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Part 5: Code of practice for dredging and land reclamation

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 122, an inside back cover and a back cover.

Foreword

Publishing information

This part of BS 6349 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 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This part of BS 6349 supersedes BS 6459-5:1991, which is withdrawn.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.

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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 underwateras 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:

a) the height, length, direction and frequency of the prevailing waves and swell;

b) the type and properties of the soil, e.g. strength, compaction, cementation, cohesion and variability;

c) the type and size of the dredging equipment;

d) the experience of the operating personnel;

e) the depth of dredging and type of depth-indicating instrumentation on board the dredger;

f) the rate of change of tidal level;

g) the strength of tidal or river currents;

h) 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 m³	Standard trailer >10 000 m³	Cutter suction	Grab hopper	Grab pontoon	Backhoe
	mm	mm	mm	mm	mm	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 regularity 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.

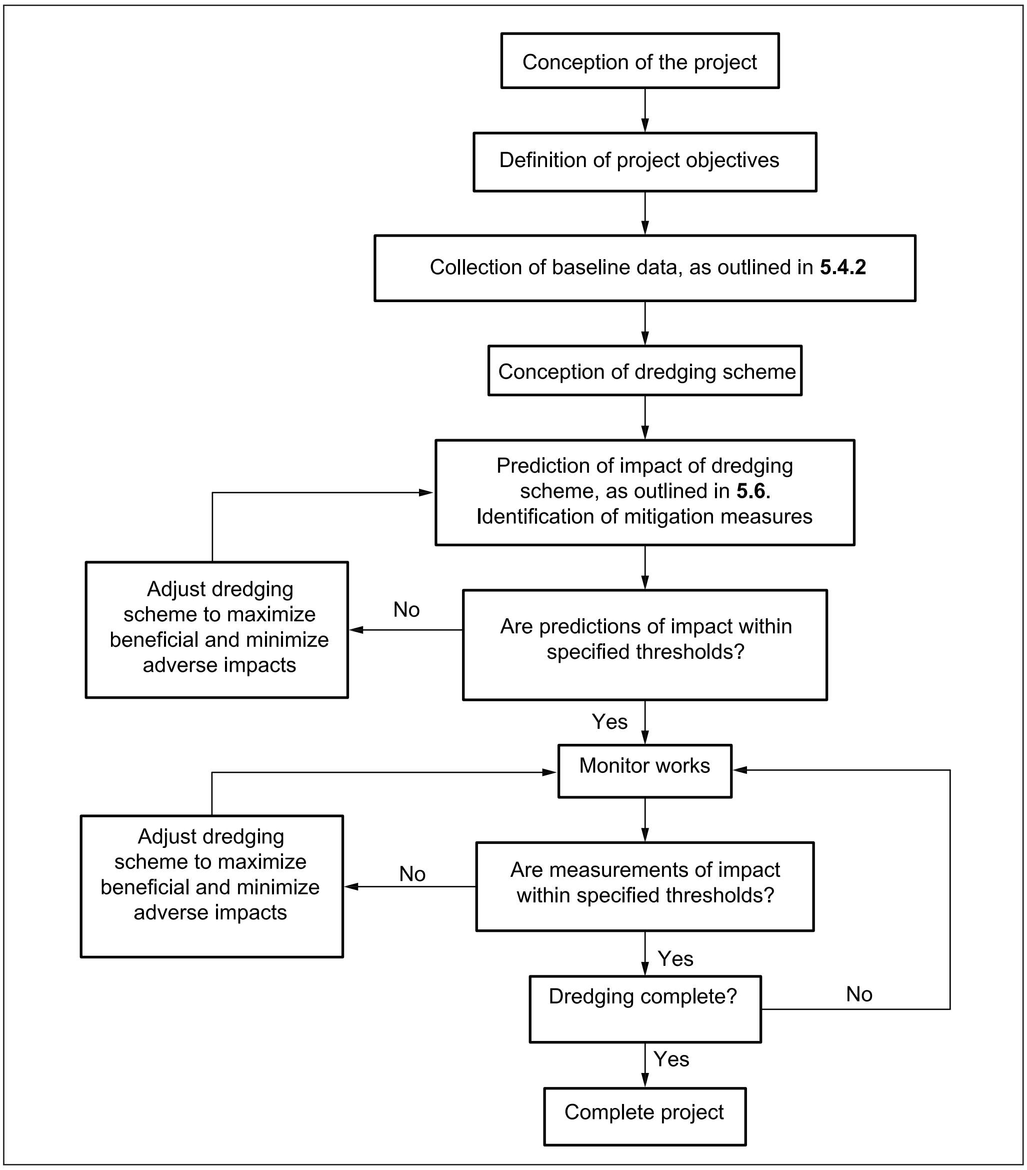
Investigations should involve some form of written and/or illustrative representation of the relationships between the sources (i.e. dredging and reclamation activities) and receptors (i.e. the environment) of environmental impacts, and the pathways that connect them (e.g. transport mechanisms or exposure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

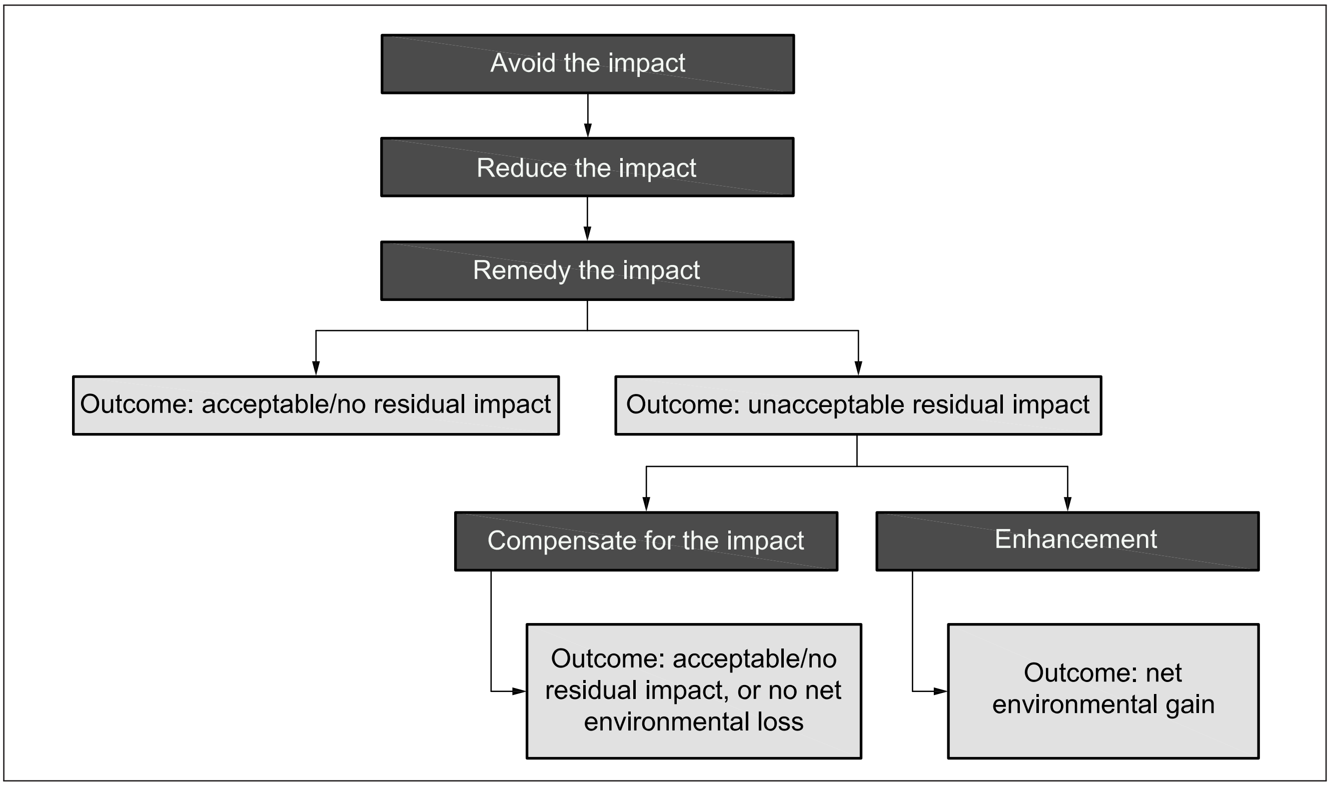
Mitigation measures should be applied to dredging and reclamation projects to negate and/or minimize adverse environmental impacts. Mitigation measures should contribute to achieving environmentally acceptable dredging and reclamation projects that meet the relevant environmental criteria.

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-com-pliance.

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 Cobbles	Can be used to penetrate and obtain core samples	Chiselling required to penetrate strata	NA	Individual cobbles can be retained	NA	NA	NA	NA
Gravels	NA	Method employed for site investigation in order to obtain representative and undisturbed samples and to carry out field (in-situ) tests	NA	Not practicable to retain gravel as an undisturbed sample unless in cemented 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	Very difficult to penetrate coarse gravel	Very difficult to penetrate coarse gravel	NA
Sands	NA		Various devices are available to obtain representative samples, but are generally of limited penetration	Patent samplers available, difficult to sample in undisturbed condition		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	NA
Silts	NA			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.

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 seabed at depths from 3 m to 25 m, depending upon water clarity.

Generally it is necessary to confirm the more important features using remote-camera inspection or, in cases where this is not possible, by using divers.

Evaluation of seabed sediment transport should be carried out in accordance with BS 6349-1-1.

The nature of the seabed is important to both the design of works that involve dredging and the selection of dredging plant, and seabed conditions should be confirmed before work begins.

6.6 Metocean data collection

Metocean data collection should be carried out in accordance with BS 6349-1-1.

NOTE This includes water levels, currents and waves.

6.7 Environmental surveys

6.7.1 Water quality

COMMENTARY ON ***6.7.1***

Water quality monitoring is a major part of many construction projects where dredging is involved since regulators and developers require advanced warning of potential changes and impacts that the dredging and construction activities might cause. Indeed such monitoring is often a formal requirement of the consenting process as well as a key interest to stakeholders.

Water quality monitoring should be carried out in accordance with BS 6349-1-1.

NOTE This includes water quality, sediment, water temperature, salinity and chemical composition.

For monitoring to be meaningful, there should be a clear understanding of the environment in which the works will be undertaken and its natural variability. Baseline data collection should be undertaken, identifying not only the sensitive receptors within the area of the works, but also the thresholds below which parameters such as light and oxygen which should not fall, and how a managed response could be implemented.

Where the construction project can be expected to run over one or more annual cycles, the pre-construction baseline monitoring should span a similar range of seasonal variation such that the natural variation of both the hydrodynamics and water quality can be determined and the linkages between the forcing processes (waves, tides, currents, river flow and meteorology) and the response of the system fully understood.

6.7.2 Suspended solids

COMMENTARY ON ***6.7.2***

Sediment in suspension can affect the design aspects of dredging works.
Any dredged formation which arrests the passage of mobile deposits is exposed to potentially heavy rates of siltation, whilst sediment released into the environment has the potential to impact on the environment through:

- *reduction in the propagation of light into the water column;*
- *deposition of material on sensitive receptors such as spawning grounds;*
- *the exertion of an oxygen demand on the water column by chemicals associated with the sediment;*
- *generation of turbidity currents.*

The effects of turbidity and suspended solids should be assessed in accordance with BS 6349-1-1.

6.7.3 Sediment quality

*COMMENTARY ON **6.7.3***

*Dredging releases sediment that can relocate at a different location. The measurement of sediment quality is fundamental for the environmental design of a dredging scheme (see Clause **5**).*

Attention is drawn to the Water Framework Directive [9].

Sediment quality should be measured by field sampling and laboratory analysis. The results should be used to define the content and potential release of contaminants.

6.7.4 Bedload transport

An evaluation should be made of the rate of infilling of dredged works due to bedload transport. This evaluation should be carried out in accordance with BS 6349-1-1.

NOTE Bedload transport is of particular concern for granular sediments located in the surf zone or within the area of wave influence.

The potential impacts of dredging on bedload transport should be carefully evaluated in relation to the near-shore zone, where littoral drift is intercepted by navigation channels or harbour works and where the dredging activity deprives the downdrift shoreline of renourishment material with subsequent shore-line regression.

6.7.5 Marine ecology

NOTE Marine ecology includes birds, marine mammals and marine reptiles.

Surveys of marine ecological components of the environment should be planned with some thought as to the timing, as many show pronounced seasonality. Consultation with regulators and other stakeholders should be undertaken and specialist advice should be obtained when planning any marine ecology investigations.

The impact on project lead in time should be evaluated and included in the planning.

6.7.6 Birds

Bird life surveys should be planned to account for seasonal variations where required to provide an adequate characterization.

NOTE For example, bird usage of an area can be split into overwintering populations, breeding populations, nesting populations and use of the area for feeding and loafing. Likewise, tidal state is also linked to feeding activity, e.g. waders exploiting intertidal mud and sand flats. An understanding of such temporal sensitivities is essential for adequate survey planning.

6.7.7 Fish and shellfish

There should be a clear purpose with regard to the need for fish and shellfish surveys, especially whether they are to address the fish and shellfish ecology of an area, or concerns regarding commercial fisheries species. Specialist advice should be obtained when planning such surveys.

*NOTE 1 Commercial fisheries are addressed in **6.8.1**.*

NOTE 2 Various techniques are available for measuring fish stocks and include:

- *acoustic methods, e.g. echo sounders (especially multi-beam);*
- *trawling;*
- *tagging;*
- *grab sampling;*
- *remotely operated underwater vehicle (ROV), still and video cameras.*

Information should be collected to describe local fish and shellfish resources both at the site and in the surrounding area. The presence and relative importance of fish and shellfish resources should be described and assessed. Important fish and shellfish resources should include:

- the major species of fish and shellfish in the area that are of significant importance in commercial and recreational fisheries;
- those species of fish and shellfish in the area that are of conservation importance;
- species that have a restricted geographical distribution and are locally abundant in the area.

For these resources, the following aspects of their ecology should be taken into account:

- spawning grounds;
- nursery grounds;
- feeding grounds;
- migration routes.

NOTE 3 Methods for examining spawning grounds, nursery grounds, flat fish populations or demersal populations are highly specific to the aims of the monitoring.

6.7.8 Airborne noise

The presence of sensitive receivers subject to potential noise impacts should be identified and appropriate limits set where necessary. In sensitive areas a background noise survey should be undertaken before works commence.

Particular attention should be paid when working close inshore at dusk and dawn when noise can travel further due to the moisture gradient and background noise levels are often low.

6.7.9 Underwater noise

*COMMENTARY ON **6.7.9***

Underwater noise can influence the behaviour of fish and marine mammals but the significance is very site-specific, being dependent on the physical characteristics of a site and the permanent or transient population. With the exception of underwater blasting, the operation of most types of dredging plant is unlikely to cause harm to marine life but might affect behaviour. For some species noise can be a deterrent, perhaps influencing migratory movement.

Expert opinion should be obtained to establish the potential for adverse effect. If there is good reason to believe that noise during dredging might have adverse effect, a programme of pre-project monitoring should be undertaken to determine the baseline conditions.

Because in areas of proposed dredging, such as ports, noise is generated by routine maritime traffic, in order to establish the baseline position, actual noise measurements should be taken at a variety of locations within the immediate and adjacent areas of proposed dredging. Measurement should continue over a representative range of tidal conditions for a minimum of 2 weeks. The objective should be to determine the current noise characteristics of locations likely to be affected by the noise level and frequency expected. The noise generated by the type and scale of dredging plant to be employed should be assessed, taking note of the working times and duration on the project.

6.8 The human environment

6.8.1 Commercial fisheries

The identification of commercially exploited fish resources should be undertaken by:

a) the examination of landings data;

NOTE 1 Such data are available from MMO or Marine Scotland with more regional data available from International Council for the Exploration of the Sea (ICES).

b) liaison with commercial and recreational fishermen, and fishing organizations operating in the vicinity of the proposed project.

NOTE 2 It is suggested that at least 5 years' worth of landings data for the period prior to the date of project commencement be examined. MMO and Marine Scotland landings data often represent an under-estimation of the true landings made within a fishery, as data from vessels under 10 m are not usually included.

Consultation with the fishing industry should be undertaken as early as possible. This should address fisheries issues as well as providing information relevant to fishery resources. Key representatives should be kept informed of progress of the project, so as to build a good working relationship with trust and co-operation.

6.8.2 Industries

Identification of industries in any areas that might be affected by the proposed project (such as water intakes) should be accomplished by liaison with local authorities, utility companies, and local trade associations. Consultation with industrial stakeholders should be undertaken as soon as possible, so that design of the project can take into account possible interferences and minimize these as far as practicable.

6.8.3 Leisure and recreation

Identification of leisure and recreation uses in any areas that might be affected by the proposed project should be undertaken by liaison with relevant stakeholders.

NOTE Stakeholders might include local authorities, the Royal Yachting Association, sports clubs and non-governmental organizations (for example the RSPB for coastal bird watching sites). Local resident consultation by way of internet websites, newspaper advertisements, newsletters and local exhibitions is also advisable.

6.8.4 Archaeology

Any sites of archaeological interest/significance should be identified and described, as should the sites of known war graves. Dredging should be avoided in any area known or suspected of containing material of potential archaeological interest. Guidance should be obtained from the local curator. If dredging is permitted, a procedure should be agreed with the curator whereby any material of potential interest is recovered, labelled, appropriately stored and the position of recovery recorded.

NOTE 1 The presence on board of a marine archaeologist might be required.

NOTE 2 Advice on such matters can be obtained from the Crown Estate, the Receiver of Wrecks, Historic Scotland, CADW (Welsh Historic Monuments), English Heritage and Centre for Maritime Archaeology, Ulster University. Wrecks can frequently be identified from navigational charts and built features are often catalogued in national monument records for the specific country within the United Kingdom, but other features such as drowned landscapes require specialist knowledge.

6.8.5 Marine traffic

*COMMENTARY ON **6.8.5***

A number of data sources are available from which to obtain information about local traffic conditions. The Maritime and Coastguard Agency (MCA) and UKHO might have access to generic vessel track data which could help identify vessel traffic densities. In the case of leisure craft and fishing vessels, local clubs and associations might publish handbooks and diaries of events. Other resources include:

- *port handbooks and other nautical publications such as "Admiralty sailing directions (Pilots)" available from the United Kingdom Hydrographic Office for the sea areas and coastline around the UK;*
- *commercial data providers such as IHS SeaWeb;*
- *automatic identification system (AIS) data from the automatic tracking systems used on ships and by vessel traffic services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites;*
- *online resources such as AIS Live and Marine Traffic (noting these tend to give current snapshots, not historical data, unless a fee is paid for additional access).*

However, by far the best source of data in harbour and coastal areas is the local port, and in particular the Harbour Master, who is able to provide detailed information on:

- *numbers and types of vessel movements;*
- *restricted areas;*
- *special events;*
- *fishing activity, both recreational and commercial (e.g. drift netting);*
- *local regulations relating to navigation and environmental protection (including bye-laws);*
- *details of other organizations to consult with (especially leisure organizations);*
- *details of any requirement for pilotage, and any costs associated with working in the port area;*
- *details of any permits or consents required in the proposed work area; and*
- *frequently much other useful information including prevailing weather and tidal conditions.*

When project planning is complete, and the project commences, the Harbour Master is able to provide assistance through the issue of Notices to Mariners to warn other users of works in progress. Depending on the level of traffic management service provided at the port [for example vessel traffic services (VTS)], it might also be possible to manage the sailing times and routes followed by other vessels, in order to avoid conflict with dredging operations.

Finally, in extreme cases, the Harbour Master might have powers to exclude other vessels from the work area for some or all of the project duration or, in emergency cases, to direct particular vessels to take certain courses of action to ensure that the dredging operation can continue safely.

Knowledge of marine traffic in the proposed work area should be obtained to ensure the project can be completed safely and with manageable interruption from other marine traffic that might need to continue using the same area.

In particular, activities should be carefully planned to ensure that dredging operations within harbour areas and port approaches have a minimal impact on other legitimate users of the sea.

A marine traffic impact assessment should be undertaken in congested areas where required for safe navigation.

The Harbour Master should be consulted at the earliest opportunity and regular contact should be maintained.

6.8.6 Vessel emissions

Dredging projects should take account of the increasing trend for vessels to be subject to environmental control measures that limit emissions to acceptable standards.

NOTE Sources of emissions include:

- *exhaust fumes;*
- *waste, bilge and foul water;*
- *waste lubricants and oil;*
- *solid waste;*
- *ballast water;*
- *fuel quality.*

The dredging operations should be planned to control such emissions as required both at sea and at berth. Engines and equipment should be properly maintained to minimize the release of noxious gases and particulates.
The suitability of reception facilities at nearby ports for the discharge of waste should be determined. The availability of shore power supply should be determined if and where required to limit exhaust emissions in port.

The fuel quality determines the release of exhaust fumes, and hence the fuel should be selected to meet the required emission standards, typically in terms of sulfur content.

These factors should be included in the environmental assessment and design described in Clause **5**.

7 Dredging plant selection

*COMMENTARY ON CLAUSE **7***

Types of dredging plant can be broadly divided into:

- *hydraulic dredging plant that convey material by the flow of water;*
- *mechanical dredging plant that convey materials by mechanical means.*

The selection of dredging equipment for reclamation with dredged hydraulic fill is covered in prEN 16907-6. The general selection of plant for hydraulic and mechanical dredging is briefly outlined in this clause.

Further guidance can found in Dredging – a handbook for engineers *[10].*

7.1 General

The selection of plant should be based on physical factors including work type, soil type, site and sea conditions and the volume of material to be dredged.

More than one type of plant can be capable of carrying out the required task. The selection should take account of a range of factors, including but not limited to:

- geotechnical conditions (see BS 5930:2015);
- dredgeability of soils and rock (see PIANC Report No. 144 [N1]);
- plant availability;
- duration required for mobilization;
- accuracy and tolerance of dredging and placement (see **15.13**);
- vessel production rates, method and works programme;
- draught and keel clearance of the vessel empty and loaded;
- location of borrow and deposition area;
- water depth and bathymetry;
- depth and width of access routes;
- hydraulic and meteorological conditions;
- waves and currents occurrence and persistence;
- economic considerations;
- contract and physical interfaces;
- suspended solids release and overflowing;
- vessel emissions and noise;
- environmental impact and criteria;
- water quality and ecology;
- presence of shipping;
- manoeuvrability, navigation, obstruction and collision avoidance.

The characteristics of dredging plant and equipment, and their advantages and disadvantages, are discussed in **7.2** and **7.3**, and should be accounted for when planning a dredging operation.

NOTE 1 A preliminary guide to the selection of dredging plant for particular tasks is given in ***7.4****.*

Estimates of productive dredging time should make a suitable allowance for the following factors, which can result in a substantial reduction in output.

a) Each of the many types of dredging plant has evolved to meet a particular requirement. As a result, some types of dredger are suited to only a narrow range of applications, while others are more versatile. It is therefore important that the methods of dredging are properly understood during the design and planning stages of the proposed works.

   NOTE 2 Guidance is given in Dredging – a Handbook for Engineers *[10].*

b) The time taken and the cost of mobilizing dredging plant often represents a major proportion of the dredging expenditure.

c) As with other types of civil engineering plant, the daily production of a particular dredger is not simply the product of its rated output and the hours manned. Dredging time can be lost for a number of reasons, e.g. haul distance, adverse weather, sea conditions, mechanical breakdown, maintenance, tide levels, adverse currents, shipping, bunkering, victualing, crew changes and suction or bucket fouling. Owing to the marine environment, the percentage of time lost can be significantly greater than is normally experienced with land plant.

The implications of using hopper overflow, such as when loading a trailing suction hopper dredger, should be carefully evaluated.

NOTE 3 Prolonged overflow can result in the release of a substantial quantity of sediment to the local marine environment with potentially adverse effect. Prolonged overflow or screening can be necessary to improve the grading of materials intended for a specific use, such as concrete aggregate, land reclamation or beach recharge.

7.2 Characteristics of hydraulic dredging plant

NOTE This subclause gives guidance on the characteristics and selection of dredgers whose principal mode of operation is hydraulic.

7.2.1 Trailing suction hopper dredger

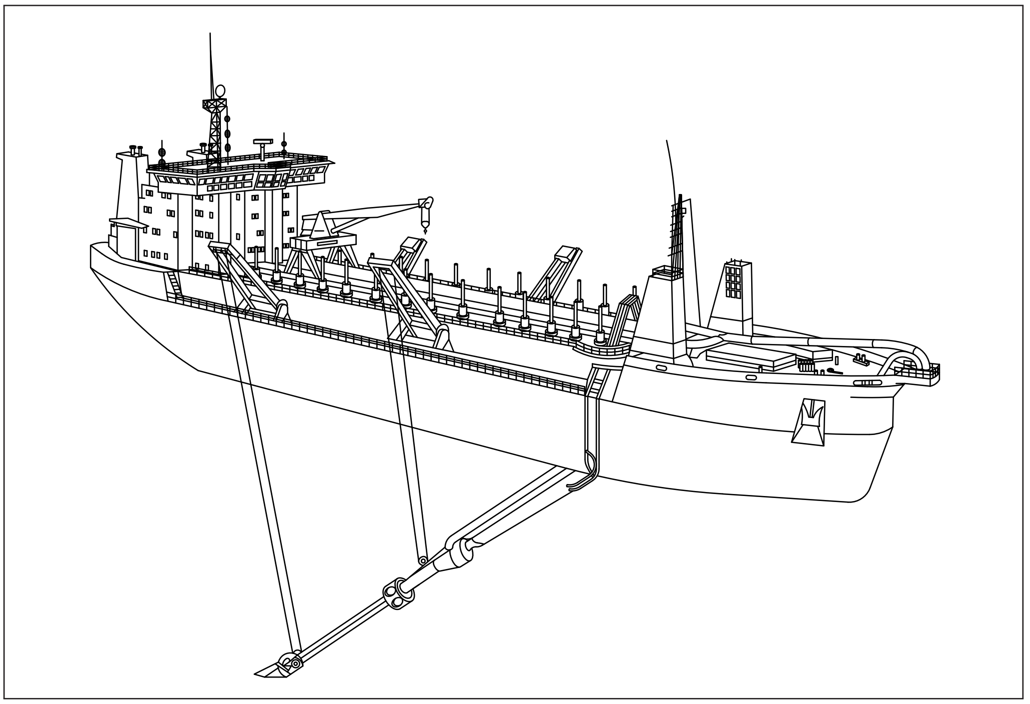
*COMMENTARY ON **7.2.1***

The trailing suction hopper dredger illustrated in Figure 3 is a ship that is suited to river, coastal or deep sea navigation, and that has the ability to load its own hold, normally called a hopper, by means of a centrifugal pump(s). Loading takes place with the ship under way. Discharge is by means of a bottom dumping arrangement or by pump discharge to shore for reclamation.

