging work round the UK, the presence of UXOs should be presumed unless clearly demonstrated otherwise, usually by specialists working with reference to the military authorities. In most jurisdictions specialist contractors are responsible for locating UXOs and the military authorities for their neutralization and disposal. Where doubt exists, UXO investigations should always be undertaken.

UXO investigations should be conducted by qualified, experienced specialists in this discipline in all dredging studies where unexploded ordnance might occur. Such investigations should be carried out and concluded in advance of any intrusive site investigations e.g. boreholes, etc.

Assistance from specialist contractors should be sought before embarking on works in areas where UXOs might lie.

6.5 Hydrographic surveys

6.5.1 General

Hydrographic surveys carried out in connection with dredging work should have the following specific objectives:

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

A hydrographic survey should also include the measurement of currents, waves, water properties and seabed characteristics.

NOTE 1 The choice of dredging plant, working times and safe navigation are all affected by sea bed levels.

The general topography of the seabed can be found on Admiralty charts, published by the UK Hydrographic Office (UKHO) which should be consulted in the first instance.

NOTE 2 Where these charts have been prepared from surveys of UK origin, more comprehensive information might be obtainable directly from the UKHO. The UKHO also holds some additional information on wrecks, and other seabed features in addition to those shown on the published chart. However, Admiralty charts are prepared for navigation rather than for engineering purposes. Detail is often sparse and imprecise in relation to engineering works. The survey information might be many years out of date. In particular, navigation charts are shoal-biased and deeper areas might not be shown at the scale of publication.

For engineering purposes, a suitably detailed and accurate survey should be made if it does not already exist.

Hydrographic survey and data collection should be undertaken at routine intervals throughout the life of a dredging project to monitor the extent of dredging.

6.5.2 Bathymetric surveys

Bathymetric surveys should be carried out in accordance with BS 6349-1-1.

While the IHO standards referred to in BS 6349-1-1 provide a good basis for understanding errors and accuracies, in the case of bathymetric surveys being conducted for the purposes of measurement, higher accuracies are achievable and necessary to avoid potential volume miscalculations, and a more rigorous accuracy should be specified where necessary to minimize the error.

Bathymetric surveys for dredging projects should be undertaken using one of the methods described in BS 6349-1-1, but are most likely to employ one of the following:

- single beam echo sounder (SBES), which might be using a single or dual frequency transducer;
- multi-beam echo sounder (MBES), which usually comprises an array of receiving transducers and a single pulse generator forming a swath of depth soundings of typically three times the water depth. Care should be taken to choose an appropriate instrument for the work, paying special attention to beam width, beam forming technique and sound frequency. Professional advice should be obtained in this respect as the technology is constantly evolving and complex.

6.5.3 Topographic surveys

Topographic surveys should be carried out in accordance with BS 6349-1-1.

6.5.4 Density surveys

COMMENTARY ON 6.5.4

If the level of the sea bottom cannot be satisfactorily determined by conventional methods, such as in areas of soft or fluid mud, it might be more appropriate to determine the relative level of material of a particular density.

If density surveys are to be carried out, the objectives of the data collection programme should be clearly defined.

NOTE Further guidance on soil density is given in 8.7.

6.5.5 Horizontal control

COMMENTARY ON 6.5.5

Accurate position fixing is essential during the execution of dredging works and its measurement. Unless the seabed is perfectly horizontal, an error in position will also produce an error in depth due to offsetting of apparent slope positions.

Horizontal control should be carried out in accordance with BS 6349-1-1.

6.5.6 Side-scan sonar

Side-scan sonar surveys should be carried out in accordance with BS 6349-1-1.

6.5.7 Seabed conditions

COMMENTARY ON 6.5.7

Some characteristics of seabed condition can be measured remotely by instruments, such as side-scan sonar and echo sounder. Others might require a visual inspection, either directly by a diver or by using a remotely operated camera. An indication of the texture of the seabed 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.