The trailing suction hopper dredger is usually rated according to its maximum hopper capacity, which can range from 750 m³ to over 45 000 m³.

The intake end of the suction pipe is fitted with a "draghead" designed to maximize the concentration of solids entrained from the seabed. The bearing pressure of the draghead on the seabed is usually controlled by an adjustable pressure-compensating system, which acts between the draghead and the hoisting winch. This system also serves to alleviate the effects of vertical movement of the ship relative to the seabed due to waves or swell.

Figure 3 **Modern trailing suction hopper dredger**



The particular advantages and disadvantages of the trailing suction hopper dredger that should be taken into account are:

- advantages:
  - straightforward mobilization procedure;
  - minimal effect on other shipping when working in areas of shipping movement;
  - independence of operation;
  - relative immunity to adverse weather and sea conditions;
  - relatively high rate of production;
  - ability to remove thin layers of material over large areas efficiently;
  - ability to transport dredged material over long distances;
- disadvantages:
  - inability to work in areas of very restricted navigation, and shallow depth;
  - depth of dredging limited by length of suction pipe;
  - sensitivity to presence of debris and foreign matter;
  - tendency to dilute fine materials severely during the loading process, bulking the volume of material contained in the hopper or for subsequent placement;
  - limited ability to dredge materials with significant inherent strength;
  - requirement for pre-treatment to facilitate dredging of material with significant inherent strength;
  - efficiency reduction in areas where suspended sediment release has to be limited for environmental reasons.

To achieve optimum performance, the draghead should be selected according to the type of material to be dredged and the dredger being used.

The plant selected should make due allowance for dredged material that is very cohesive or contains large solids, as this cannot only be difficult to dredge but can also be difficult to discharge, forming blockages at the hopper's bottom doors or valves and adjacent structure.

When the objective of the work is to reclaim land, the spoil should where practicable be pumped directly from the hopper into the reclamation area, but may alternatively be bottom-discharged to a temporary surge pit for subsequent re-handling by other equipment.

NOTE 1 See prEN 16907-6 for further guidance.

NOTE 2 Most trailing suction hopper dredgers are specially constructed to permit this operation.

Since most trailing suction hopper dredgers usually use relatively low head pumps, intermediate booster pumps should be employed where necessary to pump through very long pipelines.

7.2.2 Cutter suction dredger

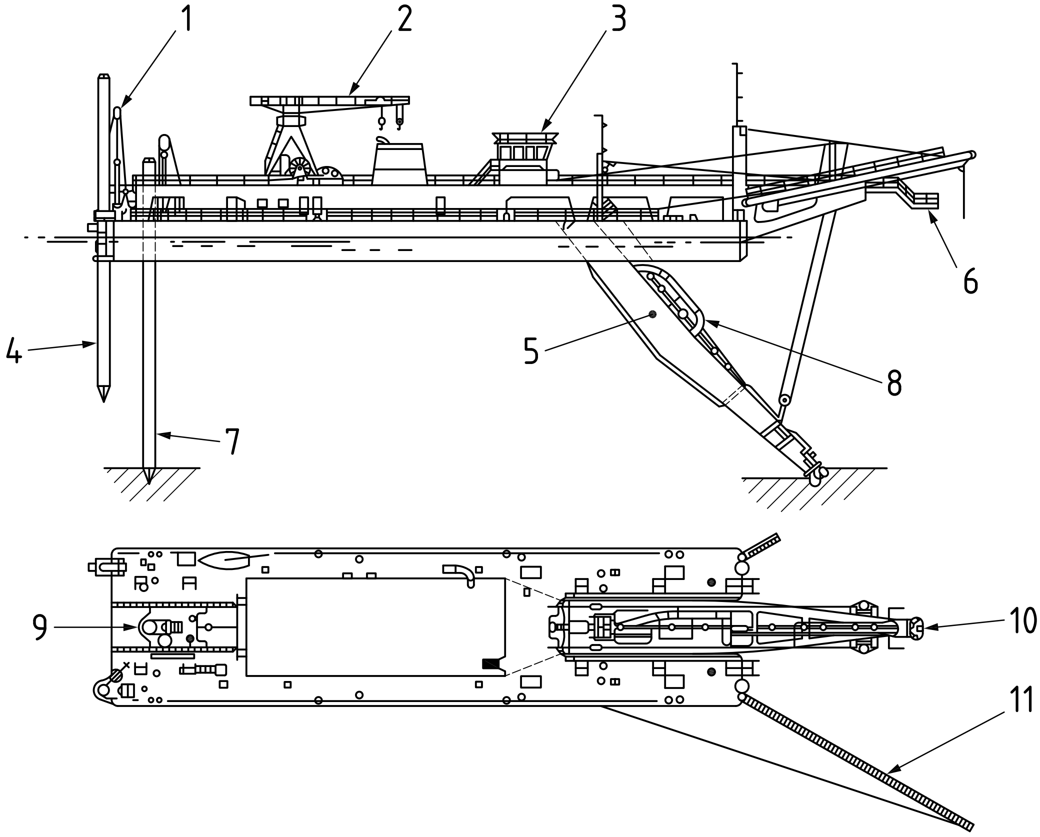
7.2.2.1 General

*COMMENTARY ON **7.2.2.1***

The more common form of construction of a cutter suction dredger is that of a rectangular pontoon (see Figure 4), although the very large cutter suction dredgers can be ships. A cutter suction dredger can be self-propelled but is more commonly dumb (non-self-propelled). Dredging usually takes place with the dredger located by spuds and swung using long anchor wires. The cutter head provides a powerful cutting action with suction pumping to discharge the dredged material, usually via pipeline, onto the seabed, re-handling pit, deposition area, onshore placement area, or land reclamation and into barges.

The cutter suction dredger (CSD) is normally rated according to either the diameter of the discharge pipe, which can range from 150 mm to 1 200 mm, or by the cutter head driving power, which can range from 50 kW to over 7 000 kW, or in the case of very large dredgers by the total installed power.

Figure 4 **Modern large cutter suction dredger fitted with submerged ladder pump and spud carriage**



Key

1	Spud hoist	7	Anchor or working spud
2	Service crane	8	Underwater pump
3	Control cabin	9	Spud carriage
4	Auxiliary spud	10	Cutterhead
5	Ladder	11	Anchor boom
6	Cutter service platform		

The cutter head, which can be electrically or hydraulically driven, encloses the suction intake of a centrifugal dredge pump. The cutter head is mounted at the extremity of a fabricated steel structure, termed the "ladder", which also supports the suction pipe. The ladder is attached to the main hull by heavy hinges, which permit rotation in the vertical plane. The ladder assembly is lowered and raised by means of a hoisting winch (or occasionally hydraulic cylinders) controlled from the bridge.

The main pontoon structure contains the dredge pump(s), the main engines and all ancillary engines, drives and equipment. An underwater pump may also be included mounted within the ladder construction.

The positioning and control of the dredger is usually by means of a combination of spuds and anchor winches. Most modern CSDs employ a centrally mounted spud carriage (see Figure 4). Occasionally only winches can be employed. Even more rarely, on very small dredgers only spuds can be employed.

The discharge from the dredge pump(s) passes over the stern (or opposite end to the cutter) of the pontoon to a heavy hose or flexible coupling, to which is connected a floating pipeline for discharge.

The particular advantages and disadvantages of the cutter suction dredger that should be taken into account are:

- advantages:
  - relatively high rate of production;
  - operation in relatively shallow water;
  - ability to dredge a very wide range of material, including weak to moderately strong rock, subject to rock strength and quality;
  - ability to convey by pumping the dredged material, with water, directly to the placement or reclamation area;
  - ability to produce a fairly uniform accurate level bottom;
  - ability to deliver dredged material pumped directly from the cutter suction dredgers to a trailing suction dredger or barge in environmentally sensitive locations where overflow is prohibited (although the resultant productivity is low);
- disadvantages:
  - mobilization impacted by sensitivity to sea conditions;
  - obstructs shipping when working in areas of shipping movement;
  - relative sensitivity to adverse weather and sea conditions;
  - dredging depth is limited by length of ladder;
  - anchor spread can pose a navigation hazard;
  - requires frequent anchor movements;
  - operation relies on anchor booms, or anchor handling tugs and support vessels;
  - sensitivity to presence of debris and foreign matter;
  - inability to efficiently dredge thin layers over large areas;
  - requirement for pre-treatment to facilitate dredging of materials with significant inherent strength;
  - tendency to dilute fine materials severely during the dredging process leading to bulking of materials for placement.

7.2.2.2 Pipelines

*COMMENTARY ON **7.2.2.2***

The most flexible pipeline construction is of reinforced rubber. It normally incorporates a jacket of buoyant material to provide a positive buoyancy when the pipeline is loaded with a pumped mixture of high relative density. The high cost of such pipelines can be reduced by using a composite construction, which mixes steel and rubber pipeline lengths.

Sinker pipelines are less susceptible to weather, tidal and current action and, because flotation jackets are not required, are significantly cheaper than floating pipeline sections. Similar to floating pipelines, their strength (and wall thickness) are very important. Sinker pipelines typically have a greater wall thickness than onshore pipeline. Unlike onshore and floating pipelines, which are normally bolted together, sinker pipelines are usually welded constructions.

Pipelines should be selected to ensure both the performance and the operational efficiency of the cutter suction dredger, taking into account the diameter of the pipeline which has a direct bearing on the efficiency of the hydrotransport process.

Pipelines fall into the following three categories.

a) Onshore pipelines. Onshore pipelines are most commonly steel with bolted flange connection with a compressible gasket between flanges, which should provide a watertight seal. When there are significant changes in elevation along the pipeline route, air valves ("snifters") should be fitted to allow the escape of trapped air, which can otherwise restrict performance, and to avoid the creation of an excessive vacuum, which can damage the pipe.

b) Floating pipelines. The strength of the pipe should be sufficient to resist high internal pressures and bending stresses. This is usually achieved by a fully flexible self-floating pipeline or a mixture of rigid steel pipe connected by sections of flexible pipe or steel ball joints. The resistance to abrasion or cutting should be balanced against the benefits of pipeline flexibility.

c) Sinker pipelines. Sinker pipelines should be adopted where needed to connect sections of floating and onshore pipeline, and where the pipes have to be laid on the seabed (as is often required to minimize navigation impacts).

NOTE Pipelines can terminate with either a free discharge or other hydraulic control mechanism such as a diffuser which is added to the pipeline outfall to reduce the discharge velocity and to spread the flow, reducing erosion and ensuring a more uniform placing of material.

7.2.2.3 Anchors

The choice of anchors to be used with a cutter suction dredger should be based on the ground conditions at the work site.

NOTE 1 Usually the cutter suction dredger works with one of the types of anchor that secure a hold by penetration into the seabed. Large cutter suction dredgers working in rock can develop winch pulls in excess of 150 t, to which has to be added the dynamic loading arising from cutter reaction and wave action.

When the seabed is hard, the need to use some type of gravity anchor, which relies on mass and friction to resist the winch pull, should be assessed.

NOTE 2 Various anchor types are covered in BS 6349-6, which is undergoing revision at the time of publication of BS 6349-5.

7.2.2.4 Cutter heads

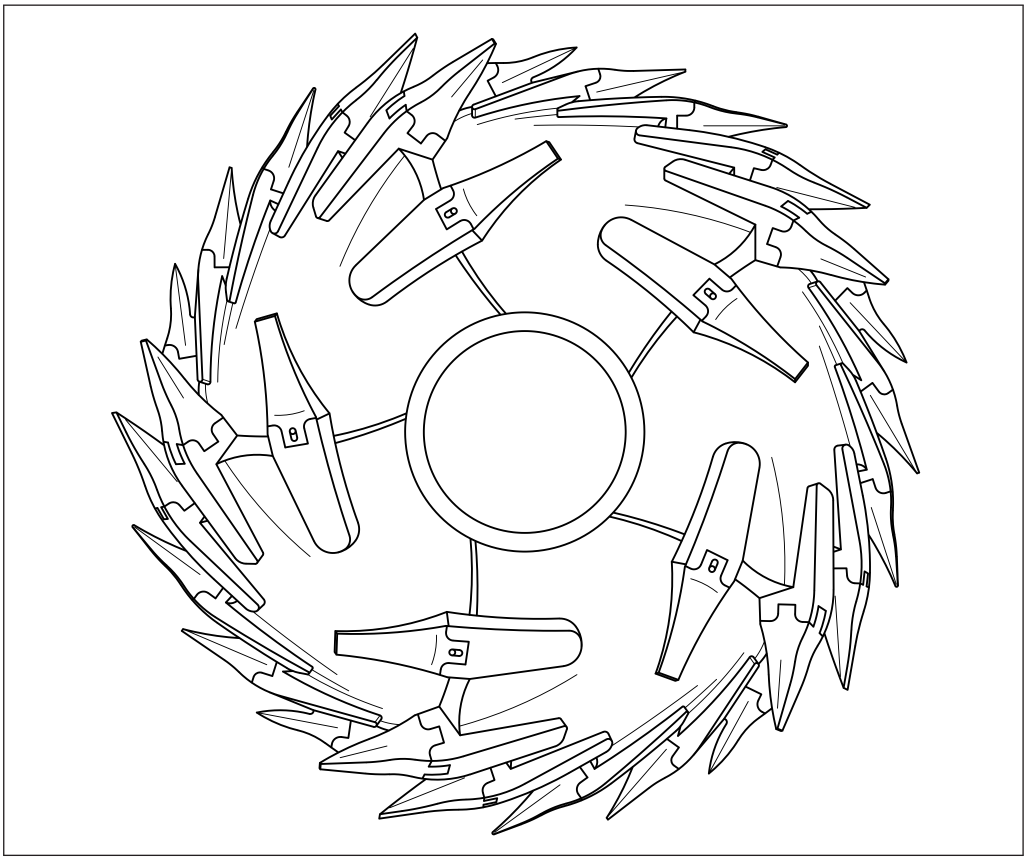
*COMMENTARY ON **7.2.2.4***

Most of the cutter heads in common use are of the "crown" type. The main body of the cutter head is formed in a cast steel alloy. The types of cutter are as follows.

- *Plain bladed cutters. Plain bladed cutters are used only in weak materials, such as silts, sands and clays. Blade edges are normally replaceable. The number of blades is selected according to the intended application.*
- *Serrated blade cutters. Serrated blade cutters are primarily for use in materials such as medium to stiff clays, medium dense sands or occasionally in very soft or heavily weathered rocks. Blade edges can be replaced when worn.*
- *Rock cutters (see Figure 5). Rock cutters are of heavy construction with a generous blade section. The blades incorporate integral sockets for the mounting of a variety of types of replaceable teeth. The shape of the blades is designed to maintain the maximum number of teeth in contact with the face regardless of dredging depth. The teeth can range from a chisel form for stiff clay and very weak rocks to a pick point form for the dredging of weak to moderately strong rocks. The teeth are made from a highly wear-resistant alloy steel and are usually attached by means of a single sprung pin, or bolt, which reduces the time needed to change a tooth to a few minutes.*

Cutterheads should be selected to have suitable characteristics for their intended purpose.

Figure 5 **Rock cutters**



7.2.3 Dustpan dredger

*COMMENTARY ON **7.2.3***

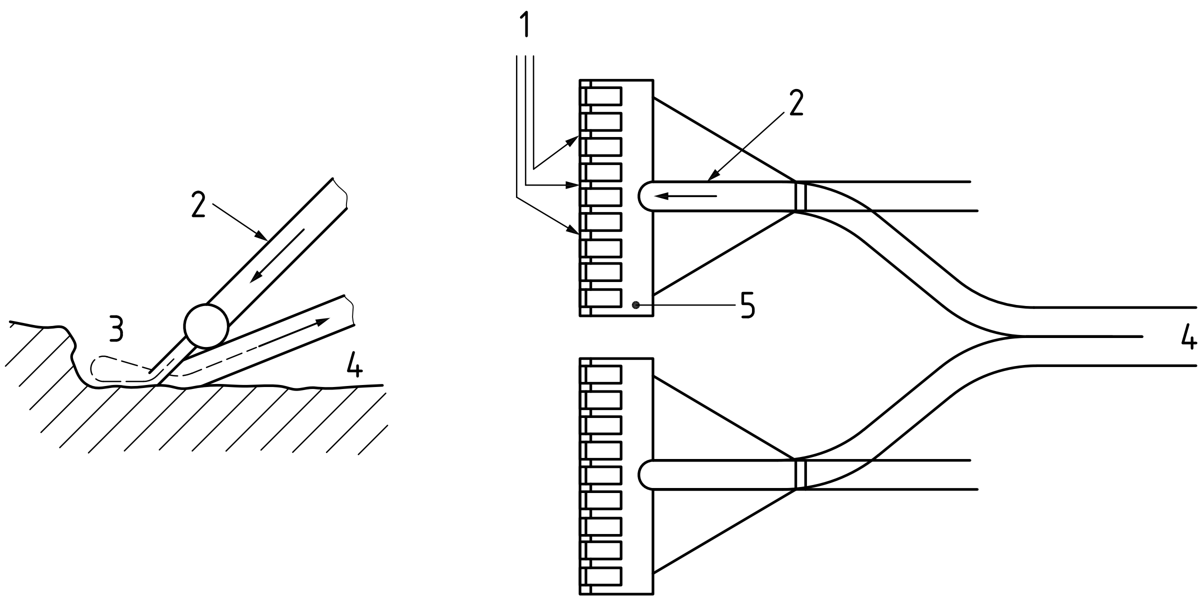
*The dustpan dredger is a suction dredger that usually discharges through a short floating pipeline but occasionally discharges into barges. In many respects it is similar to the cutter suction dredger (see **7.2.2**).*

The most significant difference between the dustpan dredger and the cutter suction dredger is the design of the suction head, which has no mechanical cutting action but relies instead on an array of water jets to loosen and fluidize the bed deposits (see Figure 6).

In normal operation the dredged material is discharged via a pipeline into deeper or rapidly flowing water a few hundred metres from the dredging area.

The dustpan dredger is similar to the cutter suction dredger but without the cutting power of the cutter head.

Figure 6 **Dustpan dredger with suction head arrangement**



a) Side elevation   b) Plan

Key

1 Jet nozzles
2 Water in
3 Water jets
4 Suction
5 Water manifold

The particular advantages and disadvantages of the dustpan dredger that should be taken into account are:

- advantages (distinct from CSD):
  - ability to remove thin deposits of granular and detritus material from relatively large areas;
  - suitable for the relocation of material forming shoals to nearby deeper areas;
  - special dustpan dredgers able to produce accurately a plane level surface to the seabed for the founding of precast structures;

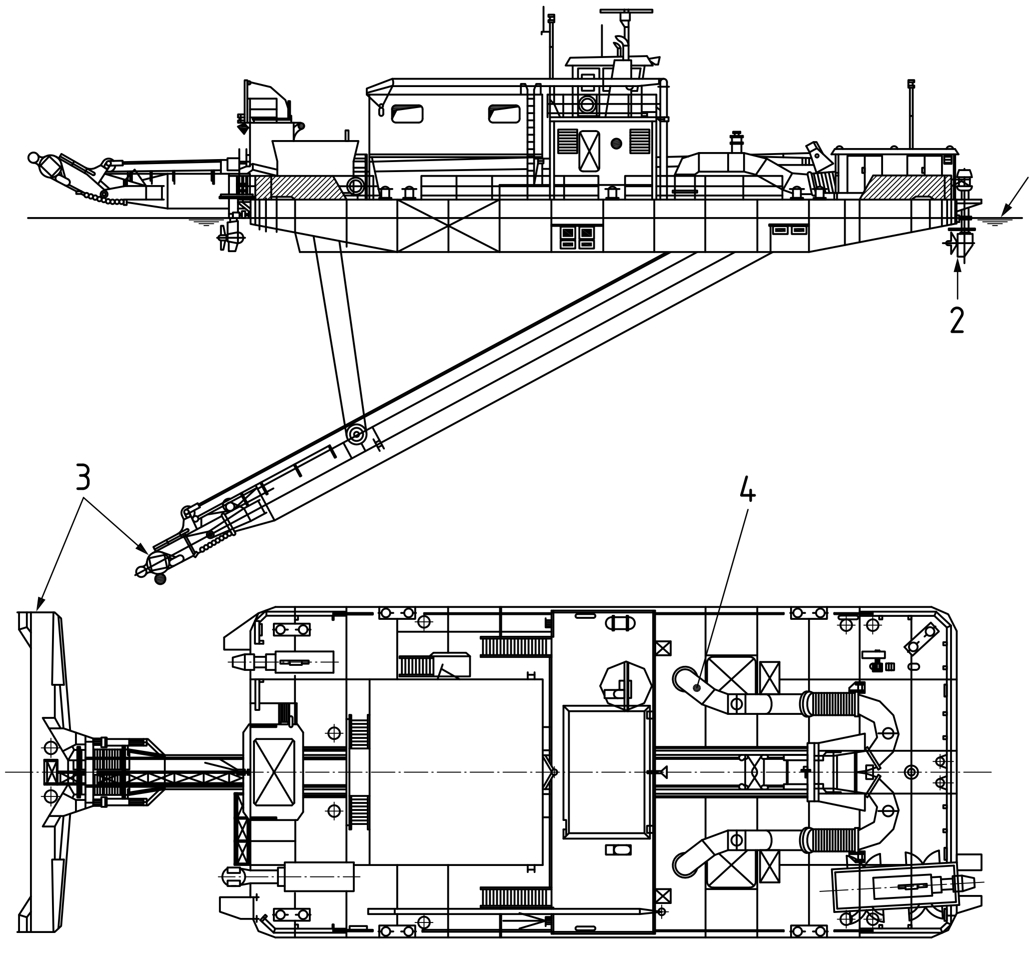
- disadvantages (distinct from CSD):
  - efficient operation limited to the dredging of recent unconsolidated deposits;
  - can resulting in bulking of dredged deposits;
  - accurate dredging in plan is limited due to anchor wire slack.

7.2.4 Water injection dredger (WID)

*COMMENTARY ON **7.2.4***

WID can be appropriate for the removal of fine sediment and recent mud deposits. The technique involves the injection of water, in high volume but low pressure, into the top layers of sediment deposits in order to fluidize these and to create a density flow (Figure 7). In this way the sediments are removed from the area to be dredged, but remain in the natural ecosystem and therefore its equilibrium is much less disturbed.

Figure 7 **Water injection dredging (WID)**



Key

1 Water level

2 Propulsion

3 Water injection nozzle bar

4 Water pumps to feed injection

WID vessels are equipped with a central pipe or a U-pipe fixed to a horizontal jet bar that is orientated perpendicular to the direction of motion. The jet bar is fed by one or two low pressure jet pumps and can be lowered with a winch to the seabed. The jet bar contains an array of nozzles over the whole length of the bar to spread the water evenly into the top soil layer. The low pressure jet pumps supply the high volume of water that is required to break the cohesion of the soil and to dilute the soil into a fluidized soil layer. WID vessels are capable of dredging fine sediments in water depths of up to 30 m.

Sailing speeds during a WID operation are usually low (1 to 2 knots). Some WID units are not self-propelled and require a pusher tug for manoeuvring. The WID vessel in these cases consists of a purposely constructed barge with pumps, a jet bar and a WID control unit. Some WID vessels are equipped with heave compensators to maintain the jet bar at a certain depth. The width of the beam can vary as well as the nozzle layout. Good manoeuvrability is an important asset for each WID vessel. Bow thrusters and double propulsion contribute to a large extent to the performance of a WID vessel.

The particular advantages and disadvantages of the WID dredger that should be taken into account are:

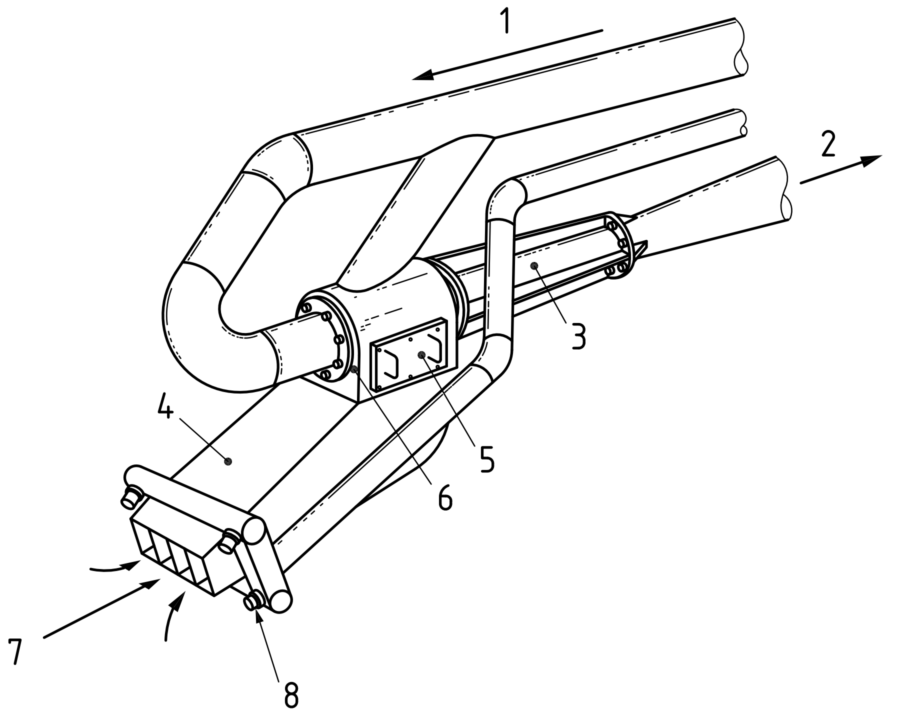
- advantages:
  - ability to work in areas of very restricted navigation;
  - operation in relatively shallow water;
  - independent operation if self-propelled;
  - relatively high rate of production;
  - ability to move fine sediment (typically <100 μm), assisted by mainly natural forces;
  - ability to produce a fairly uniform level bottom;
  - controlled release of suspended sediments in environmentally sensitive areas;
- disadvantages:
  - relative sensitivity to adverse weather and sea conditions;
  - dredging depth is limited by reach of injection arm;
  - not usually suitable for dredging coarse sand or gravel;
  - sensitivity to presence of debris and foreign matter;
  - not suitable for dredging of materials with inherent strength;
  - requirement to understand fate of material;
  - range of transport limited by natural forces at dredge location;
  - careful evaluation needed where suspended sediment release has to be limited for environmental reasons.

7.2.5 Jet pumps/dredgers

*COMMENTARY ON **7.2.5***

*Jet pumps (see Figure 8) can be incorporated into any dredger that works on the suction principle, but are normally confined to plain suction types, such as the cutter suction dredger (see **7.2.2**). They can also be used to assist in the ejection of gas from dredged mixtures with important improvements in production of materials that contain significant amounts of gas. The jet pump is positioned in the suction pipe, normally at the extremity.*

Figure 8 **Illustration of jet pump with suction intake incorporating water jetting arrangement**



Key

1	High pressure feed to jet nozzle	5	Inspection hatch
2	Mixed flow discharge	6	Main jet nozzle within housing
3	Mixing chamber	7	Induced inflow of mixture
4	Suction duct	8	Optional water jets for soil disintegration

The particular advantages and disadvantages of the jet pump that should be taken into account are:

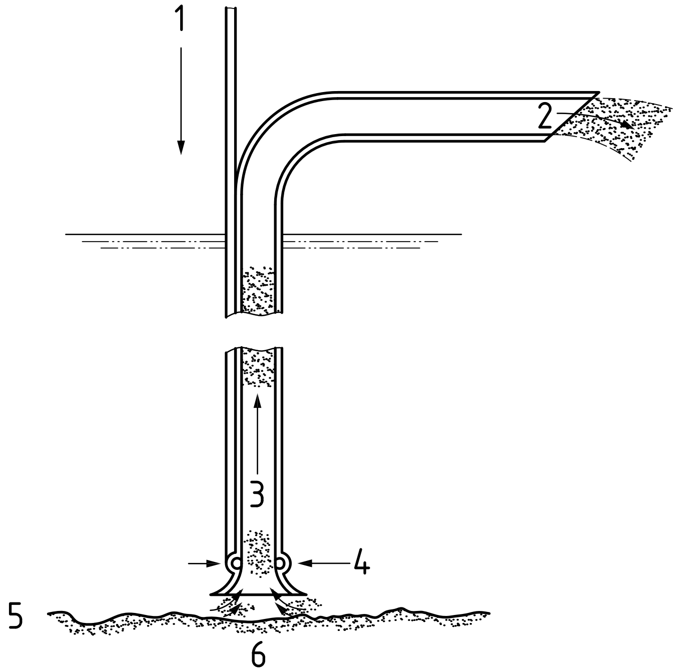
- advantages:
  - ability to dredge to greater depth;
  - ability to continue dredging with a buried suction intake without undue risk of cavitation (assuming a system designed to operate buried);
  - much reduced risk of pipeline blockage when discharging through pipelines;
  - reduced costs due to wear if handling abrasive materials;
- disadvantages:
  - significant reduction in the overall system efficiency when compared with a solids-handling centrifugal pump;
  - rather limited residual head available for the discharge of the dredged materials through pipelines;
  - maximum discharge distance is significantly less than with a centrifugal solids-handling pump;
  - for longer discharge distances or high heads, it becomes necessary to employ a conventional solids-handling centrifugal pump in the discharge line to provide additional head.

7.2.6 Air-lift dredgers

*COMMENTARY ON **7.2.6***

The air-lift dredger (see Figure 9 for method of loading) achieves flow in a pipe by the injection of compressed air at the submerged extremity of the pipe.
The entrained air results in a reduction in the density of the air/water mixture within the pipe and an upward flow is induced. Fine loose soils, including silts and fine sands, can be eroded and carried in suspension by the inflowing water. The system works best when removing fine materials in deep water.

Figure 9 **Illustration of air lift principle**



Key

1	High-pressure air	4	Annular injection high-pressure air
2	Low-velocity mixture outlet	5	Seabed
3	Induced rising flow	6	Entrained solids

The particular advantages and disadvantages of the air lift dredger that should be taken into account are:

- advantages:
    - can be assembled from readily available components;
    - great simplicity, including absence of submerged moving parts;
    - suitable for removal of fine silts, and sands;
    - small dredging assembly can be light in mass, to suit use by divers for local excavation;
    - useful as a simple underwater cleaner for the clearance of sediment from around wrecks or structures and for the cleaning of submerged foundations;
- disadvantages:
    - operation not efficient in shallow water;
    - low production rates;
    - discharge local to dredging location;

- limited to the dredging of recent unconsolidated deposits;
- can resulting in bulking of dredged deposits.

7.3 Mechanical dredgers

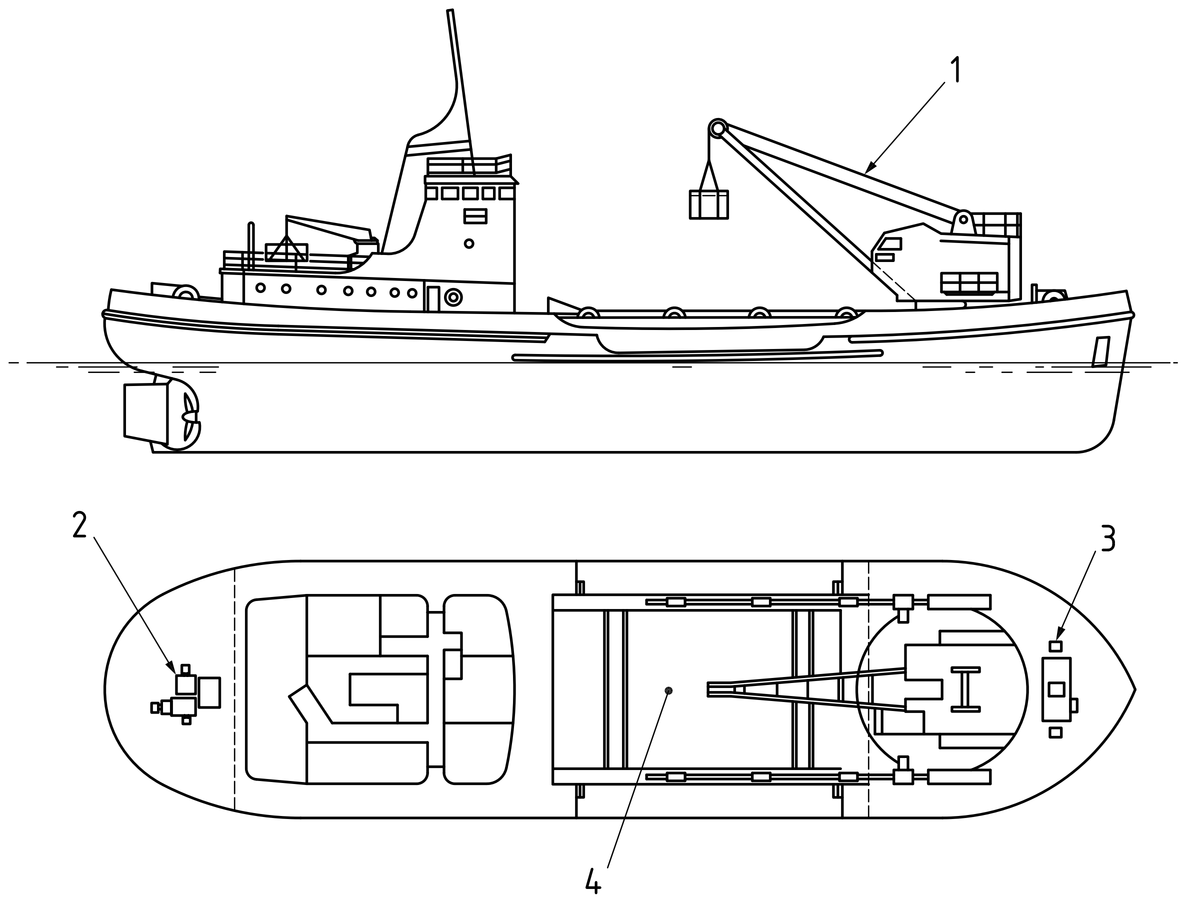
NOTE This subclause describes the characteristics of dredgers whose principal mode of operation is mechanical. The size of mechanical dredgers are generally characterized in terms of their bucket capacity.

7.3.1 Grab hopper dredger

*COMMENTARY ON **7.3.1***

*As in the case of the trailing suction hopper dredger (see **7.2.1**), the grab hopper dredger is a ship (see Figure 10), but it is loaded by means of deck-mounted grab cranes, or backhoe excavator, rather than by suction pumps. Loading takes place with the dredger stationary at anchor and the number of loading cranes does not normally exceed four. The hopper capacity is normally modest and capacities in excess of 1 500 m³ are uncommon. The method of discharge is invariably via bottom-opening doors.*

Figure 10 **Small self-propelled grab hopper dredger with single crane**



Key

1 Grab crane

2 Stern mooring winch

3 Forward mooring winches

4 Hopper

The particular advantages and disadvantages of the grab hopper dredger that should be taking into account are:

- advantages:
    - straightforward mobilization procedure;
    - minimal effect on other shipping when working in areas of shipping movement;
    - relative immunity to adverse weather and sea conditions;
    - well suited to the dredging of confined areas, such as alongside quays, in dock entrances and around;
    - depth of operation of the grab is only limited by the wire capacity of the hoisting winch drum, allowing dredge to depths not possible with other dredgers of comparable size;
    - rubbish and debris can be handled with relative ease;
    - potentially difficult rubbish and debris can be separated and stowed on deck for subsequent disposal onshore;
    - loads dredged material with minimal disturbance or dilution;
    - hopper can be largely filled with solids, with low bulking;
    - ability to transport dredged material over long distances;
    - can be operated to limit the release of suspended sediments in environmentally sensitive areas;
- disadvantages:
    - certain types of debris, such as ropes, hawsers and chains, can obstruct bottom door closure after discharge of spoil;
    - anchor wires can be a hazard to other navigation;
    - relatively low rate of production compared with most other types of dredger;
    - difficulty of producing an accurate and level bottom finish;
    - requirement for pre-treatment to facilitate dredging of material with significant inherent strength;
    - efficiency reduction in areas where suspended sediment release has to be limited for environmental reasons.

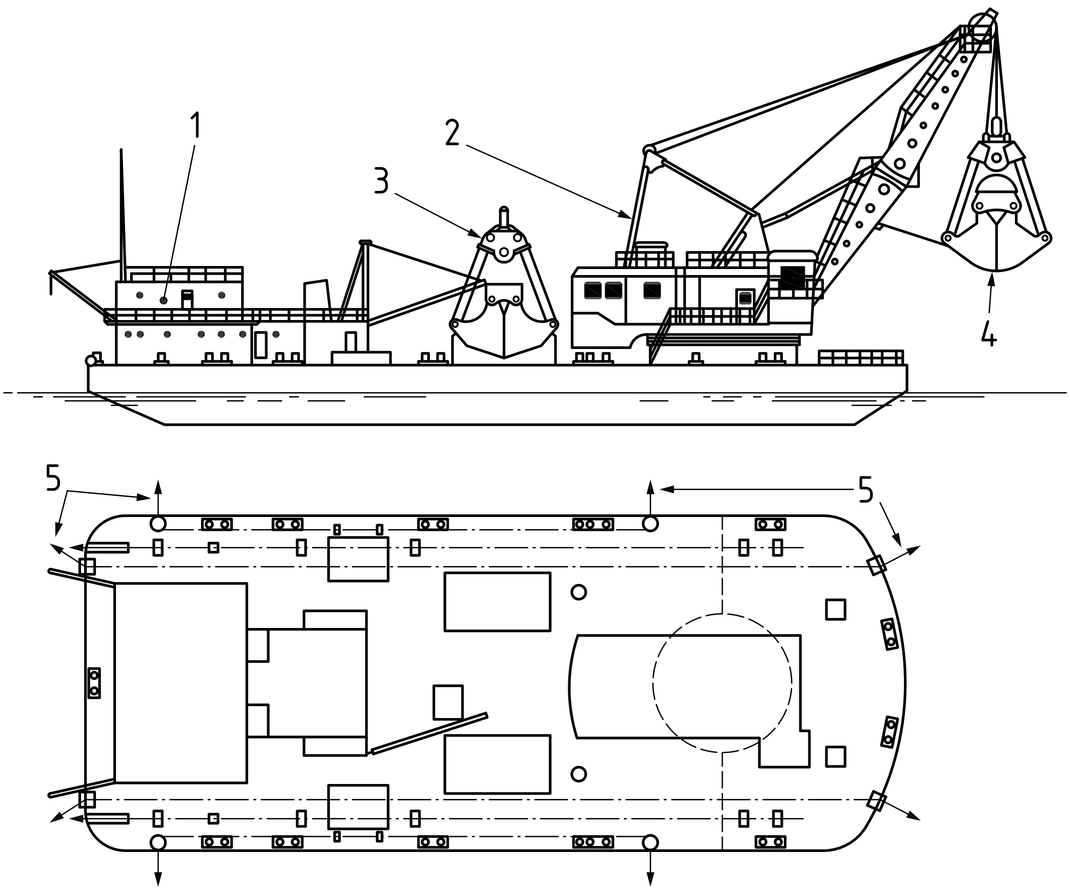
NOTE The grab hopper dredger is normally rated according to its hopper volume.

7.3.2 Grab pontoon dredger

*COMMENTARY ON **7.3.2***

*The dredging equipment of the grab pontoon dredger (see Figure 11) is essentially the same as that of the grab hopper dredger (see **7.3.1**), but the maximum capacity of the grab bucket and crane can be significantly greater. The dredger loads into independent hopper barges. This permits an uninterrupted dredging operation with the result that higher overall rates of production are possible.*

Figure 11 **Large grab pontoon dredger with all winch mooring system**



Key

1 Accommodation
2 Crane
3 Spare grab
4 Grab bucket
5 Moorings

The particular advantages and disadvantages of the grab pontoon dredger that should be taken into account are:

- advantages:
  - capable of operation in relatively shallow water;
  - depth of operation of the grab is only limited by the wire length, allowing dredging to greater depths than other dredgers of comparable size;
  - rubbish and debris can be handled with relative ease;
  - potentially difficult rubbish and debris can be separated and stowed on deck for subsequent disposal onshore;
  - loads dredged material with minimal disturbance or dilution;
  - barge can be largely filled with solids, with low bulking;
  - can be operated to limit the release of suspended sediments in environmentally sensitive areas;

- disadvantages:
  - mobilization impacted by sensitivity to sea conditions;
  - relative sensitivity to adverse weather and sea conditions;
  - obstructs shipping when working in areas of shipping movement;
  - anchor spread can pose a navigation hazard;
  - requires frequent anchor movements;
  - operation relies on anchor handling tugs and support vessels;
  - relatively low rate of production compared with most other types of dredger;
  - results depend on operator skill;
  - difficulty of achieving a complete and overlapping coverage of the bottom, particularly in deep water or where the strength of current is significant;
  - inability to efficiently dredge thin layers over large areas;
  - difficulty of producing an accurate and level bottom finish;
  - requirement for pre-treatment to facilitate dredging of material with significant inherent strength;
  - efficiency reduction in areas where suspended sediment release has to be limited for environmental reasons.

NOTE The grab pontoon dredger is normally rated according to the maximum capacity of grab (bucket capacity) that can be handled. This can range from 0.75 m^3 to 200 m^3, although the latter largest capacity is uncommon.

7.3.3 Backhoe dredger

*COMMENTARY ON **7.3.3***

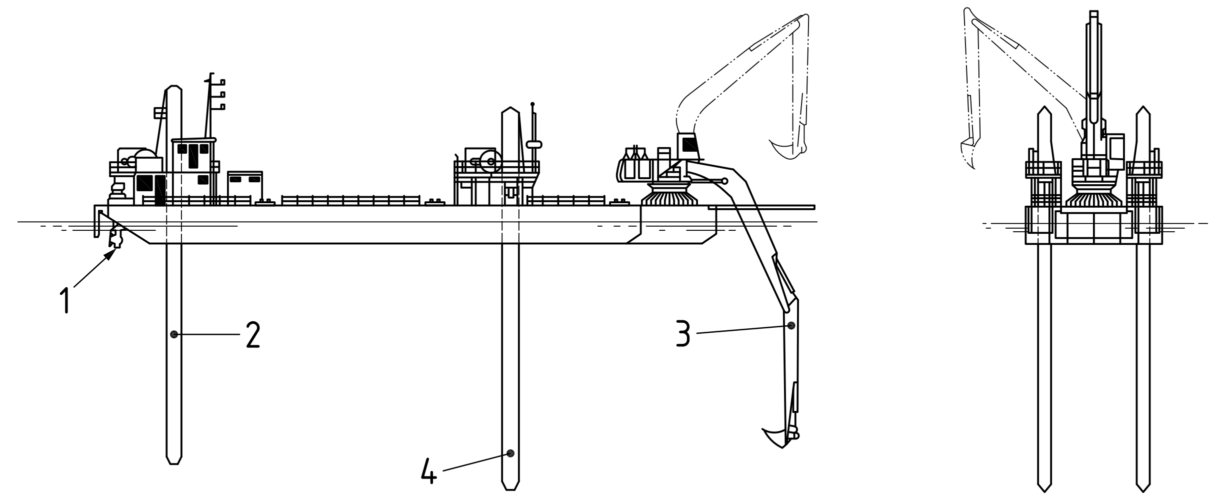
The backhoe dredger (see Figure 12) has evolved from the common land-based backhoe excavator, but whereas the land-based machine is normally mounted on a tracked or wheeled undercarriage, the dedicated dredging machine is mounted on a fabricated pedestal located at one extremity of a spud-rigged pontoon. For most dredging applications the machine is much larger than common land-based machines, being more comparable to large machines employed in the mining industry.

Where a conventional backhoe machine with tracked undercarriage is installed on a barge for dredging work, a secure, shock-absorbing pontoon mounting should be employed if the full digging potential of the machine is to be realized.

Spud location of the pontoon should generally be provided to create a positive reaction to the hydraulic digging action, particularly when dredging in difficult ground.

The backhoe dredger is normally rated according to the maximum size of digging bucket that the machine can handle. This can currently be up to 40 m^3 for the largest dredgers. The size of bucket employed should be set depending upon the nature of the material to be dredged and the maximum dredging depth. Maximum dredging depth can range from 4 m to approximately 30 m.

Figure 12 **Hydraulic backhoe dredger**



Key

1	Propulsion units	3	Backhoe
2	Walking spud	4	Fixed spuds

The particular advantages and disadvantages of the backhoe dredger that should be taken into account are:

- advantages:
  - ability to work in areas of very restricted navigation;
  - can operate close to quay walls and structures;
  - reasonable rate of production;
  - operation in relatively shallow water;
  - ability to dredge a wide range of materials, including those that contain debris;
  - ability of larger machines to dredge boulders, stiff clays and weak, weathered or fractured rocks, provided that the maximum required dredging depth is not excessive;
  - relatively accurate final dredged profile;
  - ability to produce a fairly uniform level bottom;
  - limited bulking of dredged material;
  - dredged material retains more in-situ strength characteristics;
  - can operate with a closed bucket to limit the release of suspended sediments in environmentally sensitive areas;
- disadvantages:
  - mobilization impacted by sensitivity to sea conditions;
  - relative sensitivity to adverse weather and sea conditions;
  - sufficient size and stability required in locations with significant waves or swell;
  - low rate of production when compared with dredgers with relatively continuous dredging process (i.e. cutter suction and bucket dredgers);
  - dredging depth is limited by length of boom and arm;

    - considerable dependence on the skill of the operator;
    - limited efficiently dredged thin layers over large areas;
    - requirement for pre-treatment to facilitate dredging of hard materials with significant inherent strength.

NOTE The backhoe is most efficient when working from behind the face, which means that the pontoon is located over the area to be dredged. If water depth is at any time less than the maximum draught of the pontoon, this might not be practical.

7.3.4 Bucket chain dredger

The particular advantages and disadvantages of the bucket chain dredger that should be taken into account are:

- advantages:
    - capable of operation in relatively shallow water;
    - capable of dredging relatively hard materials, including weak rock, subject to rock strength and quality;
    - loads dredged material with low disturbance or dilution;
    - barges can be largely filled with solids, with low bulking;
    - can prepare relatively level bed;
- disadvantages:
    - mobilization impacted by sensitivity to sea conditions;
    - relative sensitivity to adverse weather and sea conditions;
    - obstructs shipping when working in areas of shipping movement;
    - anchor spread can pose a navigation hazard;
    - requires frequent anchor movements;
    - operation relies on anchor handling tugs and support vessels;
    - depth of operation is limited by depth of ladder;
    - low efficiency when required to remove only a small depth of material;
    - possible failure of the buckets to discharge properly in certain cohesive materials, which tend to be sticky;
    - requirement for pre-treatment to facilitate dredging of hard materials with significant inherent strength;
    - noise levels that are higher than those generated by other dredgers.

*NOTE Bucket chain dredgers have largely been superseded by cutter suction dredgers (see **7.2.2**).*

7.3.5 Dipper dredger

*NOTE The traditional dipper dredger is a heavily constructed, rope-operated machine, that has to a limited extent been replaced by the hydraulic face shovel and backhoe dredgers (see **7.3.2** and **7.3.3**).*

Dipper dredgers should be used where appropriate for any of the following:

- where forming a dredged face is beneficial;
- to dredge access for the dredger into shallow water;
- in stratified hard material, where the lifting action can break up material that an equivalent backhoe cannot dredge.

7.3.6 Bed-levellers, rakes and ploughs

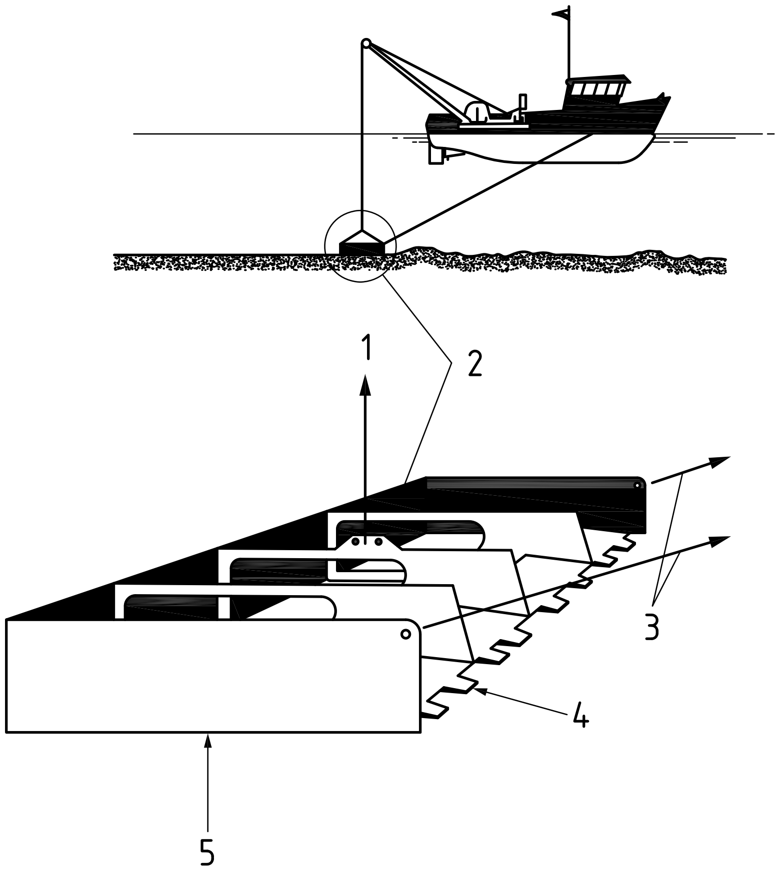
*COMMENTARY ON **7.3.6***

Bed-levellers (see Figure 13), sometimes called ploughs, are not dredgers in the conventional sense, but a means of moving material over the seabed, or causing it to rise into suspension to be transported away by natural water flow.

The function of the bed-leveller can be best compared with that of the bulldozer or grader on land. Like these land machines, the bed-leveller is only effective over relatively short distances, generally up to about 100 m. Where it is necessary to move material further, it is generally more economical to dredge the material and transport it in a hopper or by pumping.

*The bed-leveller is most commonly used to move material from high spots in shallow water into deeper areas. It can be used to move material into sufficient depth for removal by trailing suction hopper dredger, or to level off the high spots left by the trailing suction hopper dredger due to "tracking" or some other problem (see **7.2.1**).*

Figure 13 **Deployment method for bed leveller and typical bed leveller assembly**



Key

1 To hoist winch

2 Bed leveller

3 To tug forward

4 Cutter blade

5 Open bottom

Bed-levellers should be used where appropriate for any of the following:

- to level uneven areas of bed subsequent to dredging by trailing suction hopper dredgers;
- to remove debris by raking prior to dredging;

- to draw material to areas accessible for trailing suction hopper dredgers;
- to create access for a trailing suction hopper dredger into shallow water.

NOTE Rakes and ploughs can be used to remove light debris that might interfere with dredging activities prior to the commencement of works.

7.3.7 Trenching equipment

To protect offshore pipelines and cables, trenching techniques should be adopted as necessary to avoid ship, anchor and trawl impact, to reduce spanning, to avoid currents and sediment movement, such as:

- direct dredging;
- dredging and side casting;
- ploughs;
- jetting and burial machines.

NOTE Pipeline protection can be effected using equipment such as:

- *side dump barges;*
- *fall pipes;*
- *rock placement fall pipes.*

Particular care should be taken to avoid excessive fall velocities that can displace and damage pipelines and cause seabed instability.

For pipelines and cable landfalls the appropriate equipment should be selected to ensure effective production in shallow water and possible surf conditions.

7.3.8 Barges

The appropriate method of dredged material transport should be selected to suit the dredger and site conditions.

*NOTE Hydraulic dredgers, which typically discharge through floating pipelines giving high productivity, are covered in **7.2**.*

For mechanical dredgers, a variety of barges are used to support dredging operations, namely hopper, split hopper, and side dump. Specialist deep placement barges should be deployed, particularly where accurate placement is required at depth, such as when placing rockfill scour protection round seabed facilities. Self-propelled barges should be adopted:

- for the efficient transport of material over greater distances;
- in areas of adverse sea conditions where dumb barges handled by tugs, are slow and susceptible to sea conditions.

7.4 Dredger selection

Preliminary guidance on the selection of the more common items of dredging plant is given in Table 11 to Table 13. More definitive advice should be sought from dredging practitioners and professionals before committing to a particular method or plant. The tables assume knowledge of various site conditions. This knowledge should be used to determine the general suitability of each type of plant in relation to the site characteristics.

It is intended that these tables provide only a general guide to plant suitability. The tables are not definitive, and actual selection should be based on the particular plant, sea, ground and project conditions. The simplistic approach does not take account of all factors, but normally provides a reasonable indication of the optimum plant type(s) for a particular task.

Table 11 **Guidance on the selection of plant for maintenance dredging**

Site conditions	Trailing suction			Cutter suction	Grab pontoon	Backhoe	Barge unloader
	<5 000 m³	> Capacity <	>15 000 m³				
Bed material							
Loose silt	1	1	1	1	2	2	1
Cohesive silt	2	1	1	1	1	1	2
Fine sand	1	1	1	1	2	2	1
Medium sand	1	1	1	1	2	2	1
Coarse sand	1	1	1	1	2	1	1
Sea conditions							
Enclosed water	2	3	N	1	1	1	2
Sheltered water	1	1	1	1	1	1	1
Exposed water	2	1	1	3	3	3	N
Disposal to:							
Shore	1	1	1	1	32	3	1
Tide	1	1	1	1	N	N	N
Sea bed	1	1	1	3	1	1	N
Quantities							
< 100 000 m³	1	2	3	1	1	1	1
< 250 000 m³	2	1	2	1	2	1	1
< 500 000 m³	2	1	2	1	3	3	1
> 500 000 m³	3	1	1	1	3	3	1
Heavy traffic	1	1	1	2	2	1	1
Confined working	2	3	3	1	1	1	2

Key
1 = Most suitable; 2 = Acceptable; 3 = Marginal; N = Not usually suitable.

NOTE Other factors not referred to can influence the choice of dredger. The table provides only a general guide.

Table 12 **Guidance on the selection of plant for capital dredging**

Site conditions	**Trailing suction**			**Cutter suction**	**Grab pontoon**	**Backhoe**
	<5 000 m³	**> Capacity <**	**>15 000 m³**			
Bed material						
Loose silt	1	1	1	1	2	2
Cohesive silt	1	1	1	1	1	1
Fine sand	1	1	1	1	2	2
Medium/Coarse sand	1	1	1	1	2	2
Gravel	1	1	1	1	1	1
Soft clay	1	1	1	2	1	1
Medium clay	2	2	2	2	2	1
Stiff clay	3	3	3	3	3	1
Cobbles	3	3	2	2	1	1
Boulders	N	N	N	3	2	1
Very weak rock	N	3	3	1	3	1
Weak rock	N	N	3	1	N	1
Moderately weak rock	N	N	3	1	N	2
Pre-treated rock	2	2	1	1	2	1
Sea conditions						
Enclosed water	2	3	N	1	1	1
Sheltered water	1	1	1	1	1	1
Exposed water	2	1	1	3	3	3
Disposal to:						
Shore	1	1	1	1	3	3
Tide	1	1	1	1	N	N
Sea bed	1	1	1	3	1	1
Quantities						
< 100 000 m³	1	2	3	1	1	1
< 250 000 m³	1	1	2	1	2	1
< 500 000 m³	2	1	2	1	3	2
> 500 000 m³	3	1	1	1	3	3
Heavy traffic	1	1	1	3	3	2
Confined working	2	3	3	2	1	1

Key
1 = Most suitable; 2 = Acceptable; 3 = Marginal; N = Not usually suitable.

NOTE Other factors not referred to can influence the choice of dredger. The table provides only a general guide.

Table 13 **Guidance on the selection of plant for land reclamation[A)] and beach recharge**

Site conditions	Trailing suction [A)]			Cutter suction	Grab pontoon	Backhoe
	<5 000 m³	> Capacity <	>15 000 m³			
Bed material						
Fine sand	1	1	1	1	3	3
Medium sand	1	1	1	1	3	3
Coarse sand	1	1	1	1	3	3
Gravel	2	1	1	1	3	3
Cobbles	3	2	2	2	3	3
Boulders	N	N	N	N	3	3
Very weak rock	N	3	3	1	3	3
Weak rock	N	N	N	1	N	3
Sea conditions						
Enclosed water	2	3	N	1	1	1
Sheltered water	1	1	1	1	1	1
Exposed water	2	1	1	3	3	2
Placing by:						
Direct dumping	2	3	3	N	2	2
Direct pumping	2	N	N	1	N	N
Transport and pump	1	1	1	N	N	N
Barge and dump	3	3	3	3	1	1
Quantities						
< 100 000 m³	1	2	3	1	1	1
< 250 000 m³	1	1	2	1	2	1
< 500 000 m³	2	1	2	1	3	2
> 500 000 m³	3	1	1	1	3	3
Heavy traffic	1	1	1	3	3	2
Confined working	3	3	N	2	1	1

Key
1 = Most suitable; 2 = Acceptable; 3 = Marginal; N = Not usually suitable.

NOTE Other factors not referred to can influence the choice of dredger. The table provides only a general guide.

A) Guidance on reclamation with dredged hydraulic fill in given in in prEN 16907-6.

8 Maintenance dredging

*COMMENTARY ON CLAUSE **8***

Many aspects of maintenance dredging are covered in other clauses and consequently only particular aspects are discussed here.

Maintenance dredging generally involves the removal (or relocation) of soils recently deposited, usually comprising relatively fine sediments (sand and finer). Normally, the material to be removed is of small thickness and low strength. When dredging alongside quays or jetties, particularly in industrial areas, the sediments can contain materials such as spilled cargo, cables, ropes and jetsam.

In maintenance dredging the strength of the soil to be dredged is generally low and it is unnecessary for dredging plant employed to have a powerful cutting or dredging action. In many instances, particularly where dredging volumes are small, relatively lightweight equipment is adequate for the task.

*Most kinds of dredging equipment can be used for maintenance dredging. The types most commonly used are trailing suction hopper dredgers, small cutter suction dredgers, grab dredgers, backhoe dredgers, ploughs and water injection dredgers (see Clause **7** and Table 10).*

8.1 General

Dredged areas should be designed such that operational needs are met and the rate of infill into the areas is minimized. Applicability of channel/berth design techniques such as over-dredging and the use of sediment traps should be assessed in situations where accumulation rates are predicted to be high. Channel/berth design with respect to dredging is a technical activity and should be undertaken by a competent person.

The interval between maintenance dredging programmes can be as little as a few weeks or as long as a few years, and should be determined on a case-by-case (need) basis but with adequate forward planning.

8.2 Plant for maintenance dredging

Maintenance dredging (see Table 11) normally involves the removal of recently deposited fine sediments. Consequently, operators should take into account the reduced need for exceptionally powerful or heavily built equipment. If the distance to the disposal area is long, the operators should ensure that the maximum sailing speed and design of the hopper or dredger is suitable for the efficient loading and transport of fine materials.

The operational factors required when setting maintenance dredging strategy should be determined in accordance with BS 6349-1-1.

NOTE For regular maintenance dredging, the ranges of quantity to be dredged that are listed in Table 10 are for each separate campaign.

8.3 Infill calculation

Infill calculations should utilize bathymetric survey data collected over the area to be subject to maintenance dredging (see Clause **6**). Measurement of bed level before, during and after maintenance dredging should be undertaken in a careful and consistent way, with particular attention being paid to echo-sounder acoustic frequency (see Clause **6**).

To maximize the value of the surveys and the confidence in the infill calculations, consistent methods should be used for the surveys in question. If it is suspected that fluid mud might exist in an area then a dual frequency echo-sounder should be used with acoustic frequencies approximating 33 kHz and 210 kHz.

8.4 Design and planning of maintenance dredging

In the design and planning of maintenance dredging, early attention should be given to environmental aspects (see Clause **5**), including sampling and testing of the materials to be dredged for contaminants and particle size, as this informs the dredging methodology and choice of dredging plant.

NOTE 1 The number of sediment samples required for testing, and the suite of contaminants that are to be analysed, are usually informed by the relevant regulatory body (requirements can vary according to region).

The planning process should include the investigation of available options for the placement or use of the dredged material. Rather than placing dredged material at a marine disposal site, thereby removing it from the sediment budget of the estuary or coastal zone, beneficial use options should be preferentially employed where practicable, whereby some or all of the material is retained in the system. For example, there might be options available for sediment to be placed within an estuary to feed intertidal areas or for use in other forms of coastal defence or sediment cycling. Where the material is of appropriate quality, options for its use in engineering works (such as reclamations or general construction) should be investigated.

The planning of maintenance dredging operations should also take into account the port usage and in particular the anticipated vessel traffic type and density of movements.

NOTE 2 Certain vessels, such as LNG tankers, require that an exclusion, or buffer, zone is maintained around them. The exclusion zone is an area of water where access is restricted such that other vessels cannot enter, berth, moor or anchor. Unauthorized entry into the zone, which extends below the water level to the seabed and under any wharf adjacent to the zone, is classed as an offence. Such exclusion zones can have significant implications for the planning of dredging operations.

NOTE 3 Attention is drawn to the following legislation in respect of dredging activities in general, and licensing and environmental impact assessments in particular:

- *Marine and Coastal Access Act 2009 [11];*
- *Marine Works (Environmental Impact Assessment) Regulations 2007 [12];*
- *Conservation of Habitats and Species Regulations 2010 [13];*
- *Offshore Marine Conservation (Natural Habitats, etc.) Regulations 2007 [14].*

8.5 Methodology

The method of dredging and the particular type of plant to be employed should be determined on the basis of the specific dredging requirement and the particular characteristics of the site (see Clause **7**).

If the planning and design of dredging shows that the release of sediment to the environment needs to be strictly minimized then the viability of using plant with low release rates (e.g. backhoe dredgers and grabs with visors) should be assessed, along with the use of techniques such as placement via barges, without overflow (see Clause **7**).

When routinely using water injection dredging for maintenance activities, planning should include provision for coarsening of the bed sediments at the site over time, as this can be a consequence of the use of the technique (ultimately a trailing suction hopper dredger might need to be employed periodically to remove the coarse lag sediments; see Clause **7**).

Those involved in designing and planning maintenance dredging should bear in mind that at certain sites such as quays and jetties it might be possible and advantageous to position dredging plant on land.

Where dredging close to structures, dredging methodologies should clearly set out how removal of material close to the structure is to be achieved, without damage being inflicted on the structure. The regime for monitoring the integrity of the structure should also be agreed and set out.

*NOTE A guide to the selection of plant for particular types of maintenance dredging activity is given in Clause **7** and Table 10.*

8.6 Frequency of maintenance dredging

A maintenance dredging strategy should be developed taking into account the practical constraints on navigation, dredging equipment, efficiency, availability, weather, operational and environmental windows, to determine the economic and environmentally preferred, or otherwise optimal, dredging method and frequency.

The frequency of a maintenance dredging programme should be assessed taking into account:

- the rate of sediment accumulation in the areas to be dredged;
- the operational requirements of the waterway (i.e. shipping for a navigation channel, flow rates for a river channel).

The optimum timing of dredging (e.g. with respect to seasonal and tidal variations) should be assessed, as dredging might not be possible or permitted (via licences) under certain conditions, while its efficiency and benefit (with respect to retention of materials in the sediment transport system) might be increased under others. Numerical modelling should be used to inform such assessments for projects of an appropriate scale.

8.7 Soil density and maintenance dredging

*COMMENTARY ON **8.7***

Some waterway bed sediments are of a semi-fluid nature, consisting of very fine particles in a dense solution (referred to as fluid mud). Where such materials have been shown to exist consistently and have been extensively investigated in terms of their characteristics, ports sometimes operate a policy whereby vessels knowingly navigate through such fluid muds. Operation of such a system is sometimes referred to as the "nautical bottom approach". The density of fluid mud deposits is at a minimum at the upper surface and increases with depth. In these situations, the position of the bed is difficult to define and therefore difficult to measure. Determination of water depth purely on the basis of the record produced by a high frequency echosounder (e.g. 200 kHz or higher) can occasionally result in dredging being carried out at intervals that are shorter than is strictly necessary to preserve safe and proper navigation depths.

Fluid mud is particularly likely during and immediately after dredging in some environments. The materials can then consolidate and/or be subject to transport beyond the dredging location.

The existence of fluid mud does not necessarily mean that the material is safe to navigate through. The density of fluid mud is often used operationally (measured) to provide a guide to its navigability (or otherwise). However, the relationship between navigability and density varies between ports, demonstrating that it is not simply density which governs navigability. The rheological properties of fluid mud are important to navigability, as are the characteristics and operation of the vessels making passage.

For the adoption of the nautical bottom approach, the density and rheological properties of fluid mud at the bed of a waterway should be established, with due attention being paid to the way in which these properties vary spatially and temporally (particularly tidally and seasonally) and the way in which the properties are measured (rheology can be altered by sediment sampling and transport).

Specialist advice should be sought with respect to the collection and interpretation of rheology and density data in terms of vessel navigability/manoeuvrability, bearing in mind that once data analysis and interpretation has been undertaken it might be decided that a full scale trial is needed using an agreed vessel. Following conclusion of the investigation, if it is decided to use a nautical depth approach then fluid mud density and/or rheology measurements should be used operationally in order to inform the need for maintenance dredging. The optimum method of dredging in relation to the allowable draught should be established through assessment and experience built up at the site. The likely efficiency of water injection dredging should be assessed; at some sites this is used to reduce the density of fluid mud and enhance its navigability and propensity for transport.

8.8 Alternative and supplementary strategies

*COMMENTARY ON **8.8***

Hard engineering structures such as training walls and current deflecting walls are sometimes used in order to try to reduce maintenance dredging requirements.

The use of training walls for this purpose is now relatively rare in the UK and many other locations due to factors such as cost, performance of the structures and unintended side effects arising from rigid structures.

Sediment traps are sometimes included in the design of dredged areas to increase the interval between maintenance dredges. The purpose of a sediment trap is to accommodate infill material that would otherwise have accumulated in a navigation or berth area. The use of sediment traps does not negate the need for maintenance dredging altogether, as the traps themselves require dredging in order to remain functional. As traps fill and become less efficient, the infill rate of the navigation area/berth can be expected to increase.

Specialist advice should be sought if alternative and supplementary measures to maintenance dredging are being considered. The design of any alternative or supplementary strategy should be subject to detailed study prior to its implementation and can include numerical modelling. These studies should focus not only on the effectiveness, cost and potential benefits but also on the potential for negative impacts on the surrounding environment and infrastructure.

8.9 Disposal of material

The disposal of dredged materials should be undertaken in accordance with Clause **12**.

9 Capital dredging

*COMMENTARY ON CLAUSE **9***

Capital dredging occurs where an area is dredged for the first time or to a greater depth than previously dredged.

9.1 General

The project site should be characterized by the investigation methods in Clause **6** relating to:

- site bathymetry;
- soil conditions;
- metocean and sea conditions;
- environmental surveys.

The dredging scheme should be designed to meet the respective performance criteria in Clause **4.4** and the environmental design criteria in Clause **5**.

9.2 Capital dredging plant

*COMMENTARY ON **9.2***

In many cases, capital dredging involves dredging a range of different materials. The unpredictability can be reduced by a good quality soils investigation. The requirements of the work can also be very varied. Consequently, versatility can be important, in respect of both the ability to tackle a wide range of ground conditions and the ability to work in a variety of ways, e.g. employing varying methods of spoil disposal.

*A guide to the selection of plant is given in Clause **7** and more specifically the plant commonly employed is given in Table 12.*

Generally, plant to be employed upon capital works should be of more rugged construction and greater power than plant of the same type designed specifically for maintenance work, as the material is undisturbed with consequently stronger in-situ strengths and higher densities.

9.3 Debris

Areas that are likely to contain appreciable quantities of debris, such as at fitting-out, scrap and river berths, can be difficult to dredge with trailing suction-type dredgers or cutter suction dredgers, and should be fully evaluated so that the area can be cleared before capital dredging, by suitable equipment such as grab or backhoe dredgers or cleared by means of a bottom rake or plough (see **7.3.6**).

NOTE Attention is drawn to the legal requirements in connection with the disposal of debris.

9.4 Particular geotechnical conditions

9.4.1 General

The soil conditions illustrated in Table 11 to Table 13 can all affect capital dredging works and should be taken into account during design, plant selection and operations, as described in **9.4.2** to **9.4.6**.

9.4.2 Clays

NOTE 1 Certain clays of high plasticity adhere to the buckets of any bucket-type dredger. As a result, the material can be difficult to discharge from the bucket and subsequently can be difficult to discharge from the hopper into which it is loaded. Special jetting facilities might be required to assist the release of dredged clays.

When the presence of highly plastic clays is suspected, hoppers should be employed that have a regular internal construction with an unobstructed opening for spoil placement to allow rapid discharge.

The appropriate plant should be selected for dredging the clays at the dredging location (Clause **7** and Table 11 to Table 13).

NOTE 2 Selection of the incorrect plant can lead to production being substantially reduced in areas of stiff and hard clays and where boulders are present.

9.4.3 Peat

Special measures should be applied as necessary when dredging peat due to its low density, possible gas content and tendency to swell rapidly upon the removal of any overburden.

If pumped onshore, the containment areas should have sufficient excess capacity to cope with the high bulking that commonly occurs.

Suction methods should be avoided if possible.

NOTE When loaded into hoppers by pumping, the maximum load is governed by the concentration of the peat in the incoming mixture. No increase in hopper load is achieved by continued pumping after the hopper is filled with mixture.

9.4.4 Flints

The selection of plant should account for the highly abrasive nature of flint that can cause exceptional wear rates in pumps and pipelines, especially where high concentrations of flint cobbles or nodules are found, often on the surface of weathered chalk deposits.

NOTE Dredging might be most economical using a bucket-type dredger.

9.4.5 Vegetation

Appropriate provision should be made in areas of heavy vegetation, such as seaweed, reeds, rushes, mangrove, etc., which can cause serious problems for suction-type dredgers.

Care should be taken to avoid vegetation causing pump blockage and engine overheating on blockage of the cooling system of the dredgers or other craft on the site.

NOTE Where high concentrations of weed are known to occur, it might be preferable to employ bucket-type dredgers or to employ separate plant to clear the weed in advance of dredging.

9.4.6 Dredging of cobbles and boulders

*COMMENTARY ON **9.4.6***

Cobbles and boulders do not usually occur in large volumes on their own. When they do, appropriate plant can be selected. However, they are commonly found in glaciated or volcanic regions, usually as a constituent of glacial tills or agglomerates, in which identification of the boulders can be extremely difficult. It is as a constituent of these materials that they pose the greatest problem in dredging.

The most effective dredgers for dredging cobbles and boulders are those that would be used for fragmented rock, generally the mechanical bucket-type dredgers, but the material in which the cobbles and boulders lie, usually complex clay, sand and gravel beds, might be best dredged by a suction, cutter suction or trailing dredger, which is not suitable for cobbles and boulders.

Therefore, material containing cobbles and boulders can either be dredged as a composite mass at low output by a mechanical dredger, which is only slightly dependent on boulder percentage, or be dredged by suction, cutter suction or possibly trailing dredger giving a high output. In the latter case, the high output can fall sharply with an increasing boulder percentage and with the further risk that large boulders cannot be dredged.

When the production of suction, cutter suction or trailing dredgers is reduced by the presence of boulders the method should be adjusted, and if necessary the equipment modified if reasonable production rates are required.

NOTE Boulders that have been left behind by a suction dredger, or that have been pushed to one side by a mechanical dredger, might still have to be removed. This can usually be achieved with a grab dredger, although there might be instances when the boulders are so large that some alternative has to be found. The following methods have been used successfully:

- *blasting, followed by grab dredging;*
- *dredging alongside the boulder to make a pit into which the boulder falls, below the dredge level (this can create problems for any future dredging work);*
- *trawling the boulders with wire nets from a specially adapted fishing boat (unlikely to be successful except in ideal conditions).*

9.5 Dredging of naturally well-graded sands

*COMMENTARY ON **9.5***

On some sites it is found that natural grading of sand has occurred in such a way that the material packs together tightly with smaller particles filling most of the interstices between the bigger particles. The resulting sand in its natural state has a great resistance to penetration and, even when removed from the seabed and placed in a hopper, can reform into a compact mass, which can be difficult to discharge.

Such materials can also prove difficult to discharge from hoppers. In hoppers with chain-operated bottom doors, the sand can consolidate around the chains to such an extent that upon release of the chain tension the doors remain closed.

Alternatively, "arching" within the sand mass can resist discharge, even though the bottom doors are open or, in the case of split hoppers, the hull is partially split.

Dredgers that exert a positive thrust in their digging action should be adopted, to achieve satisfactory outputs in naturally well-graded sands.

10 Rock dredging

*COMMENTARY ON CLAUSE **10***

The dredging of rock often requires extensive pre-treatment, most commonly by drilling and blasting, adding further activities that are difficult to exercise in marine conditions even with modern custom-built plant and equipment. As a result rock dredging is the most expensive type of dredging carried out in normal maritime and fluvial engineering. In this context, rock is considered both as a solid rock mass, and also as an extensive mass of material cemented together in a matrix.

The ease, or otherwise, with which rock can be dredged is dependent on the rock strength and rock quality. Rock comprising pieces of high strength is easily dredged if the rock mass is highly fractured and fractures are open. Rock with few or very tight fractures can only be dredged directly if of low strength. The limiting strength, most commonly described by the compressive strength (UCS), is dependent on the type, size and power of the dredger to be employed. For very large and powerful cutter suction dredgers, the upper limit for direct dredging of good quality rock is typically taken as about 70 MPa, but with a low production rate.

10.1 General

Site investigations should be carried out within the areas to be dredged to determine whether rock is present in any quantity, however small. For example, agglomerated and cemented sands should be treated as rocks, while boulders need not. The dredging of cobbles and boulders should be carried out in accordance with **9.4.6**.

It should be determined whether any rock found can be dredged directly without pre-treatment, or whether pre-treatment is necessary, and if so to what degree. Rock that cannot be dredged directly should be pre-treated to facilitate dredging, usually by drilling and blasting.

NOTE Pre-treating of rock greatly increases the complexity and time taken to execute a project, as non-explosive methods are slow and laborious, and explosive methods require special safety measures, licences and additional specialist plant.

10.2 Direct dredging

Dredgers for the removal of rock that has not been pre-treated should be selected for their ability to penetrate and break up the rock during the excavation process (see Table 11).

The classification of soil and rock for dredging should be in accordance with PIANC Report No. 144 [N1]. Soil descriptions should be in accordance with BS 5930:2015.

10.3 Plant for rock dredging

*COMMENTARY ON **10.3***

*Direct rock dredging is possible only with very rugged and powerful dredgers. Some rock can be dredged directly; others can require pre-treatment (see **10.5**).*

*Rock that can be dredged without pre-treatment can best be dredged by large cutter suction dredgers (see **7.2.3**), dipper dredgers (see **7.3.5**), backhoe dredgers (see **7.3.3**) or bucket chain dredgers (see **7.3.4**). Very large grab pontoon dredgers (see **7.3.2**) can occasionally be used. Guidance on the ease with which rock can be dredged is given in PIANC Report No. 144 [N1].*

*If the area of dredging is continuously exposed to moderate or heavy wave attack, the use of stationary dredgers other than grab dredgers can be impractical. A large trailing suction hopper dredger (see **7.2.1**) fitted with rippers in the draghead can be used in some circumstances if the rock is very weak (<5 MPa) and weathered (RQD <70%).*

Most rocks that can be dredged directly are sedimentary rocks and corals. Generally igneous or metamorphic rocks can be made suitable for dredging by pre-treatment. However, the in-situ state of the rock has a profound influence on the ease with which it can be dredged.

10.3.1 Rock characteristics

The following rock characteristics should be taken into account.

a) Thickness of rock layer. Thin layers or lenses of rock, even if moderately strong, might be dredgeable if the dredger can get under the lower surface to break up the mass.

b) Weathering. The degree of weathering affects rock strength. Highly weathered rock often becomes quite friable and relatively easy to excavate. Weathered layers might be dredgeable, but other layers might not (see PIANC Report No. 144 [N1]).

c) Jointing and fracture planes. The natural jointing and discontinuity of a rock, described as rock quality, are highly significant when determining the ease with which the rock can be dredged. The spacing, orientation, continuity, tightness and surface texture of fracture planes also have an effect. These parameters are assessed by rock quality designation (RQD) and total core recovery (TCR).

d) Rock strength. Rock strength is usually expressed by reference to the uniaxial compressive strength of the rock. The point load index tests (see *The point load strength test* [15] and ASTM D5731) are also used as parameters for assessing rock strength with regard to the ease with which the rock can be dredged

10.3.2 Limiting factors

The following limiting factors should be taken into account when planning rock dredging operations.

a) Sea state. The exposure of the dredging site due to the effects of weather and sea action is of great importance when selecting plant for the dredging of rock. In exposed locations the effect of swell on the hull of the dredger can cause the vessel to rise and fall and thereby give rise to excessive forces on the excavating head or anchoring system of the dredger. This can cause damage and loss of production, which is more severe when dredging rock than when dredging weak materials.

b) Water depth. Dredging depth is limited by the dredger's operational draught and the maximum downreach. The backhoe is more susceptible to limitation in deep water, due to the twisting forces imposed on the boom during the digging part of the dredging cycle and reducing tear out force with depth.

c) Excavation face height. Most dredgers benefit from having a moderate depth of material to excavate. However, thicker cuts can be more difficult to excavate by backhoe and dipper because these machines operate best by breaking off slabs of rock and thinner slabs are easier to break. Bucket and cutter suction dredgers chip away smaller fragments of rock and benefit from a good depth of cut. Bucket dredgers can remove up to 2 m thickness of material but the optimum depth of cut is very dependent on the nature of material.

*NOTE The above factors are directly related to dredging rock. More general limiting factors for dredgers are set out in Clause **7**.*

10.3.3 Dredger characteristics for dredging rock

For a preliminary assessment of suitable dredger characteristics for dredging rock, the factors listed in Table 14 should be taken into account.

Table 14 **Characteristics of dredgers able to dredge some rocks without pre-treatment**

Dredger type	Fragmentation/excavation	Type of rock dredged
Cutter suction	Rock is chipped away by cutter teeth. Production is relatively high.	Strong sedimentary rocks, sandstone, siltstone, mudstone, chalk and marl, corals and moderately strong limestone and igneous rock
Bucket chain	High point loads on bucket teeth, continuous process. Tendency to break out slabs of rock in certain conditions of bedding. Alternate buckets can be replaced by ripper teeth.	Most sedimentary rocks up to moderately strong
Dipper	Very high point loads on teeth. Rock is levered out, which can result in large slab formation in certain types of bedding.	Thin lenses of sedimentary rocks and weakly cemented conglomerates. Massive chalks, marls, weak sandstone, corals and volcanic tuffs
Hydraulic backhoe	Positive bucket action with strong leverage through bucket "crowding". Tear out falls off sharply with increasing depth. Method tends to produce large slabs in certain bedding conditions.	Moderately weak sandstones and shales at shallow depths. Weak sandstones, corals and conglomerates at greater depth
Trailing suction hopper dredger	Heavily constructed vessels with high propulsion power can be employed with ripper teeth in the draghead.	Chalk, weak sandstone, breccia, conglomerates, very weak limestone
Grab pontoon	Very heavy bucket of reduced capacity necessary to achieve initial tooth penetration. Very variable and often unpredictable results. Low production.	Very weak sedimentary rocks and corals

NOTE For fragmentation and bulking recommendations, see Table 15.

10.4 Dredging pre-treated rock

The degree of rock pre-treatment required to enable dredgers to excavate should be determined according to the type, power and size of the dredger and the form and strength of the rock.

When determining the ease of dredging pre-treated rock, the following factors should be taken into account.

a) Fragmentation. This varies considerably in broken rock. The maximum size of dredgeable rock is usually controlled by the dimensions and power of the machine, so it is important that most of the rock is below a specified size. Production rates might be governed by the size of the largest rocks rather than the median.

   It is prudent to have plant available to dredge the oversize fragments or to break down to within the acceptable size range. Whether or not it is necessary to provide additional plant depends on the size of the project.

b) Bulking. This is important as it results in a looser rock mass that is more easily penetrated by the cutting action of the dredger. Higher bulking results from increased explosive charge size.

NOTE Table 15 provides guidance on the relative importance of fragmentation and bulking required for the various dredgers.

Table 15 **Optimum fragmentation and bulking of rock normally required to allow satisfactory dredging**

Dredger type	Optimum fragmentation (diameter refers to D_{95})	Bulking required %
Cutter suction, 1 200 mm suction pipe	Up to 300 mm. The smaller the better for pumping. Large pieces are unacceptable	10 to 15
Bucket 650 L rock buckets	Up to 300 mm. Some larger pieces are acceptable if not too large to pass through the well	10 to 20
Dipper 5 m^3 bucket	Up to 800 mm. Larger pieces can be raised depending upon bucket size and power available	10 to 20
Backhoe 5 m^3 rock bucket	Up to 500 mm. Larger pieces in isolation are acceptable depending on bucket size and power available	10 to 20
Grab pontoon 5 m^3 rock bucket	Up to 300 mm with occasional larger pieces	20 to 30
Trailing suction, 800 mm suction pipe	Less than 100 mm. Any significant occurrence of larger pieces is liable to block draghead.	25 to 40

NOTE 1 The table refers to pre-treatment by drilling and blasting.

NOTE 2 Bulking means increase in rock volume (or heave) from voids resulting from the explosion.

NOTE 3 Suction and bucket sizes under "Dredger type" are not absolute limits, but operation with smaller sizes can be difficult.

10.5 Pre-treatment

Pre-treatment of rock prior to dredging should be carried out for most igneous and metamorphic rocks and also for strong sedimentary rocks. The necessity for pre-treatment should be determined according to:

a) the rock state and the type of dredger to be used;

b) the quantity to be dredged;

c) restrictions on blasting and noise levels.

When dredging small quantities the option to pre-treat and dredge with a smaller, more easily mobilized dredger should be balanced against the option of bringing in a larger dredger that could dredge without pre-treatment.

A suitable method of pre-treatment should be selected, of which the following are typical examples.

1) Percussion, chiselling, or rock breaking by percussive methods is one of the oldest forms of pre-treatment. In its simplest form a heavy needle or chisel, weighing from 5 t to 30 t, is dropped vertically onto the rock. This method is slow.

2) Power driven rock breakers fitted with pneumatic or hydraulic rock hammers, which drive a chisel into the formation, are more productive. These can be attached to the dipper arm of large backhoe dredgers.

3) Rock ripping can be carried out by modifying the equipment on a dredger to take one or more ripper teeth in place of, or attached to, the standard excavating unit. Examples of this are the single teeth that can be fitted in place of the bucket(s) on hydraulic backhoe or bucket dredgers and the rows of teeth that can be attached to the draghead of trailing suction hopper dredgers. Pre-treatment by rock ripping is usually slow. For backhoe dredgers, production deteriorates sharply with increasing water depth.

4) Rock splitting is conducted by drilling closely spaced holes in a continuous line to provide an accurate cut face, usually enhanced by explosives or expanding agents. Rock splitting is slow, with a low production rate, and should be adopted only for the removal of small volumes.

5) Surface blasting relies on explosives charges laid on the rock surface, often with limited results.

6) Drilling and blasting is usually conducted with holes drilled into the rock, charged and blasted to fragment the rock.

Pre-treatment methods in items 1) to 3) or similar should be applied in cases where the use of explosives is not permitted or the volume to be pre-treated is small. Power-driven rock breakers should be used for higher production rates. The methods in items 5) and 6) are more common, and are addressed in more detail in **10.6** and **10.7**. The pre-treatment method should be selected according to the volume and thickness of rock and the fragmentation and bulking required to enable the dredger to excavate the material.

Drilling and blasting is the most widely used method of pre-treatment and should normally be adopted for bulk rock excavation, where permitted, as the method is effective and can achieve a high production rate.

The recommendations in BS 5607 should be followed when explosives are to be used.

The charge load, spacing and drill pattern should suit the rock type and degree of fragmentation required.

10.6 Surface blasting

*COMMENTARY ON **10.6***

Pre-treatment of rock underwater can be achieved in a limited number of cases by contact or surface blasting. In surface blasting, explosive charges are laid in contact with the rock surface and the charges are detonated in such a manner that the explosive shock wave travels towards the rock face. The efficiency of this method depends on the water depth and the intimacy of the contact between the charge and the rock. It can only be used where rock is exposed or where overburden can be cleared before the charges are positioned. The effect is improved by increased water depth since the additional water pressure serves to confine the blast.

Since surface charges release energy in every direction, a considerable proportion is lost to the surrounding water causing a high waterborne shock wave and, in shallow water, a waterspout and an airborne shock wave.

Surface blasting can be effective for fragmenting boulders, weak sedimentary rocks and thin layers of rock and cemented soil, particularly when overlying weak material.

Charges require to be accurately positioned by means of specially constructed spacer frames or mattresses and to be weighted or fixed in areas of surf or strong currents to prevent movement.

A special type of surface charge is available in the form of the shaped charge. The shaped charge utilizes the Munroe effect, which concentrates the shockwave into a localized jet and thereby improves its ability to achieve penetration into the rock. It is used in the same manner as a surface charge.

In general, surface blasting gives poor fragmentation and little or no bulking of the rock. Secondary blasting is frequently required to achieve satisfactory results. However, it is sometimes advantageous for very small volumes of rock, particularly in remote areas where the mobilization of drilling equipment might not be justified.

All pre-treatment methods which employ the use of explosives are very costly. These are complicated by the necessity for stringent safety measures, compliance with regulations and protection of the environment and nearby structures.

For satisfactory production, surface blasting should only be adopted for thin layers of rock and where the equipment for higher production cannot be made available economically and in the required timescale.

10.7 Drilling and blasting

*COMMENTARY ON **10.7***

Drilling and blasting consists essentially of drilling holes in the rock to a regular, predetermined pattern and depth, charging them with explosives and detonating a group of charges, either instantaneously or separated by millisecond delay intervals. The drill holes are usually vertical, but angled drilling can be successfully employed in special circumstances.

Drilling is usually carried out from a floating or elevated pontoon, but for very small or otherwise inaccessible areas it can be performed by divers. The drilling pattern is primarily controlled by the amount of explosive required to give the desired fragmentation of the rock and the diameter of the holes drilled.

A typical drilling pontoon and a typical drilling platform are shown in Figure 14 and Figure 15 respectively.

10.7.1 Drilling patterns

Subject to the degree of fragmentation to be achieved and the characteristics of the drilling barge employed, drilling patterns should be such that the burden and spacing are similar, and holes should be drilled beneath the design level by an amount equal to the greater of the burden or the spacing. The extent of over-drilling should be sufficient to ensure that full fragmentation occurs to the design dredge level.

NOTE The pattern itself can be rectangular or triangular, depending on how the pontoon and drills are moved (see Figure 16). A triangular pattern is likely to give more consistent fragmentation since the maximum distance that the rock can be from any blast hole is reduced for any pattern area. However, rectangular patterns are often used because they are easier to execute and might be more appropriate for specific purposes, such as pre-treatment for trenches. Common drilling patterns and illustration of the terminology used are shown in Figure 16.

10.7.2 Extent of drilling and blasting

Drilling and blasting should extend to a point outside the rock dredging area (see Figure 17).

NOTE The necessity to blast outside the periphery of the delineated rock dredging area depends on the behaviour of the rock during blasting. It is possible for rock adjoining the blasted area to be cracked and to heave by bulking so that the rock surface moves upwards.

10.7.3 Depth of rock

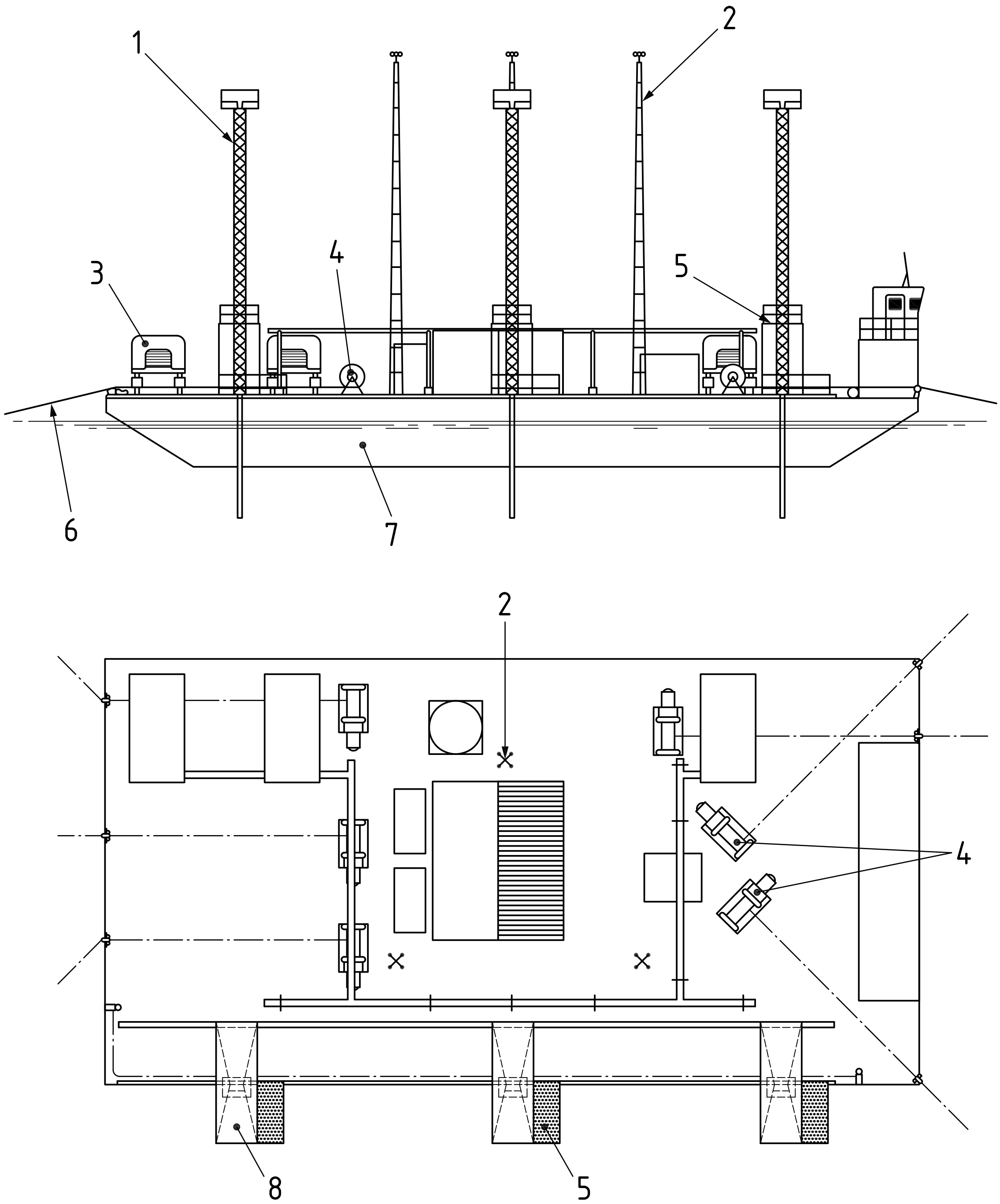
The site conditions should be assessed to determine the depth of rock that can be blasted in one cut. As rock thickness increases, particular care should be taken with respect to control of deviation from vertical drilling.

NOTE 1 Excessive deviation from the vertical affects the burden and spacing of the charges and thus the fragmentation. It can also cause sympathetic detonation between holes.

NOTE 2 Very small thicknesses of rock require the same overdrilling and charging as large thicknesses.

NOTE 3 The sequence of overburden drilling is shown in Figure 18.

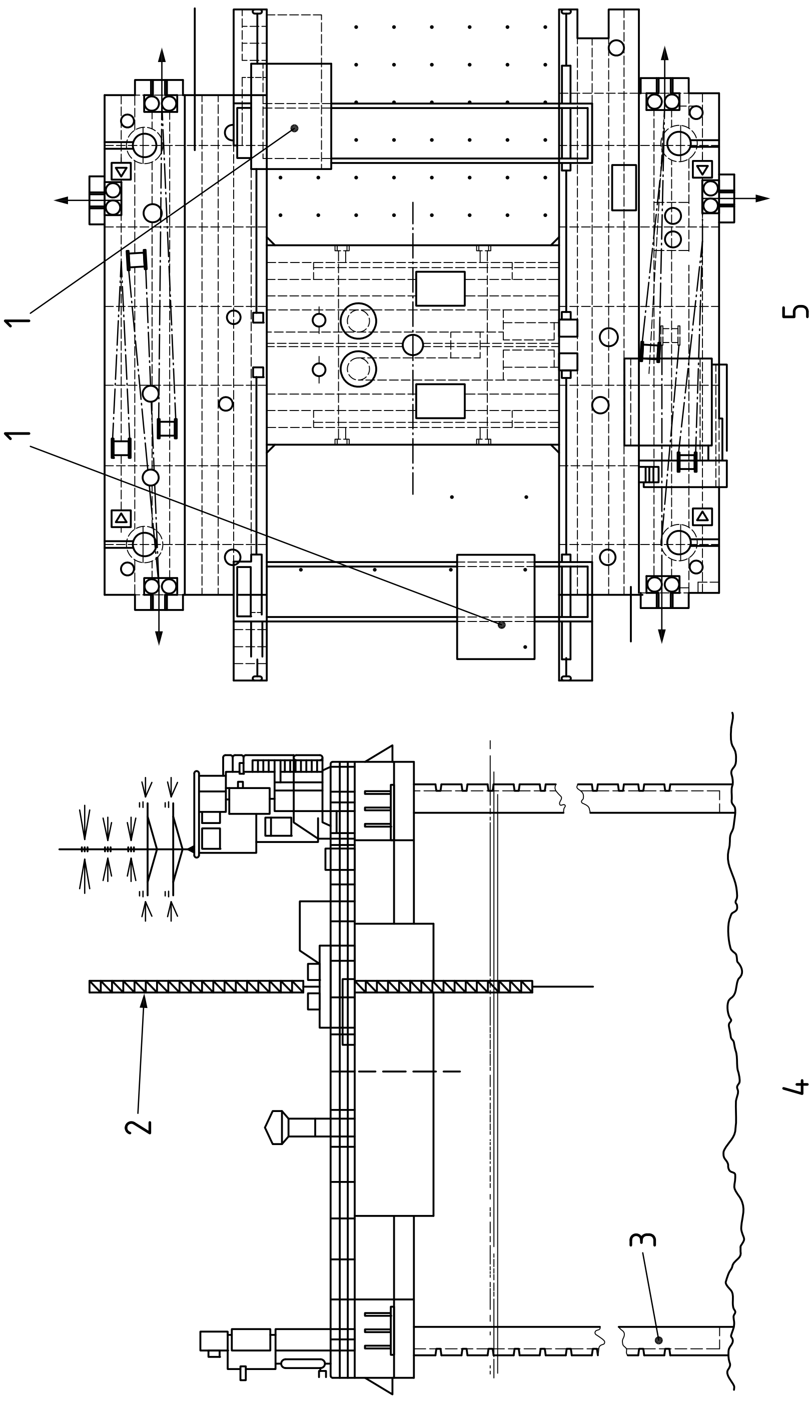
Figure 14 **Typical over-side three-tower floating drilling pontoon with winch location**



Key

1	Drill towers	5	Operator platform
2	Light masts	6	Mooring wires to anchors
3	Power units	7	Pontoon
4	Mooring winches	8	Drill tower unit

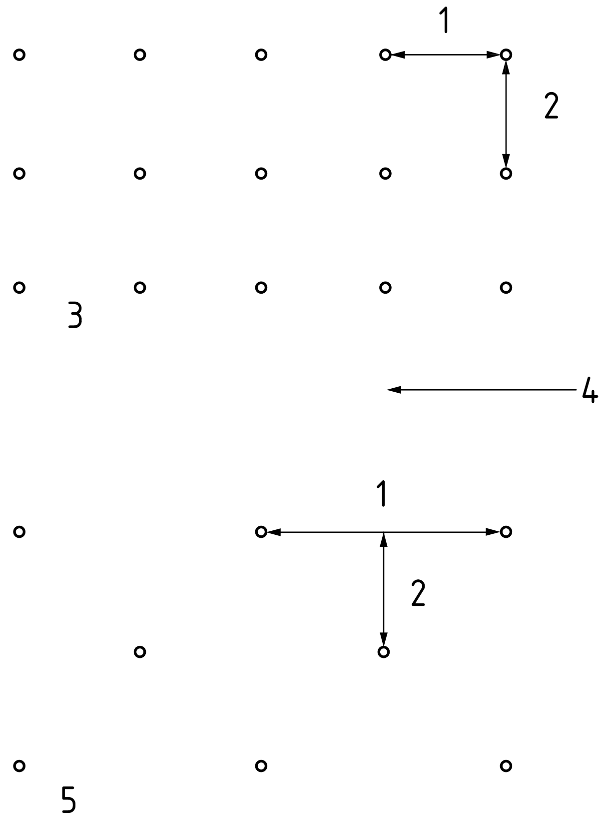
Figure 15 **Self elevating H configuration drilling platform**



Key

1 Moving tower carriage
2 Drill tower
3 Jack-up legs
4 Seabed
5 "H" pontoon structure

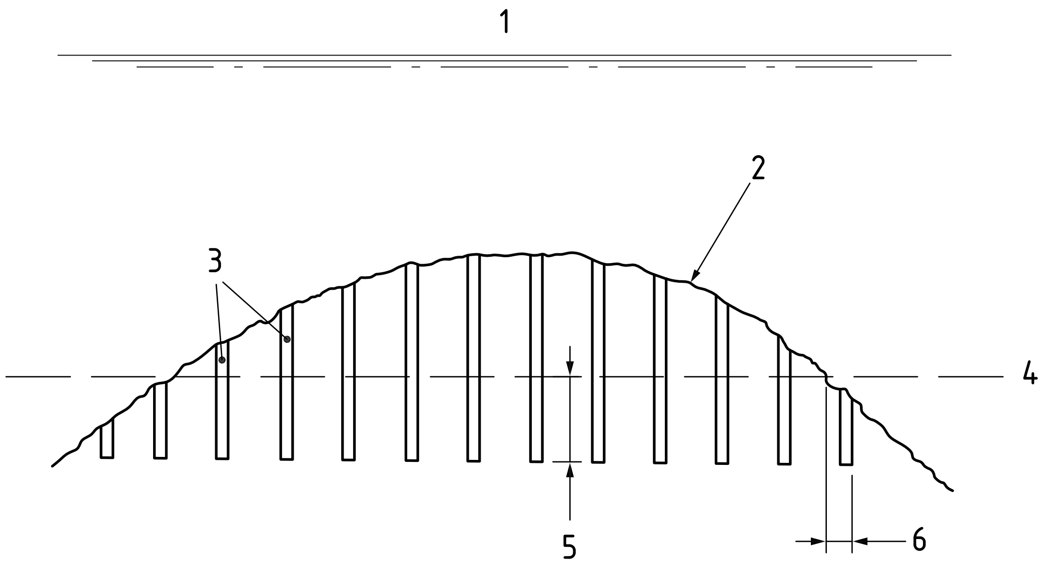
Figure 16 **Common pre-treatment drilling patterns and terminology**



Key

1 Spacing
2 Burden
3 Rectangular
4 Direction of movement of pontoon or bridge unit carrying drills
5 Triangular

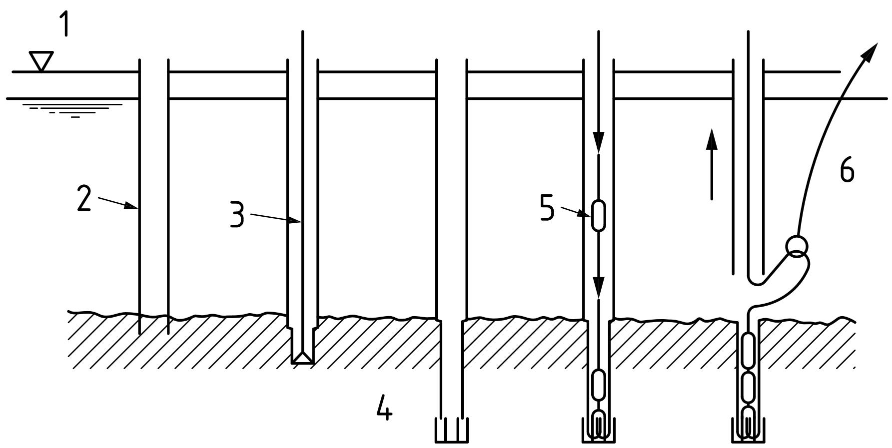
Figure 17 **Example of the need to extend drilling and pre-treatment beyond the depth and extent of required dredging**



Key

1 Water level
2 Rock outcrop
3 Drill holes
4 Design level
5 Overdrill
6 Marginal drifting

Figure 18 **Illustration of sequence of the overburden drilling method**



Key

1 Deck level
2 Outer casing
3 Inner drill string
4 Drilling completed
5 Explosive charges
6 Retrieving fuse

10.7.4 Drilling systems

Drilling for underwater blasting should be carried out using one of the following methods, choosing the most appropriate method according to the site conditions.

a) *Sea surface operations.* Drilling operations from the sea surface are carried out from floating or elevated pontoons. In shallow water areas, land-based equipment can be used from a temporary working surface formed by filling the area with material to a level just above high water.

b) *Underwater systems.* Divers are able to operate hand drills underwater. However, difficulty can be experienced in positioning and penetration rates are low. In addition, the site has to have little or no overburden.

   Provided that they can be positioned, crawler rigs are more efficient than divers with hand drills. Their disadvantage is that the seabed has to be reasonably flat and this is seldom true of a virgin rock outcrop. The seabed might therefore require some levelling before a crawler rig can be used.

   All underwater diver-controlled systems are adversely affected by heavy swell, strong currents and high turbidity, which all conspire to lower the output and to make accurate positioning more difficult.

10.8 Explosives and initiating systems

10.8.1 Explosives

For underwater use, explosives should be of the high strength gelatinous or slurry type. For efficiency and safety, the explosive should be sufficiently water-resistant to remain underwater for up to 24 h without being unduly affected by the water.

NOTE 1 It is expected that after immersion for a long period, the explosives are rendered inert.

The explosive should be chosen to be compatible with the method of initiation selected.

NOTE 2 Explosives with high velocities of detonation (VODs) are usually preferred as they give good fracturing in strong rock.

NOTE 3 Some explosives have two VODs; one high and another lower. High water pressure affects ease of detonation and can cause the explosive to detonate at its lower velocity. In such circumstances boosters might need to be inserted in the detonating system to overcome the problem.

A detonating explosive charge is capable of detonating another explosive charge placed in near proximity to it. This is called sympathetic detonation and depends on the sensitivity of the explosive, the separation distance and the medium(s) through which the explosive shock wave is transmitted. This effect should be avoided because of the uncontrolled detonation of charged boreholes that can result, perhaps causing misfires or leading to excessive vibration when delayed detonation has been planned in order to limit vibration.

Manufacturers of explosives should be consulted when selecting explosives and detonating systems.

10.8.2 Initiating systems

A suitable initiating system should be chosen, of which the two main types are detonating cords and long lead electrical detonators.

When using detonating cord, it should pass through all of the cartridges being used in a particular borehole. The cords from each borehole should be connected together at the surface. Care should be taken that cords do not cross, as a cord can be severed before it has propagated the detonation.

NOTE A preferred method is the use of long lead electrical detonators which minimize the risk of boreholes not detonating and, when short delay detonators are used, enable vibration to be controlled.

There are various types of electrical detonation systems, and manufacturers of explosives and accessories should be consulted to determine the best system to suit a particular site and proposed blasting pattern.

11 Dredging of materials for reuse

11.1 Marine borrow area development

*COMMENTARY ON **11.1***

The area where materials are dredged for subsequent use is known as a marine borrow area.

The following parameters should be determined for dredging operations relating to marine borrow areas for reclamation with dredged hydraulic fill:

- borrow area and location;
- geotechnical and geophysical data and investigation;
- soil conditions;
- fill characteristics;
- availability of suitable reclamation material;
- quality and testing of fill material;
- disposal of excess materials.

NOTE Requirements for such operations are given in prEN 16907-6.

11.2 Extraction of materials for aggregates

The quantity of suitable material to be removed from the borrow area should be sufficient to ensure efficient extraction and of a quality such that the minimum of post-processing is required to produce acceptable clean aggregate materials for the construction industry or other relevant use.

The available quantity of suitable material that can be extracted from a borrow area should be estimated taking into account:

- layer thickness;
- extent and geometry of the area;
- requirement for post-dredge processing and washing.

The gross volume of available material should be calculated as the area multiplied by the layer thickness, or by using ground modelling. Corrections for bulking and losses should be taken into account.

NOTE 1 The following aspects can reduce the extractable quantity of material:

- *water depth too shallow/too deep for dredging plant;*
- *the presence of an unsuitable overburden layer;*
- *build-up of a layer of fines in the borrow area resulting from extraction methods. This layer of fines can disturb the extraction of the underlying layers.*

NOTE 2 If the suitable material occurs as layers or lenses within unsuitable material, selective dredging is required. This results in a reduction in the recovery rate of suitable material with an adverse impact on production and cost.

NOTE 3 If the borrow area contains a significant amount of boulders, a situation can occur where only the finer fraction is retrieved from the borrow area. In this case an accumulation of boulders can take place preventing the extraction of the underlying layers.

The volume of extractable material should take account of the required slopes for stability of the borrow area, which needs to be factored in to the calculation of the available quantity of material.

For major extractions, site investigation should be sufficient to provide a 3D model of the borrow area so that the extraction of suitable materials can be optimized, taking account of the geometry and side slope stability. To maximize the yield, the model should be updated throughout the dredging operation and modified to suit the as-found site conditions.

11.3 Land-sourced borrow and quarry development

*COMMENTARY ON **11.3***

Land-sourced fill can comprise the full range of geotechnical materials including:

- *fines comprising clay and silt;*
- *granular materials: sand, gravel, rocks, and rockfill.*

11.3.1 General

For engineered reclamations and coastal protection works, granular materials should be used to provide better mass fill properties, most particularly strength, and stiffness as far as is practical.

Low fines fill is preferred to provide good engineering mass fill properties. High fines content fill should be adopted where required to meet environmental constraints or where low permeability is required.

NOTE 1 A difficulty arises whenever significant percentages of fines are present, as the natural tendency is for the fines to segregate during placing.

NOTE 2 A well-graded material containing a high percentage of coarse particles is better able to absorb higher percentages of fines without any adverse effect due to the greater voids ratio.

The maximum percentage of fines that is acceptable in materials for land reclamation depends to some extent on the overall grading of the material, and should be carefully assessed to ensure the performance criteria are met.

Land-sourced granular fill should be used on major reclamation projects, if available and where economically viable, with particular application for:

- bulk fill;
- heavy load areas, where a specified bearing capacity is required;
- areas where low settlement is required;
- seawall core.

Land-sourced rockfill should be used on major reclamation projects where suitable for:

- seawall core and revetment construction;
- heavy load areas where high bearing capacity and very low settlement are required;
- reclamation temporary bunds.

11.3.2 Land-based quarries

Land based borrow areas should be located as close as is practicable to the area of filling where land access is available, or to the marine load out point where transhipment is required.

Where possible fill should be sourced from nearby or related projects that have excess spoil.

The selection of the borrow or quarry should take into account the following:

- volume of fill required;
- available materials for land reclamation works;
- volume of suitable fill material;
- volumetric change during dredging and reclamation;
- transport distance;
- re-handling of material;
- disposal of unsuitable materials;
- quality control of the dredged materials.

NOTE 1 The characteristics of the fill material within the borrow area determine the fill properties which in turn control the engineering performance of the fill mass forming the reclamation.

The selection of the borrow area should be based on the analysis of the results of an adequate soil investigation and an assessment of the properties and performance of the resultant reclamation.

This design should further identify the need for and feasibility of ground improvement and the disposal of unsuitable material.

NOTE 2 CIRIA publication C683 [16] gives guidance on the identification and development of borrow and quarries for use in marine and similar works.

12 Disposal, displacement and beneficial use of dredged material

12.1 General

NOTE 1 Further information on this subject can be found in Environmental aspects of dredging *[3].*

Planning and implementation of dredge material disposal, displacement and beneficial use should be undertaken by individuals with sufficient knowledge and experience to ensure that these activities are successfully achieved.

All disposal, displacement and use (including beneficial use) has the potential to be subject to licensing and should be assessed for such.

*NOTE 2 A major use of dredged material is in reclamation, which is covered in more detail in Clause **13** and Clause **14**.*

Material removed for capital or maintenance dredging by mechanical or hydraulic dredging methods is commonly disposed of at licensed disposal sites; however, this sediment should be identified as a potential resource by those responsible for its dredging.

The method of beneficial use/disposal of material arising from dredging should be treated as one of the most important considerations at the design stage of any dredging work. Disposal, dispersion and beneficial use of dredged sediment should be evaluated as part of the planning of the project and should be addressed in the environmental assessment phase. To inform such planning and assessment the sediments to undergo disposal, displacement or beneficial use should be appropriately characterized, as described in Clause **6**.

In any beneficial use or disposal operation, the means by which the dredged material is to be transported to the point of use or disposal should be determined.

In the UK, the Marine Management Organisation (MMO) should be consulted, as the MMO licenses the disposal of dredged material at sea. Additionally, landowner consent is likely to be required in the UK, where the Crown Estate owns almost the entirety of the seabed out to the 12 nautical mile limit.

NOTE 3 Attention is drawn to the waste hierarchy given in the Water Framework Directive [9] applied by MMO, with disposal at sea being a last resort:

- *prevention;*
- *re-use;*
- *recycling;*
- *other recovery;*
- *disposal at sea.*

NOTE 4 Examples of environmental beneficial use include material placement for:

- *feeding intertidal areas in an estuary to maintain their sediment budget;*
- *promoting the growth of saltmarsh and mudflats;*
- *habitat creation;*
- *maintenance of longshore and other sediment processes;*
- *beach renourishment;*
- *coastal protection;*
- *flood defences.*

12.2 Sediment constituents

NOTE 1 More than 90% of the sediment from navigation dredging is relatively uncontaminated, natural, undisturbed sediment, and is considered acceptable for a wide range of uses (see Environmental aspects of dredging *[3]).*

Planning with respect to the disposal, dispersion and beneficial use of dredged sediments should take account of the sediment constituents, not just in terms of physical characteristics such as particle size but also in terms of likely contaminants present, and of meeting the criteria essential for the protection of the environment. The testing (characterization) of the materials in question should be appropriate for the activities planned and the environments where dredging is being undertaken and those which will receive the materials. Planning of contaminant testing should take into account the potential need for both chemical testing and microbial testing.

An iterative approach to characterization of materials to be dredged should be assessed in terms of its potential benefits, e.g. the first chemical analyses in a project may be undertaken on a relatively small number of samples for a comprehensive suite of analytes, with the results of such an investigation being used to inform more detailed investigations on a smaller list of analytes for all samples.

If materials to be dredged are found to be contaminated to such an extent that their use could be unacceptable or have to be restricted then treatment of the sediment should be assessed as an option, to evaluate whether this improves the potential for the materials to be used and whether this is a viable and practical option.

Remediation dredging involves the removal of contaminated sediments with the potential to cause harm, and in such cases the need for specialist control measures (e.g. silt curtains) should be carefully assessed.

*NOTE 2 Disposal options can broadly be divided into three categories: unconfined; confined disposal (**3.10**); and confined disposal facilities (**3.11**). Sometimes semi-confined placement options are also referred to.*

12.3 Beneficial use

Whenever and wherever possible, dredging schemes should seek to adopt a beneficial use strategy for the dredged material. There are often advantages to retaining dredged material within the sediment transport cell from which it was removed rather than permanently removing it from the sediment transport system, and beneficial use schemes of this type should be assessed for viability.

NOTE Examples of beneficial use include:

- *feeding intertidal areas in an estuary to maintain their volume;*
- *promoting the growth of saltmarsh;*
- *maintenance of longshore and other sediment processes;*
- *beach renourishment;*
- *coastal protection;*
- *use of dredged material as a construction aggregate;*
- *flood defences.*

12.4 Disposal at sea

*COMMENTARY ON **12.4***

Disposal at sea is a common practice for material arising from both capital work and maintenance dredging, with the dredged material to be disposed of within a specified licensed area. Such licensed areas are monitored and managed in the UK. In the UK, as in many other parts of the world, disposal at sea is controlled by legislation.

If beneficial use of dredged materials is not a viable option then disposal should be assessed as an option. Familiarity with the licensing process for disposal should be gained at an early stage such that the timescales and requirements (and the consequences of these) are properly understood and addressed. Early steps should include assessment of contaminant levels in the material being considered for disposal (is sampling required) and investigation of where licensed disposal sites presently exist and their status in terms of the amount and type of material they are capable of receiving.

NOTE In some circumstances it might be possible for a new disposal site to be opened (licensed); however, this typically requires substantial investment in terms of characterization of potential locations, and consequently timescales are long and outcomes uncertain.

12.5 Displacement

12.5.1 Side casting

*COMMENTARY ON **12.5.1***

Side casting involves the discharge of dredged material via the dredger bucket or by pumping to an area adjacent to the dredging zone.

*The system can be used in certain maintenance dredging situations (see Clause **8**).*

Side casting is most commonly used for new works when the dredged formation is only temporary, such as in the dredging of a trench for the placing of a pipe or cables. It can also be convenient in these cases to re-dredge the side cast material for use as backfill to the trench.

When dredged material is to be placed by side casting, the placement should be sufficiently remote from the dredged area and on the downdrift side to minimize the risk of re-entry of the side cast material to the dredged area.

For granular materials, deposition should be well outside the limits of the natural side slopes of the dredged area.

NOTE Fine granular materials often disperse widely during settlement through the water column and can easily be re-mobilized from the seabed; thus, as a result of tidal currents and wave action, a significant proportion of the dredged material sometimes has the potential to re-enter the dredged area. Expert design of such works is required to prevent such inefficiencies.

12.5.2 Agitation

*COMMENTARY ON **12.5.2***

Dredging by agitation involves forcing material into suspension by mechanical or hydraulic means in order that it can be transported away by the naturally occurring currents.

The success of agitation methods depends upon the distance and area over which the suspended solids are transported and dispersed. This is dependent on the height to which the bottom sediments are raised in the water column, the fall velocity of the particles, their threshold of motion and the current/wave climate.

The design and potential environmental impact of agitation dredging should be evaluated by a competent person.

12.5.3 Bypassing

When granular sediments are removed by dredging from the coastal sediment transport system, such as in the maintenance of channels that intercept and trap littoral drift, assessment of sediment management options should include the return of the dredged sediment to an area nearby within the downdrift sediment system. Assessment of the potential effects of such activities should be undertaken in advance by a competent person.

NOTE In this way, potentially harmful effects on the downdrift coastline can potentially be avoided or at least reduced. This process is referred to as bypassing.

12.5.4 Onshore/intertidal containment (confinement) areas

*COMMENTARY ON **12.5.4***

*Onshore/intertidal containment (confinement) areas are specifically constructed to contain material which cannot be used (land reclamation is a form of use and is covered in Clause **13**). Drainage of material consisting of fine particles of silt and clay can be a prolonged process, and any areas of land set aside for use as containment area are likely to be rendered unsuitable for development for a significant period if they receive materials of this type.*

12.5.4.1 General

The containment area should be located as close as is practical to the point at which the discharging dredging vessel is moored, ideally in sheltered waters to facilitate discharge.

Routes should be determined for pipelines conveying the dredged slurry to minimize disruption to marine and land-based activities.

The location of containment areas should be selected following detailed assessment by a competent person of potential environmental and social impacts.

The containment area design should ensure that the total capacity is sufficient to accommodate the increase in material volume due to the reduced density of the material and the need for sufficient retained depth of water to capture the sediment during the discharge of the supernatant water.

NOTE Moisture is most readily released when the surface area of the deposit is large relative to its depth.

12.5.4.2 Depth of deposition in containment area

*COMMENTARY ON **12.5.4.2***

For free-draining granular materials it is often not necessary to regulate the depth of deposition. For fine materials, particularly those that contain an appreciable fraction of clay particles, some limit is necessary if drainage and consolidation within a reasonable time are to be achieved.

The optimum depth of deposition varies according to circumstance but, as a general guide, any area that is to be filled in a single process should not exceed a finished infilled depth of 1.5 m. For permanent sites, progressive infilling can be carried out, in which case each intermediate lift of the fill area elevation should be confined to approximately 1 m.

NOTE 1 These depths refer to the thickness of deposit immediately following the effects of rapid dewatering and initial consolidation.

The total containment area capacity should be 10% to 20% greater than the final volume of dredged material that is to be accommodated.

The containment area, layout depth and weir settings should be configured to settle out the suspended soils while discharging suitably clean supernatant water to the environment.

NOTE 2 Such discharges can, in some cases, have sediment concentration and contaminant thresholds applied by regulators.

NOTE 3 Various methods are available for the determination of containment area capacity. Guidance is given in Long term management of confined disposal areas *[17] and* Dredged material confinement facilities as solids liquid separation systems *[18].*

NOTE 4 Fine sediments that are transported into the containment area by pumping release their moisture very slowly and consequently high bulking can persist for relatively long periods, resulting from the increased moisture content. Actual bulking depends upon the particular characteristics of the dredged material. There is a fairly rapid initial settlement of the fine materials and an accompanying progressive appearance of clear water, followed by much slower consolidation of the settled solids.

12.5.4.3 Containment area enclosure

It is usual to contain dredged material onshore within purpose-built retaining embankments. Where practicable, these should be constructed using the material that naturally exists across the site. If the site is overlaid with a reasonable depth of topsoil, this topsoil should be stripped off in advance of any deposition, so that it can be used at the end of the disposal area's life for top dressing.

The overall enclosed area can be subdivided to permit filling on a sequential basis. If this is done, the degree of subdivision should be determined according to the minimum size of enclosed area that is necessary to achieve settlement of all fine materials, or of all materials above a certain specified size that are to be retained within that particular area (the quality of discharge waters which is to be achieved can also be a controlling factor).

The height of the enclosing bunds should be adequate to contain:

a) all the dredged material that is to be retained in the area;

b) an adequate depth of water to allow the deposition of the final material pumped into the area;

c) an additional freeboard against over-topping or breaches resulting from weathering of the top section of the bund.

NOTE 1 In practice, a freeboard of between 300 mm and 500 mm is normally adequate.

NOTE 2 Retention lagoons which are designed to hold, or are capable of holding, more than 25 000 m^3 of water above the natural level of any part of the adjoining land are subject to the control and provisions of the relevant legislation. Attention is drawn to the Reservoirs Act 1975 [19], the Mines and Quarries Act 1954 [20] and the Mines and Quarries (Tips) Act 1969 [21].

12.5.4.4 Containment area drainage

*COMMENTARY ON **12.5.4.4***

Drainage of the supernatant water during the filling process can best be achieved by means of a temporary or permanent weir structure. A common form of temporary construction consists of a steel fabricated weir box, rectangular in plan, with three solid sides and a front constructed to accommodate drop-boards, which allows the level of the weir to be raised as the filling of the containment area progresses.

For permanent overflow structures, large-diameter, precast concrete manhole rings provide a convenient method of achieving both a progressively higher overflow level and a long weir surface within a relatively small, confined area.

The release of moisture from the material subsequent to deposition can be achieved by evaporation, vertical drainage and lateral drainage. Of these three, evaporation is the most important, and hence there is a need to keep the deposit thickness to a minimum. The process of evaporation can be accelerated by increasing the surface area exposed to the atmosphere. This can be done by regular ditching at very close centres creating a corrugated section to the deposits. Owing to the soft nature of the deposits, special equipment is required for this ditching process.

Bottom drainage occurs naturally when the containment area is sited over a granular, free-draining subsoil. Alternatively, some form of bottom drainage can be installed before filling commences. In many cases, however, the permeability of the deposited dredged material is very low, and consequently any drainage system needs to be at very close centres to be effective. Traditional drainage methods, such as clay or tile drains, are unlikely to be effective unless precautions are taken to prevent the ingress of fine material. Such measures can include the use of a synthetic filter membrane.

The design of containment areas should take into account the need for both:

a) drainage of the supernatant water during the initial filling process; and

b) the long-term drainage that has to occur to allow adequate consolidation of the infilled material.

12.5.5 Offshore containment (confinement) areas

*COMMENTARY ON **12.5.5***

Offshore containment (confinement) areas are specifically constructed to contain material which cannot be used to achieve the function of the project and whose nature is such as preclude other methods of disposal.

The general recommendations for confinement areas given in **12.5.4** should be followed, excepting that offshore containment areas are usually formed by dredged pits in the seabed, often taking advantage of worked out borrow areas. Where the free mixing of the deposited sediments is considered undesirable for environmental reasons, a capping layer of uncontaminated suitable material should be provided to contain the material below. The type, form and thickness of the capping layer should be set by a careful evaluation of the site conditions to ensure that containment is effective.

13 Reclamation

*COMMENTARY ON CLAUSE **13***

This clause covers reclamation works including:

- *reclamation with land-sourced materials;*
- *reclamation of edge structures and bunds;*
- *geotextiles in reclamation;*
- *beach and foreshore recharge.*

*The placement of fine materials, such as those arising from maintenance dredging in ports, is dealt with in Clause **12**.*

Reclamation with dredged hydraulic fill is covered in prEN 16907-6. Additional information on reclamation with hydraulic fill is given in the CUR/CIRIA Hydraulic fill manual *[22].*

Land reclamation can require that areas that are permanently submerged or subject to regular tidal inundation be raised to levels that are permanently above sea level, or can require that existing land be raised to a higher level to improve bearing capacity, quality or accessibility.

Dredged fill can also be used for forming embankments and for filling caissons, gravity structures and sheet pile cells.

13.1 Reclamation performance criteria

The fill selected and the method of placing should meet the reclamation performance criteria in Table 8, that primarily relate to stability, settlement, strength and drainage.

In order to determine the rate and amount of settlement that results when strata are loaded by the placing of fill, the characteristics of the in-situ soils to be loaded and of the fill material should be determined.

Normally this should be done through a site investigation and subsequent laboratory testing in order to establish a baseline for the existing soil conditions and to identify if there are any potential contaminants in the sediment.

Fill materials undergo a change of density, resulting in the final placed fill density being greater or, more commonly, less than the in-situ density of the source material, termed the bulking factor. Calculations to determine the rate and extent of foundation settlement subsequent to the placing of fill should therefore be based upon the maximum in-place density of the fill material, where possible determined by laboratory or site testing.

13.2 Site preparation

NOTE Site preparation might be unnecessary if the ground upon which the dredged fill is to be placed is firm and provides a reasonable foundation.

13.2.1 General

Where the existing site is characterized by excessive weak superficial deposits, these should be removed before filling commences, or a method to improve the soil should be employed. (see Clause **14**). The decision on which approach to follow should be influenced by engineering and economic judgements.

Predicting and controlling settlement in the in-situ soil might not be practical, and this should be accommodated in the scheme design.

Removing soils in the preparation of the reclamation area inevitably leaves a layer of soft disturbed soil behind over the formation that should be addressed either practically or by design.

13.2.2 Fill materials

Where practicable, granular fill materials should be used for land reclamation projects, as discussed in Clause **11**.

Occasionally, long-term land reclamation can be carried out using cohesive materials that arise from maintenance dredging (see **4.4.2**). In such cases, the consolidation period for the fill is usually measured in years and the resulting land is only capable of supporting light loads unless the fill is stabilized or modified to reduce the water content. If the use of pumped cohesive soils results in a semi-fluid deposit, the design of the containment enclosure should take account of the initial high loading caused by the hydrostatic pressure exerted by the contained material.

13.2.3 Land-sourced fill materials

*COMMENTARY ON **13.2.3***

The choice of material for use in land reclamation is influenced by the materials that exist locally or that can be obtained within an economic radius of the site.

The optimum material is a well-graded, free-draining sand with particle sizes in the range of 0.10 mm to 0.60 mm. Sand and gravel mixtures are normally also suitable.

Materials that are not well graded consolidate less well.

In many instances limits are placed on the solids content of discharge water. When fill is placed in water without containment bunds, the free escape of draining water normally removes most of the fine particles.

The construction of a reclamation using tipped fills placed using conventional earthmoving plant, with the fill sourced from spoil heaps, quarries or excavations formed for other aspects of a project, should be designed in accordance with BS EN 1997-1:2004+A1 and carried out in accordance with BS 6031.

Cohesive fill >15% fines passing 63 µm sieve should be used with care, as materials that are finer than 63 µm can be subject to excessive losses during handling and placing.

Care should be taken with carbonate sands as these can suffer significant degradation when loaded or mechanically compacted (see PIANC Report No. 144 [N1], Section 5 for intermediate materials).

13.2.4 Volumetric change

*COMMENTARY ON **13.2.4***

Changes in bulk density arise at various stages of the quarrying, handling and placing processes. When the in-situ material in the borrow area is disturbed and broken up by the quarrying process, the bulk volume of the material increases, giving a commensurate increase in the bulk density. Volumetric change can be influenced by several factors and is very dependent on both the characteristics of the material and the nature of the transport and handling processes. The volume increase is particularly marked for rock fill where the drilling and blasting operations significantly increase the volume.

The scheme design should assess the likely change in volume due to bulking.

13.3 Placing of land-sourced fills

The simplest method of placing land-sourced fills is by end tipping from trucks into the water in the reclamation area. Particular care should be taken with end tipping to:

- ensure that the fill slope is sufficiently stable to support the loaded and unloading truck;
- provide sufficient width for truck turn around by-passing and reversing;
- prevent trucks accidentally driving off the reclamation down the tip face;
- control the inclusion of soft in-situ bed materials under the reclamation;
- limit the amount of fines released into the adjacent waters.

The end tip stability should be fully assessed, with an evaluation of the geotechnical conditions of the in-situ soils on which the fill is placed, both for shallow and deep seated slope failures. Where there is a possibility of slope failure, an alternative method of placement should be sought, such as pushing the fill over the tip face by front end loader or bulldozer.

End tipping fill onto a soft or muddy formation both overrides the seabed soils and drives the softer soils seaward. Potential consequences that should be addressed are that:

- the stability of reclamation is reduced by the inclusion of the weaker soils under the formation interface leading to end tip failure;
- the softer soils are pushed ahead as a bow wave build-up and increase in stiffness as they drain, such that the reclamation overtakes and subsumes the bow wave leaving a permanent weakness and source of high settlement within the reclamation.

End tip failures should be avoided wherever possible both on safety and quality grounds. If end tip failure is considered a possibility, appropriate measures should be taken that might include:

- better cleaning of the substrate prior to placing fill;
- inclusion of a strong geotextile or geogrid at the base of the fill to reinforce the interface and to prevent mixing of fill with the foundation soils;
- barge dumping a fill layer blanket over the formation to reduce the end tip height and improve stability;
- using coarse angular rockfill with a high voids ratio to absorb the fines.

NOTE 1 Once the end tip has failed, the resulting soil is a mixture of fill and soft material that can take considerable reworking to achieve the required engineering performance.

Great care should be taken not to allow a substantial bow wave of disturbed mud to form, as once formed treatment is difficult.

Care should also be taken when removing the soft soil bow wave, as the bow wave provides support to the tip face and removal can promote an immediate collapse.

NOTE 2 In rare cases the material under the reclamation can be forced out to well up in front of the tip face, again requiring difficult removal.

The arrangement of bunds and control structures should ensure that the flow paths and settlement times allow the solids to settle into the reclamation area such that the discharge water meets environmental criteria requirements for the amount of suspended solids in the discharge.

13.4 Use of rockfill

*COMMENTARY ON **13.4***

Rockfill is suitable for use in reclamation areas where the following is required:

- *erosion protection from waves, currents and wind;*
- *high bearing capacity;*
- *low settlement;*
- *absorption of fluid mud.*

When placing rockfill, the following factors should be taken into account.

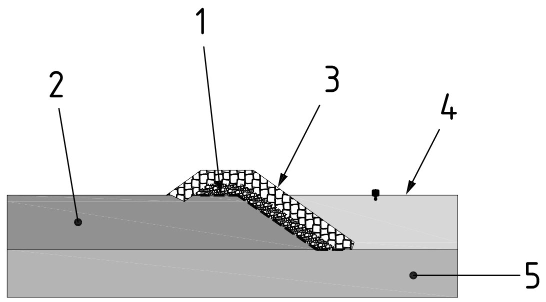
- Rockfill dumped from the surface reaches considerable velocities before impacting the seabed. Where a rapid release is required and less accurate placement is acceptable, side dump barges should be used as necessary for the controlled release of rockfill.
- In shallow water, the draught of the placing vessel limits the height of the rockfill to typically around 3 m to 5 m depending on the plant. Placing at higher levels requires tidal working or lifting plant such as cranes, loaders or conveyors on shallow draught barges.
- Levelling of rockfill for caisson and similar foundations requires specialist equipment to provide a flat even surface that can receive the structure without local overstressing.
- Historically divers have been used to prepare a bed of levelling stone for structure foundations. The use of mechanical underwater screeding and levelling systems is becoming increasingly common; especially as air diving becomes very ineffective at depths below 20 m and hyperbaric diving methods are needed, greatly increasing the complexity of operations at depths greater than 20 m.

13.5 Bunds, revetments and breakwaters

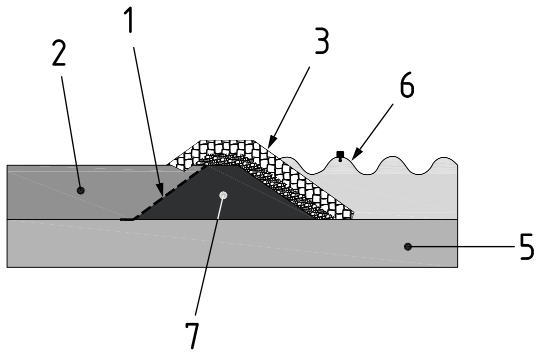
The edges of the reclamation area should be designed to ensure that slope stability is maintained and that erosion of the newly placed fill and or the retaining bunds is minimized.

NOTE 1 The details shown in Figure 19 can be used as typical details subject to detailed design for waves and water movements.

Figure 19 **Reclamation – Typical edge details**



a) Conventional revetment to protect reclamation fill placement



b) Rubble containment dyke to protect reclamation fill placement

Key

1 Geotextile filter

2 Reclamation fill

3 Rock armour

4 Calm water

5 Firm foundation

6 Wave forces

7 Rubble containment dyke

Rockfill bunds are often used to contain the edges of reclamations, and should be designed to:

- be geotechnically stable;
- have a grading or filter layers to retain reclamation material;
- be resistant to erosion by waves, currents and run-off.

Rockfill revetments placed on the surface of bunds, slopes and other fill areas should be adopted as necessary to prevent erosion from water, wind or other forces.

NOTE 2 Revetments are normally hard materials which can resist the erosion forces and can include:

- *precast concrete units;*
- *armour rock – see CIRIA publication C683 [16];*
- *rockfill – loose placed or grouted with hot poured bituminous grout;*
- *precast concrete units in linked mats;*
- *open stone asphalt – small graded stone with bituminous binder;*
- *stone pitching;*
- *rock-filled gabions.*

Geotextile or granular filters should be used where required with all types of revetment to ensure that the base materials are not washed into the pores or open spaces in the revetments by water movements, tides, waves or flowing waters.

When rockfill is often used to form breakwaters, designers should take into account the rapid increase in volume with depth due to the necessary side slope.

NOTE 3 For instance, a breakwater with a 10 m wide crest and 1:2 side slopes has a cross-section volume of 300 m³/m when 10 m high, 1 000 m³/m when 20 m high, and 2 100 m³/m when 30 m high.

Breakwater value engineering studies should review the benefits of placing a vertical wall above a submerged rockfill mound formed by caisson, counterfort, blockworks and similar walls.

13.6 Geotextile containers

*COMMENTARY ON **13.6***

When the dredged spoil is very fine, containing a large percentage by volume of silt and clay size particles which have to be retained, the spoil can be pumped into tubular geotextile containers. The geotextile tubes are formed using high strength woven geotextiles. The tubes typically have a diameter of 2 m to 5 m and can be stacked or manoeuvred to form cylindrical structures up to (and exceeding) 200 m in length. The fill is pumped into the tubes through an entry valve; water is filtered from the spoil through the pores in the geotextile leaving the drained material as a stable fill. As shown in Figure 20, the tubes can be located by placing on a prepared formation or held in place with geotextile flaps that can act as scour aprons, as shown in Figure 21. Typical dimensions of a filled geotextile tube are shown in Figure 22 and Table 16.

Geotextile tubes can be stacked to form bunds which can be used to form the perimeter bunds of lagoons into which dredged spoil can be placed as reclamation areas on shore or in tidal conditions.

Typical layouts are shown in Figure 23.

Geotextiles are durable when covered, or can be left exposed for several years in moderate climates, but should be covered as soon as possible when used in regions with high intensity sunlight, e.g. between the tropics.

Figure 20 **Long section showing geotextile tube being filled, inlet at left with two vents towards the right-hand end**

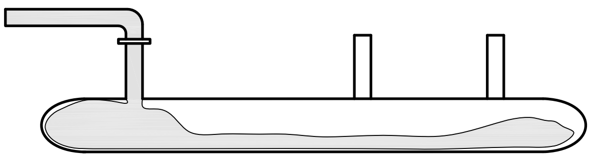


Figure 21 **Typical section of a geotextile tube with two flaps forming scour aprons**

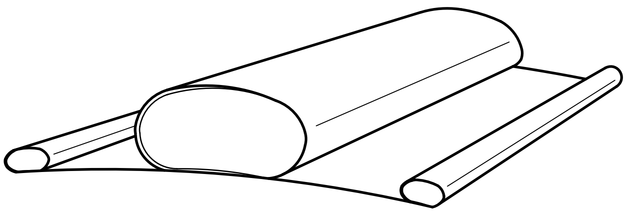
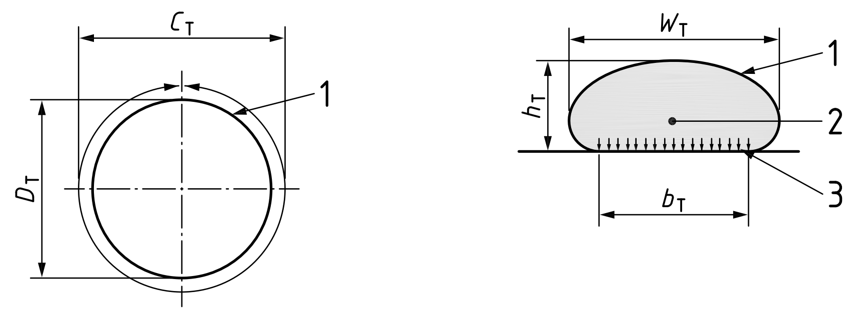


Figure 22 **Geometric properties of a geotextile tube**



a) Empty geotextile tube parameters b) Filled geotextile tube parameters

Key

1 Geotextile tube

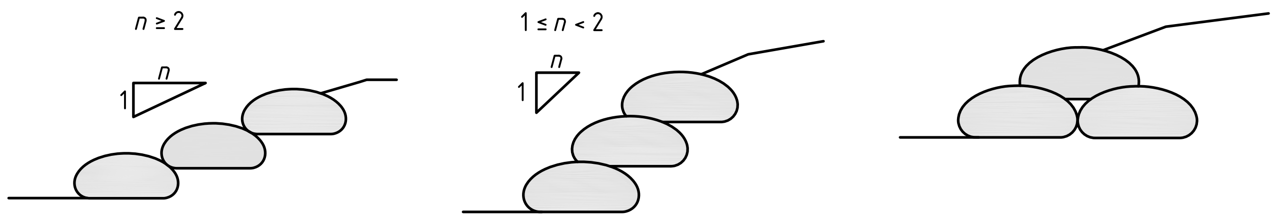
2 Cross-sectional area, A_T

3 Average vertical stress at base, σ_v'

Table 16 **Geometric properties of geotextile tubes based on the diameter of the basic geotextile tube**

Parameter	In terms of theoretical diameter, D_T	In terms of circumference, C_T
Maximum fill height, h_T	$h_T \approx 0.5D_T$	$h_T \approx 0.6C_T$
Filled width, W_T	$W_T \approx 1.6D_T$	$W_T \approx 0.5C_T$
Base contact width, b_T	$b_T \approx 1.1D_T$	$b_T \approx 0.35C_T$
Cross-sectional area, A_T	$A_T \approx 0.57D\gamma^2$	$A_T \approx 0.06C_\gamma^2$
Average vertical stress at base, σ_v'	$\sigma_v'' \approx 0.6\gamma D_T$	$\sigma v' \approx 0.19\gamma C_T$

Figure 23 **Typical arrangements for placing geotextile tubes**



a) Gentle slope b) Steep slope c) Triangular stacking

NOTE 1 For gentle slopes, the weight of the upper tubes does not impact the stresses on the lower tubes. For steep slopes, the stresses imposed by the upper tubes impact the stresses on the lower tubes. For triangular-shaped stacked tubes, the upper tube impacts the stressed on the lower tubes, and additional stresses are imposed at the base of the upper tube.

NOTE 2 Stacking geometry is also governed by foundation soil strength.

13.7 Beach and foreshore recharge

*COMMENTARY ON **13.7***

The terms nourishment, replenishment, and recharge can be used interchangeably, so for clarity, the term recharge is used in this standard. Beach and foreshore recharge involves replacing sediment lost through erosion with imported sediment.

Beach recharge involves adding sediment above the high water contour, producing a wider and higher beach which improves the amenity value of the coastline. In contrast, foreshore recharge typically only results in the raising of beach or nearshore seabed levels below high water, and sometimes just below the low water line.

Beach recharge can be used to increase beach levels to reduce wave attack or for amenity purposes, or can be required to create a barrier for sea defence purposes. It has certain advantages over "hard defence" methods, including environmental, recreational, financial (distributed costs), lower local disruption and less chance of detrimental effect on adjoining beaches.

Beach and foreshore recharge is controlled and licensed in the UK. The Marine Management Organisation represents a useful source of information.

13.7.1 General

Testing of material (particle size analysis and contamination) should be undertaken to meet licensing requirements and inform design and contract specification.

13.7.2 Design specification

*COMMENTARY ON **13.7.2***

Sediment from many different sources can be used for recharge, including sediment from dredging navigation channels or from areas on the seabed licensed for aggregate winning.

The design of a recharge project should be based on a knowledge of the physical conditions of the site and the reason for recharge; whether for coastal defence, the creation/refurbishment of beach amenities, or other reasons. Both long-term average and short-term extreme weather and sea conditions should be used to determine the life expectancy of any recharge. Numerical modelling of the beach should be carried out to establish the effects of the grain size and resultant profile on the beach. The models should be carefully calibrated using the baseline data to demonstrate the validity and accuracy of the model.

Knowledge of the physical conditions of the site should be based on several years of monitoring of the processes affecting the beach. The baseline monitoring should include:

- topography (including seasonal and storm responses);
- the wave climate;
- water levels;
- meteorological conditions (see Clause **6**); and
- the sedimentological grading of the site (see **13.7.4**), and potentially that of the proposed recharge material if it is subject to change.

13.7.3 Material sources

*COMMENTARY ON **13.7.3***

Materials used in recharge can come from several different sources, including but not limited to:

- *existing licensed marine sources;*
- *new marine sources, for which new licences are required;*
- *materials arising from maintenance and capital dredging activities;*
- *land-based sources.*

Within the Water Framework Directive [9], there is a waste hierarchy which comprises:

- *prevention;*
- *re-use;*
- *recycle;*
- *other recovery;*
- *disposal.*

The source of materials used in recharge should be selected such as to ensure that the type of sediment chosen creates and maintains the required beach morphology, and also that the extraction licence allows sufficient sediment to be supplied.

NOTE 1 The beneficial use of material from maintenance and capital dredging is actively encouraged in the UK.

The type of dredger to be used should be chosen according to the dredging requirements, location, water depths at both source and at the delivery location, placement method required, volume of sediment required and the sediment used in the recharge.

*NOTE 2 The choice of plant is covered in Clause **7**.*

13.7.4 Material grading

*COMMENTARY ON **13.7.4***

The range of gradings that are acceptable for a particular application are normally referred to as a grading envelope. The grading envelope is determined by the beach slope required and the physical processes at the beach. When using dredged sediments, there can be no guarantee that the sediment loaded into the dredger will match samples taken from the same area at a different time because of the natural variability in the seabed sediments. The process of dredging also has the potential to alter grain sizes. It is generally impractical to make refined changes to the particle size distribution of material loaded onto dredgers through sorting, even if the return to the seabed of the unwanted sizes is permitted.

The chosen envelope should take into account the natural variability of sediment and the different processes that it will go through before it is sampled on the beach.

NOTE An example grading envelope, including examples of acceptable and unacceptable sediments, is shown in Figure 24.

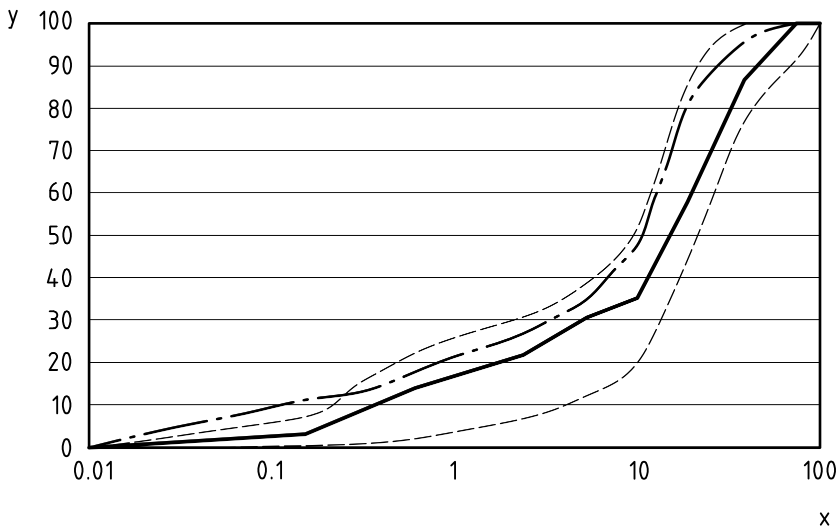
13.7.5 Materials

*COMMENTARY ON **13.7.5***

Usually beach recharge utilizes sand (0.063 mm to 2 mm) and gravel (2 mm to 60 mm) sized materials.

Soils are classified by grain sizes. Definitions of soil types are given in BS ISO 11277.

Figure 24 **Example grading envelope with examples of acceptable and unacceptable sediments**



Key

x Grain size, in millimetres (mm)

y Cumulative percentage

– – – Grading envelope

—— Acceptable

—·— Unacceptable

Material for beach recharge should be of such a size that the losses that occur naturally under the influence of waves, tides and currents are not excessive.

The grading of the material should be similar to, or coarser than, that occurring naturally on the beach to be replenished or on stable beaches that are subject to similar conditions.

NOTE 1 The addition of even small amounts of gravel or coarser particles to a sand beach can be detrimental to the amenity of the beach.

NOTE 2 The optimum grading of material for a stable beach is totally dependent on the site. As a rule of thumb, the use of coarser material than the natural beach results in a steeper beach slope and the use of a finer material results in a less steep beach slope. In reality, there are many other factors which affect beach slope, such as permeability and sediment sorting. Empirical relations have been established that provide an estimate of the effect on beach slope of different sediment size (see Table 17).

Table 17 **Beach slope – Approximate sediment size trends for natural beaches**

Median sediment size D_{50}	**Mean beach slope**	
	Moderate wave climate	**Severe wave climate**
mm		
0.2	1:50	1:100
0.3	1:25	1:50
0.5	1:20	1:25
5	1:8	1:20
10	1:7	1:8
20	1:4	1:7

NOTE Data taken from HR Wallingford Report SR 350 [23].

13.7.6 Monitoring of recharged beaches

The spacing of the beach profile locations depends on the shape and size of the beach, but once agreed upon, the locations of the profiles to be monitored should be assumed to be fixed for the duration of the works. The cross-sections should be at centres close enough to be representative of local variations and should extend over the alongshore distance which can be affected by the recharge. The profiles should also include the adjacent beaches where there is a chance that they are connected with respect to sediment transport.

NOTE 1 The surveys of the adjacent beaches do not need to be as detailed as for the recharged frontage.

The offshore extent of the survey profiles should be determined by the historical data which shows depth of closure.

NOTE 2 The depth of closure is the seaward extent of any profile change.

If such data exist, a sensible lower limit can be determined from the profiles, however in the absence of these data, the profiles should extend to a nominal closure depth (see the article *Field data on seaward limit of profile change* [24]) of 10 m or to a maximum of 10 km offshore.

The results of the monitoring should be used to evaluate the performance of the beach recharge and the need for further recharge.

The two main objectives of sampling of sediments on the beach for recharge schemes should be to:

- determine the grading of the sediment and how it changes with time; and
- ensure that the sediment delivered to the beach fits into the required grading envelope.

The locations of the samples should remain consistent for the duration of the works and subsequent monitoring so that trends in the grain size can be identified easily.

A sufficient number (and size) of beach samples, for particle size analysis, should be taken to provide a representative picture of the beach sediments. Sampling should extend from above high water to the closure depth and extend into the adjacent areas where the beach is not well separated from these with respect to sediment transport.

The monitoring of the beach before, during and after the recharge should provide morphological and sedimentological data:

- to give an understanding of the annual variability of the natural beach, via baseline surveys;
- to give assurance that the sediment properties and volumes are as required, during the recharge works; and
- to give an indication of the success of the recharge, via post-placement surveys.

Since profiles are seasonably variable, comparison of levels can be of only limited value. A more reliable indication of change is given by measuring the change in beach sectional area above an arbitrary reference elevation, which should be below the closure depth.

NOTE 3 From these beach sections, changes in beach volume can be calculated. The shoreline management plans and other documentary sources can assist with understanding of the wider sediment transport system.

Beaches formed of dredged gravel can form small "cliffs" if the material dredged is not well matched to that on the beach in terms of the detail of the constituents of the sediment. These cliffs can be hazardous and should be avoided.

13.7.7 Beach recharge scheme management

The management of any beach recharge scheme should have oversight of the quantity of the recharge material and its quality, the accuracy of placement and changes soon after placement; if the sediment grading changes, profiles are affected.

A procedure should be put in place that sets out clearly the actions to be taken in the event of the placement of sediment not meeting the agreed standard during the course of the works.

The volume of sediment deposited is different from that dredged, due to bulking and losses. Specialist advice should be sought as part of the early design process to address the potential implications of changes in volume and particle size as a consequence of the dredging process. It should be agreed, at an early stage, which volume of sediment, that extracted or that deposited, will be used as the design measure; the latter is more meaningful, particularly if volume in the finished profile is referred to.

Sediment grading should be monitored regularly and accurately, to ensure that the sediment deposited is within the grading envelope stipulated in the design.

14 Ground treatment

14.1 General

The need for ground treatment should be based on:

- the nature and method of placement of the reclamation fill;
- the properties of the fill material;
- any underlying soft/weak in-situ materials left in place;
- the functional requirements of the end user.

The extent of ground treatment should be determined largely by the functional requirements stipulated by the end user, taking account of the bearing capacity and settlement restrictions of the proposed development.

NOTE 1 Use for bulk storage of materials has a bearing capacity requirement, but a settlement limit is probably not required. Container stacking areas where the shifters are programmed or controlled by a central computer system have small ranges for variations in bearing capacity and post-construction settlement. Imposition of excessively onerous limits within the functional requirements can result in excessive ground treatment, which is reflected in cost to the developer.

The fill to be placed in a reclamation should ideally be a granular material with a limited amount of fines. However, it is frequently necessary (for either environmental reasons or disposal issues) for granular fill to be placed above soft compressible clays that form the foreshore or river flood plain. Both the reclamation fill and any soft in-situ material left in place should be assessed for treatment to satisfy the functional requirements of the development.

NOTE 2 The nature of the ground treatment depends upon the materials involved. Where fine-grained materials, such as any in-situ soils, are left in place before placement of the reclamation fill, settlement is a major concern. Settlement has three phases: immediate, consolidation and secondary. The largest element is the *consolidation phase, where porewater is squeezed out of the soil by pressures induced by the placement of load from the fill. Drainage of these excess (pore) water pressures can take a significant period of time to occur.*

Potential for soil liquefaction of fine-grained soils used for reclamation should be examined, particularly in highly seismic zones. Suitable ground treatment methods should be selected when liquefaction is an issue.

Weak saturated fine-grained materials are not typically amenable to vibratory methods of treatment; normally, consolidation should be promoted by application of load (a surcharge) and by the improvement of drainage by installing band drains, or vibro stone replacement.

NOTE 3 Placement of granular materials by hydraulic methods frequently results in a loose material with limited bearing capacity and potentially significant creep settlement characteristics. These are commonly treated by vibratory methods.

The choice of ground treatment method should be influenced by the geotechnical requirements and engineering performance objectives. Appropriate site supervision, quality control and monitoring procedures should be put in place during execution of ground treatment techniques to ensure successful implementation, and an appropriate level of pre- and post-treatment testing should be carried out to determine whether satisfactory performance has been achieved.

14.2 Types of ground treatment

14.2.1 General

When planning and designing a reclamation, a balance should be sought between the quality of the available fill and the need for ground treatment, especially where only higher fines content fills are available. The designer should take into account the benefits and application of the full range of ground treatment methods available to improve the strength and compressibility characteristics of materials within reclamation.

NOTE Typical methods include:

- *pre-loading and surcharging;*
- *drainage;*
- *soil replacement;*
- *vibration;*
- *inclusions.*

It is not intended to give a full description here; these methods are described in detail in the ICE Manual of geotechnical engineering *[25] and advice can also be sought from specialist contractors.*

The level at which the ground treatment is executed should be selected with care, taking the following factors into account.

- Below water, ground treatment is logistically more challenging and less effective due to the low effective stress from soil particle buoyancy.
- Above water level, placing and compacting fill material in layers is straightforward by conventional roller or similar methods as given in BS 6031.
- Working from the reclamation surface both reduces the depth of the applied treatment and avoids having to penetrate the dense compacted near surface layer.

- Working from the surcharge top level maximizes the effective stress, but increases the depth of penetration.
- Working platform height should be limited to ensure that edge structures remain stable.

The selection of ground treatment method should take full account of:

- the time required to achieve the planned soil improvement;
- the influence of water level and pore pressures on the submerged weight of soil and reduction in effective stress;
- possible conflicts with major earth movements, dredging and other works on the site;
- the consequent implications for the construction programme.

Typical ground treatment options that should be taken into account when designing ground treatment include those described in **14.2.2** to **14.2.6**.

14.2.2 Pre-loading and surcharging

To pre-load a site, fill should be placed such that the loads applied to the foundations are at least the same as the long-term final loads for the fill and any service loads.

A settlement allowance should be added to the reclamation levels to ensure that the required load is applied and maintained and that the final level remains at or above the design formation level. The fill should be left for a sufficient period of time to allow settlement to take place and for the bearing capacity to improve under the fill's self-weight before final development.

NOTE 1 Where subsequent consolidation of the underlying or reclamation material is liable to exceed the allowable settlements, pre-loading the site is rarely sufficient, as the soil remains compressible even after a long time. To reduce the compressibility an additional surcharge can be placed, or other ground treatment method adopted.

The surcharge should be placed above the required finished levels, to provide sufficient additional load to over-consolidate the compressible soils and densify the non-compressible soils, with loads preferably greater than the final in-service loads of the development. Where practicable the surcharge material should be the same as the reclamation fill, to avoid quality issues of mixed soils and to simplify management.

NOTE 2 The surcharge loading is used to accelerate primary consolidation settlements of fine-grained foundation materials and to reduce secondary consolidation (creep) type settlement, with an increased bearing capacity resulting from the increased effective shear strength.

NOTE 3 Particular care is needed when surcharging adjacent to existing quay walls and edges of structures to fully evaluate and ensure their stability.

14.2.3 Drainage

Where the foundation soils are fine-grained materials with low permeability, the drainage of excess porewater and settlement under the loading for both pre-loading and surcharge can take a considerable time to complete. Where required, the time for consolidation should be reduced by improving the drainage.

The horizontal drainage path should be reduced by the installation of a close grid of vertical drains [normally pre-fabricated band drains (PVD) of geotextile encasing a PVC core].

NOTE 1 Drains do not alter the secondary creep characteristics of the material but do advance the onset of creep, thus reducing post-construction movements.

The ground treatment design should take account of the importance of maintaining the granular drainage blanket's function during the consolidation process, especially if any non-granular permanent or temporary surcharge is placed above the blanket.

If large settlements are expected, care should be taken that the compression of the band drains does not cause kinking of the drain which can result in a significant loss in drainage capacity.

NOTE 2 This can be achieved either by using specialist non-kink band drains or by installing a second set of band drains to restore drainage capacity.

The design of vertical drains should take into account that the horizontal permeability of laminated estuarine clays is often higher than the vertical permeability due to the presence of silt and sand partings.

NOTE 3 The spacing of the drains can be increased where the horizontal permeability is high.

NOTE 4 The vacuum consolidation method uses a system of PVD drains installed from the ground/treatment surface, with an impermeable cover membrane to allow a vacuum to be developed over the area being consolidated. A vacuum is applied to the ground surface to simulate the loading to be applied in service without the requirement for application of a conventional surcharge load. Vacuum dewatering can be advantageous where placement of a pre-load or surcharge is not practical, such as in inter-tidal zones, areas too weak to support surface plant, or where either surcharge material is in short supply or there are concerns with stability of any placed surcharge.

NOTE 5 Application of the vacuum produces a pressure on the soil which facilitates accelerated isotropic consolidation in the soil mass. The resultant reduction in pore water pressure increases the effective stress. Where the vacuum method is used in near-shore applications, the resulting effective stress increase also includes the overburden pressure of the seawater. Information regarding vacuum pre-loading is given in BS EN 15237:2007, Annex B.

14.2.4 Soil replacement

Soil replacement should be undertaken by the excavation of in-situ soft compressible materials and replacement by better quality reclamation fill, compacted as necessary to achieve the required engineering strength and settlement criteria.

NOTE 1 Where suitable the excavated fill can be relaid and compacted.

NOTE 2 The costs of this process can be offset by a reduced scale of ground treatment required, and the relatively shorter timescale to achieve the required strength. For projects where particularly stringent limitations on settlement are imposed, this method can be a necessity.

14.2.5 Vibration – Vibro compaction, dynamic compaction, impact rolling

To ensure that reclamation fills placed hydraulically are compacted to give the required properties for development, vibro compaction using surface rollers or deep compaction plant should be used to densify the fills.

To densify loose fills and natural soils, the application of vibration or dynamic impact loadings should be used to compact the materials by rearranging the granular soil particles into a denser state to give greater strength and stiffness.

NOTE 1 The densification reduces void ratio and compressibility with a corresponding increase in the angle of shearing resistance. The improved soil allows higher imposed design loadings, smaller settlements and increased seismic resistance.

Vibro compaction techniques should only be used when the layer to be compacted is more than 1.0 m thick.

NOTE 2 Vibro compaction involves the penetration of a vibrating poker into the ground to densify materials to the depth of the poker. Some soils only require compaction using a vibrating poker, but the same or similar plant is often used for the construction of vibro replacement or displacement stone columns. In some circumstances, vibro stone columns act as vertical drains. Information regarding vibro techniques is given in BS EN 14731.

Dynamic compaction and rapid impact compaction should only be used when the large intensity vibrations will not damage adjacent structures.

NOTE 3 Dynamic compaction involves the dropping from height of a heavy weight on pre-determined grid patterns, involving one or more treatment passes to improve soil stiffness. Rapid impact compaction is similar in effect to dynamic compaction but involves dropping a weight onto a plate with a diameter of about 1.5 m using a hydraulic actuator to lift the weight.

NOTE 4 Compaction using impact rollers can be used on fills up to 2 m thick. The rollers have an eccentric shape which imparts a sudden force to the ground surface.

NOTE 5 Dynamic compaction treatment can also be performed below water using barge-mounted cranes and stream-lined weights with holes cut out to reduce water resistance and increase impact velocity on the seabed.

The pattern and spacing of compaction treatment should be tailored to the project design requirements.

Vibro compaction and vibro replacement should be carried out through fill from above high tide levels, but may also be carried out near-shore, working from barges or pontoons, or sometimes using large cranes reaching out from existing quays (see Figure 25).

14.2.6 Inclusions

When the site conditions are not suitable for simple vibro compaction to achieve the design strength or stiffness, vibro replacement (stone columns), jet grouting (soil/cement columns) and deep mixing (soil/cement columns) techniques should be used to form a stiff column of material at close centres within the soil mass extending to more competent materials at depth.

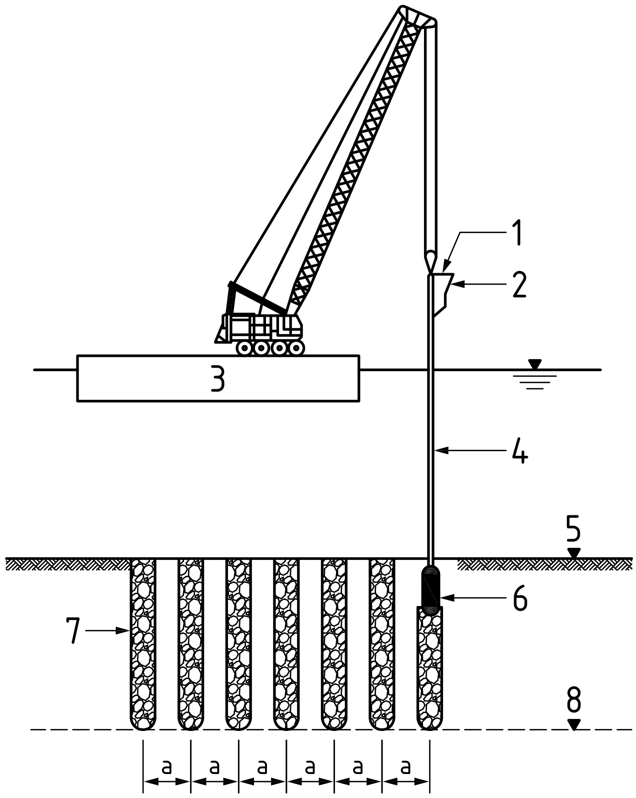
NOTE The installation of stiff soil elements rely on a load transfer system (BS 8006-1 describes the design of the load transfer system) near the surface which distributes a large part of the applied load to the stiff columns or piles, resulting in a reduced load being applied to the soil. The transfer system usually comprises layers of compacted fill, sometimes reinforced with geotextiles or geogrid. The spacing of the columns together with the thickness of the load transfer system are variables in the design. Vibro replacement (stone columns) has an additional advantage in that the columns can also act as vertical drains allowing a greater rate of settlement.

14.3 Design process

14.3.1 General

The design process should be determined on a case-by-case basis according to the individual project, but this subclause outlines the procedure that is commonly followed.

Figure 25 **Vibro equipment working off barges/pontoons during a reclamation project**



Key

1 Stone aggregate feed hopper
2 Hopper and pressure vessel
3 Barge
4 Extension tubes/feed pipes
5 Seabed level
6 Vibrator probe
7 Completed stone columns
8 Varying depth
a Stone column grid spacing

14.3.2 Pre-contract ground investigation and preparation of functional requirements

An initial ground investigation should be carried out to enable preliminary assessments of the need and/or degree of ground treatment required and to inform preparation of the functional requirements. This also allows contractors to assess the risk posed by the ground conditions. This investigation should at least be sufficient to identify the nature and extent of materials beneath the future reclamation and to identify the potential nature of the materials to be used as reclamation fill. The investigation should include strength and compressibility tests (which should include either permeability testing and/or rate of consolidation determination) of in-situ soils.

The functional requirements should be formulated taking cognisance of the type and extent of ground treatment shown by the investigation as likely to be required, together with the operating conditions required of the end user. The imposition of onerous requirements has a major effect on the degree of treatment required, and the functional requirements should be determined with care to avoid unnecessary costs.

NOTE 1 The ground treatment can be designed on the basis of the ground investigation data together with the functional requirements.

NOTE 2 It can be that several combinations of treatment (height and duration of surcharge, drain spacing, vibro spacing) offer the same results. Here, a view needs to be taken of the risks of each combination of method together with costs.

14.3.3 Ground treatment design and preliminary trials

Having determined the most appropriate ground treatment required, preliminary trials should be carried out to confirm that it will meet the functional requirements.

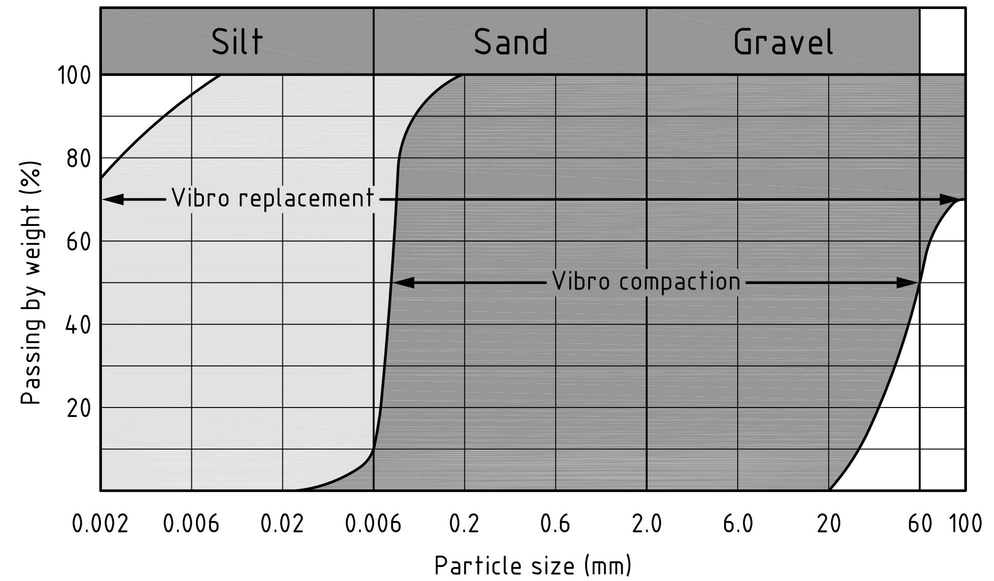
NOTE 1 In the case of vibro or inclusions, this usually takes the form of cone penetration tests and zone loading tests (see ***14.4****).*

NOTE 2 Where surcharge is used, then, in addition to trial embankments, reliance is often placed on monitoring the first phases of construction, since results from this can usually indicate whether any modification is required which can be incorporated into later phases.

NOTE 3 The preliminary assessment for the selection of ground treatment method may be made using Figure 26.

NOTE 4 Further guidance can be found in Chapter 84 of the ICE Manual of geotechnical engineering *[26].*

Figure 26 **Range of soils suitable for treatment by vibrocompaction and vibro stone column techniques**



(After Serridge and Slocombe [26])

14.3.4 Further ground investigation

Where the pre-contract ground investigation does not provide all the data required fully to design the ground treatment required, additional ground investigation should be implemented if advantageous. This investigation should be focused on the design requirements of the ground treatment, and should include definition of strength, compressibility and rate of consolidation parameters. In fine-grained materials, where these are to be left in place, the duration of the compressibility tests should be extended such that secondary consolidation (creep) characteristics can be assessed.

14.3.5 Ground treatment implementation

On completion of investigations, design and trialling, construction of the ground treatment can begin. This should normally be preceded by a series of tests to determine the condition of the reclamation fill and the foundations following placement. In granular fill material used for reclamations, tests should determine the relative density and may be cone penetration tests (CPT), standard penetration tests (SPT) or pressuremeter tests (PMT).

NOTE A problem with the SPT and PMT testing is that a borehole is required to test the fill at depth and tests are only carried out at intervals down the borehole, typically 1 m, making the testing somewhat slow and limited. The results of PMT tests are a stiffness modulus at each test depth, which, whilst it might be useful for elastic settlement calculation, is frequently not included in functional requirements. The CPT, which gives a near continuous profile without the need of a borehole, is the most common form of testing.

The spacing or frequency of soil tests should be planned to ensure that the properties of the fill are adequately measured.

14.4 Performance monitoring

On completion of the ground treatment, further testing should be carried out to determine whether the reclamation performs in terms of bearing capacity and future settlement, as required. This testing should typically include the following.

- To assess future settlement characteristics of the reclamation, settlement observation points should be established over the area of the reclamation and monitored both during the construction period and after. Settlement monitoring points established on the original ground surface prior to filling are particularly useful to establish the full settlement history of the original ground. Observation points that are destroyed by construction or during development should be re-established nearby so that a continuous record of settlement is available.

  Standpipes and piezometers should be deployed where knowledge of ground water level, and pore pressures is required, and magnet extensometers should be deployed to reinforce settlement monitoring. Inclinometers should be deployed where lateral ground movements need to be monitored.

  The data from observation points during construction allows verification of the parameters used for design. If the parameters back-analysed from the observation points are more onerous than assumed, then the treatment applied should be reassessed. The earlier this back-analysis is carried out then the longer the period of construction remaining and the less additional ground treatment measures can be required. The converse is also true: early examination and scrutiny of this data might show more optimistic parameters and allow a reduced degree of treatment in future areas than would be the case had the examination taken place later.

- Repeating the CPT (or SPT/PMT) and comparing the pre- and post-test results. If the criteria given in the functional requirements (or detailed by the contractor in the design) in terms of either relative density, cone resistance or modulus, are shown to have been achieved, treatment can continue to the next area. If the criteria are not met, the reasons should be investigated and further treatment carried out followed by testing.

- To demonstrate bearing capacity and settlement performance, zone loading tests (ZLT) can be undertaken. These are large (typically 3 m square) plates that are loaded to a pre-determined pressure. Settlement readings are taken on all four corners over a period of time, often extending over a number of days. Plotting settlement against time allows an estimation of the secondary (creep) characteristics of the fill and thus its future settlement.

Acceptance of the reclamation/ground treatment relies on the results obtained from monitoring and testing. The effort required in acquiring this data in terms of resources should not be under-estimated. If the data available for scrutiny is too sparse for reliable conclusions on future performance to be ascertained, then acceptance of the reclamation should be delayed until more data is obtained.

NOTE Good quality data is of paramount importance as inaccurate and/or unreliable data is very difficult to back-analyse. This delays the construction programme and hence is likely to have potential contractual implications and significant cost increases.

15 Management and supervision

15.1 Project management

15.1.1 General

Good project management on the part of the client and the contractor should seek to achieve the project objectives in the most efficient and economical way and should take account of the following goals:

- set and meet health, safety and environment objectives;
- set and meet cost, schedule and quality objectives;
- effectively supply, operate and maintain the dredging and ancillary plant;
- manage communications between all parties involved in the project activities;
- successfully implement contract variations if required;
- optimize the working method given the available resources;
- plan and implement mitigation measures if needed.

15.1.2 Roles and responsibilities

For the successful execution of a dredging project, the roles of the various parties and their responsibilities should be clearly defined. The line management responsibilities should also be identified.

NOTE Clear definition of responsibility is particularly important during the execution phase of a project and in the event of an emergency incident.

15.2 Execution planning phase

Once a dredging contract has been awarded, a further, more detailed, phase of planning should be undertaken, specifically in relation to the execution of the works, which should recognize the temporal sequence of the tasks and their interdependence. This is a key phase and should be undertaken rigorously for the following reasons:

- a well-planned project is easier to manage;
- the progress of the activities can be compared with the predicted progress;
- corrective action can be taken in the event that the expected progress is not achieved; and
- unexpected circumstances can be dealt with according to pre-determined contingency plans, thus minimizing delays.

During the construction planning phase the project implementation team should be selected, and all relevant project-specific management plans should be prepared and approved. A careful check should be made at this stage to ensure that there are no outstanding permits and licenses required. The responsibility for resolving any outstanding issues should be defined between the parties, and the necessary timescales factored into the project planning.

The project-specific management plan should include:

- dredging or reclamation methodology;
- work schedule (the dredging/reclamation execution plan);
- project safety and emergency response (the health and safety management plan);
- environmental management (the environmental management plan; see **5.7.5**);
- project measurement (e.g. survey) and reporting requirements (see also **15.12**);
- project execution and resource plan.

During this planning phase all the other parties, either directly involved in the project or affected by the dredging/reclamation activities (including early works; see **15.4**), should be notified of the forthcoming execution of the works.

The dredging contractor should prepare method statements for the dredging activities which should include as a minimum:

- information, including applicable drawings and documents;
- organization, including organizational charts, roles and responsibilities;
- communication, on site and between parties involved, including stoppage of work;
- tools and equipment, including safety instructions;
- work execution, including step-by-step description and the people and tools involved, risks and mitigating measurements;
- schedule.

15.3 Mobilization phase

Once the contractor responsible for the dredging/reclamation has been served with the notice to proceed (after the contractual pre-mobilization requirements have been fulfilled), the mobilization of equipment and personnel to the construction site should start (this is when the project and site safety plans are implemented).

Mobilization of equipment and personnel should follow the planned stages, mobilizing only the resources agreed at each stage of the project.
The equipment and personnel required to complete the early works and site preparation should be mobilized at the beginning of the project, with the dredging equipment being mobilized only when all the early works have been completed, or as agreed in the dredging and reclamation mobilization plan.

Staged mobilization might not be possible in all cases, for example at remote or exposed locations. In these situations, provisions for adequate laydown, storage and vessel moorings should be planned and agreed in advance in order to accommodate unused or standby equipment.

15.4 Early works and site preparation phase

Within the early works and site preparation phase of the project, all of the activities that need to occur before the dredging works can commence should be completed.

NOTE 1 The number, type and duration of the required activities is variable and changes from one project to another.

NOTE 2 Common early works activities are:

- *provision/procurement of site security and access;*
- *installation of survey benchmarks and tide gauges;*
- *provision/procurement of accommodation;*
- *provision/installation of site offices;*
- *provision/preparation of lay-down areas and workshops;*
- *provision of consumables (e.g. water, food and fuel);*
- *installation of temporary and inclement weather moorings;*
- *installation of environmental monitoring equipment;*
- *preparation of the reclamation areas (in case of a reclamation project).*

15.5 Works implementation phase

15.5.1 General

During the implementation phase of the project, the works should be carried out in accordance with the plans developed during the planning phase.

As the works progress, the quantity and quality of the work completed should be monitored regularly. Regular progress meetings involving all stakeholders should be held to ensure that any issues are identified and can be dealt with in a timely fashion.

15.5.2 Communication

For effective management of dredging and construction operations, systems should be established prior to site work commencing to allow clear, concise official and unofficial communications between the dredging and construction contractors, the client and other responsible authorities.

During the execution of the works, especially if the project is large and complex, the client and other key parties should be provided with daily reports on activities over the previous 24 h and those planned in the coming 48 h. Important operational data (e.g. environmental performance against thresholds, material types encountered, working hours, vessels on site and any delays) should be included, such that dredging and construction activities are properly coordinated and managed. Reports should be provided at the start of each day and should include details of dredging plans for the current day and a day ahead. Daily reports should be in written format. Weekly progress reports should be provided by the dredging contractor setting out progress achieved as compared with the schedule for the works.

Teams of field staff (including those on vessels) need to be able to communicate effectively when on site and systems should be in place at the start of the works to allow this (one potential way of achieving this is via the use of VHF radio, subject to the necessary licences and permissions). Communication systems can perform an important safety function and as such should be robust.

For simultaneous operations (SIMOPs), i.e. operations occurring in the same (or adjacent) area at the same time, a SIMOPs procedure should be established and agreed before site work commences. This procedure should provide guidance for all parties involved in the SIMOPs, with the purpose of reducing risk and ensuring that the operations are conducted in a safe manner.

The procedure should clarify which individuals (or project roles) should be responsible for the management of the SIMOPs, which operations are considered to be SIMOPs, what additional risk analysis needs to be performed for those operations and how the arising risk control measures should be implemented.

15.5.3 Vessel location system

*COMMENTARY ON **15.5.3***

International Maritime Organization's International Convention for the Safety of Life at Sea requires that passenger ships and all vessels larger than 300 t have to carry an automatic identification system (AIS) transponder. AIS information can be received by on-board receivers, AIS base stations, and satellites to provide the vessel location, heading and speed.

Major projects and those with high marine traffic risks should take full advantage of the AIS system by installing a dedicated AIS VHF receiver and data logger, to allow the tracking of vessels, to monitor safety and the identification of high navigation risk areas. AIS transponders should also be provided on tugs, work boats and powered and dumb barges and other small vessels on major projects where:

a) there are:
   - high marine traffic risks;
   - high vessel movement coordination requirements;
   - significant navigation hazards;
   - exclusion zones to protect infrastructure such as pipe and cable landfalls;
   - environmentally sensitive areas;

b) work is undertaken at night;

c) visibility is poor;

d) the site is exposed to severe sea conditions and storms.

15.6 Supervision

Supervision of the dredging operations is essential and it should be performed by both the dredging contractor and the client in order to:

a) verify that the dredging operations conform to all of the project procedures and management plans;

b) ensure that the work conforms to specifications and tolerances;

c) ensure that the work is performed safely and in accordance with the construction schedule, cost estimate and environmental management plan.

15.7 Health and safety

NOTE Advice on health and safety matters can be obtained from the Health and Safety Executive.

The health and safety management plan and all other project-specific plans dealing with health and safety matters should be accessible to all personnel on the project. All project personnel should make themselves familiar with the plans relevant to them and, in particular, the specific responsibilities that they have according to their role on the project.

15.8 Environmental

The predicted environmental changes and impacts arising from a dredging/reclamation project, and the mitigation, compensation and monitoring agreed with regulators, should be clearly and concisely set out in project documentation prior to baseline environmental monitoring commencing (see Clause **5**). Project planning, agreements (including with regulators) and management should allow for dynamic control of the works (e.g. changes in dredger production rate) according to feedback from the environmental monitoring (this is sometimes referred to as adaptive management), provided that the scale of the project is such that this is appropriate. For adaptive management of this type the use of near real-time monitoring equipment should be assessed for its viability.

Where environmental thresholds have been agreed with regulators, clear systems and documentation should be in place prior to commencement of the works in order to set out what these thresholds are and the way in which they are to be managed (including informing of regulators with respect to performance and actions if thresholds are being approached or exceeded). Such information should be disseminated to, and agreed by, all relevant parties (contractor's team, client's team and regulatory team).

15.9 Quality, documentation and reporting

15.9.1 Quality management

The client and contractor organizations should operate quality management systems which apply the principles of well-established, internationally-recognized quality management systems, including:

- customer focus;
- leadership;
- involvement of people;
- process approach;
- system approach to management;
- continual improvement;
- factual approach to decision making;
- mutually beneficial supplier relationships.

In addition, a project-specific quality management plan should be written, agreed and approved prior to the commencement of the works. The project quality management plan should provide guidance on the quality objectives, roles and responsibilities, strategies, and practices to be adopted for the measurement and audit of quality. The document should also detail the approach to be adopted in order that corrective action can be quickly applied to any identified non-conformities.

15.9.2 Document control

A project document control system should be implemented in order that a standard procedure is adopted for controlling the issue, receipt, authorization and storage of all documentation related to the project.

The document control system should be consistent with the project quality management plan and described in a project document control procedure. The document should be prepared, agreed and approved prior to commencement of the works.

15.10 Progress reporting

A progress reporting procedure should be prepared, agreed and adopted at the start of the project. The procedure should specify the topics to be reported on, the required contents of the reports and the frequency at which the reports should be issued. The procedure should also describe the review and sign-off procedure for the reports (including timescales for completion).

15.11 Site positioning and control

In order to achieve accurate dredging, accurate positioning methods should be used, to reduce the likelihood of the plant operating outside of the scope of work. Before commencement of the work on site, the client should specify and agree with all relevant parties the coordinate system and the horizontal and vertical datums to be used for the project as a whole. Such matters should usually be dealt with in the technical specification for the work and might be set out as part of the contract.

The use of AIS vessel location systems should be adopted as described in **15.5.3** to monitor general vessel movements and locations on site.

Dredging vessels should be equipped with differential (or better) satellite positioning systems, integrated with electronic charts/digital terrain models and other displays as necessary in order to indicate visually, in real time the position of the vessel and the position of the active dredging component (cutter head, drag head, bucket, etc.) in relation to the seabed and any near-by structures. Such displays should also show the design depth and the agreed dredging tolerance. These positions should be recorded and be available for auditing. Great care should be exercised in the choice of datums to be used, particularly when dredging works extend over long distances.

15.12 Measurement and testing against design

15.12.1 General

The methods of measurement to be used for any dredging/reclamation project should be clearly described in the works specification documents and be agreed well in advance of the works. The methodology used for the measurements should be consistent between surveys to ensure that the potential for variations introduced as a consequence of methodological changes is minimized.
The selection of methods of measurement (including the detailed specifications) should be undertaken with reference to the overall accuracy and precision of these methods and the potential consequences of the accuracy and precision limitations with reference to the purpose of the measurements.

Changes in the bulk volume of materials during the dredging and reclamation process should be taken into account when measuring dredging and reclamation works.

NOTE Increases in material volume as a consequence of dredging are sometimes referred to as "bulking". Further information regarding sediment density and volume changes as a consequence of sediment placement (and following sediment placement) is given in the CUR/CIRIA Hydraulic fill manual *[22].*

15.12.2 Capital and maintenance dredging

The design basis for capital and maintenance works should define the geometrical characteristics of the dredged area that need to be achieved at the end of the project. The design basis for capital and maintenance works should also define the tolerances that need to be respected when executing the dredging. For accurate measurement, the volumes requiring removal in order to meet the design should be defined using up-to-date bathymetric survey data (see **6.5.2**).

15.12.3 Bathymetric/topographic measurement surveys

Bathymetric surveys should be used as a means of measurement of progress against design for dredging (see **6.5.2**), and topographic surveys used as a means of measurement for reclamation. Where reclamation levels are below water level in their early stages, bathymetric surveys should be used to measure progress.

If a project involves winning of sediment, or its disposal, offshore then bathymetric survey should also be used in these circumstances to ensure that the dredging/placement activities have been undertaken within the area licensed.

Comparison of surveys undertaken at different times (level difference plots and volume difference calculations) should be used to illustrate the progress of works and/or other matters.

15.12.4 Tolerances

Dredge tolerances should form part of the written specification of the works and are often included in the dredging contract as well as licences/permissions. Tolerances should take account of the dredging plant to be used and the environmental conditions such as wave heights. Measurement to assess compliance with tolerances should take account of the level of accuracy of the measurement method versus the magnitude of the tolerance.

NOTE Tight tolerances (relative to the capabilities of the plant/operators under the conditions on site) usually lead to works taking longer than they might otherwise.

15.12.5 Debris, contamination, boulders

High quality site investigation should be employed to identify and quantify debris, contamination and boulders as well as practicable in the planning phase of the works. Dredging contracts and schedules should take account of the presence of such materials and the likely accuracy with which it has been possible to quantify them.

15.12.6 Pre-treatment areas for rock dredging

The method adopted for the measurement of the pre-treatment work should be determined according to the pre-treatment method applied. Drilling and blasting should typically be measured on a per square-metre basis for a given depth of fragmentation, while measurement for mechanical pre-treatment and superficial blasting is commonly calculated on a volume basis.

15.12.7 Hopper volume measurements

Direct measurements of load volume are sometimes made by taking a number of soundings of the level of material in a hopper from a number of fixed reference points around the hopper. However, such measurements should be treated with caution as large spatial variations in the surface level of loads can sometimes occur, and the sediment surface cannot be well defined in the case of fine materials (silt and mud). Interpretation of the volume information collected should take into account the potential effects of bulking and compaction, noting that sediment density increases with depth within the hopper.

NOTE During dredging, sediment is liberated from the bed which is not retained in the hopper. This might be as a result of overflow from the hopper or the disturbance caused by the dredge plant interacting with the bed, for example.

If an alternative to hopper volume measurements is required then use of the displacement of the dredger to calculate the mass of material in the hopper should be assessed for its suitability, noting that the procedure requires thorough calibration.

15.12.8 Solids production data from on-board dredge computers

If such data are to be used then the accuracy of the systems in question should be understood and the data derived checked against other sources of information to ensure consistency. Where mixed materials are being dredged, particular care should be taken as accuracies can be reduced or vary.

15.13 Dredged area quality control

The geometric design of the dredged area should specify the final depth, the bottom width, the side slope and the acceptable tolerances.

Measurement and monitoring of dredged areas should be undertaken by a bathymetric survey using a multi-beam or single beam echo sounder. The survey should run multiple survey lines along the line of channels and trenches, in addition to running check lines at regular intervals perpendicular to the trench line. The following survey campaigns should be undertaken for trenching operations, as a minimum:

- during the project planning phase, to determine the volume of the seabed material to be removed by dredging to meet the design specification;
- a pre-dredge survey, to determine the exact bed levels prior to the commencement of the works;
- a post-dredge survey, to confirm that dredging is complete and the dredged depths have been achieved within the required tolerances.

15.14 Bar sweeps

Where depth is critical, such as in areas containing rock or boulders, complete reliance should not be placed in echo sounder, multi-beam or sidescan sonar techniques. The use of bar sweeps (a technique involving suspending a bar below a vessel/float at a known depth) should be adopted in cases where there is the possibility of hard material above the dredged level. The bar used should be sufficiently heavy and properly monitored so that non abrupt obstructions above the design dredged level do not simply lift the bar without giving an indication to the operators in the towing vessel.

15.15 Reclamation quality control

NOTE 1 Reclamation by hydraulic fill is covered in prEN 16907-6. This subclause applies only to reclamation by other methods.

The design basis for reclamation works should define the geometrical characteristics and the fill properties of the reclamation that need to be achieved at the end of the project.

Topographic surveys (see **6.5.3** and BS 6349-1-1) should be used to determine the geometrical characteristics of the reclamation and the volume of the fill material. Bathymetric surveys should be used in the early stages of reclamation if the level is below water level. Volume calculations should be made by performing before and after surveys of the reclamation area.

NOTE 2 Bulking of the material in the hopper of the dredger, and the loss of fines during excavation and overflow, both affect the volume of material discharged from the dredger.

Similarly, attention should be paid to potential volume changes arising from sediment transport and placement beyond the dredger and fines losses from reclamation weir boxes.

If the ground upon which reclamation fill material is to be placed is soft or is underlain by weak, compressible deposits, settlement beacons or plates should be installed on an appropriately spaced grid pattern prior to placement commencing. Settlement beacons are very vulnerable to disturbance during filling and should be of substantial construction.

NOTE 3 An alternative to the use of beacons for recording settlement is the installation of flat concrete slabs or steel plates. Upon completion of filling, the level of the plate should be determined by probing through the fill.

Where there exists a significant difference in the density of the foundation soils and that of the reclamation fill material, the level of the interface should be determined using cone penetrometer methods. The same method should be used to determine the final density of the fill materials.

A reclamation quality control programme should be undertaken to verify that the quality and performance of the placed fill material is in accordance with the design requirements.

When designing reclamation quality monitoring tests the following strategies should be appraised for their suitability:

- material testing: confirmation that fill material meets the specified fill criteria through material testing (soil sampling);
- behavioural monitoring: monitoring the behaviour of the placed reclamation fill to confirm that the specified criteria for settlement and deformation are being met;
- performance testing: tests the ability of the reclamation to perform under specific conditions (load tests);
- process monitoring: standards, codes of practice or trial tests can provide construction methodologies that, if properly followed, can ensure that the desired performance characteristics are met.

Table 18 provides an overview of the reclamation properties which should be measured and monitored during construction and the tests or monitoring techniques that are commonly implemented for each. The construction schedule should be planned to take into account the time required to complete each of the tests to avoid delays to the progress of the works.

15.16 Demobilization phase

Once the contractor responsible for the dredging/reclamation activities considers that the scope of work has been fulfilled to specification (which can include a requirement to maintain the dredged areas up to a contractually agreed handover date), a bathymetric/topographic survey should be undertaken to verify that the works have been completed in agreement with the agreed specifications.

If this can be confirmed the client should issue the final acceptance or notice of completion to the contractor. If the post-dredging survey demonstrates that the scope of work has not been completed, the deficiencies should be detailed and rectified before the work can be considered completed. Demobilization of equipment and personnel should occur in planned stages, similar to the mobilization phase, based on requirements.

Table 18 **Overview of reclamation properties to be measured and monitored during construction** *(1 of 2)*

Characteristic and property to measure and monitor		Purpose of measurement	Test or monitoring technique	Reference/Note
Geometry	Spatial dimensions of the reclamation and containment bunds	Verify that the geometrical design meets with the requirements	Bathymetric and topographic survey	BS 6349-1-1
Soil properties	Particle size distribution and angularity	Verify the material is well mixed and efficient compaction is achievable	Sieve analysis	BS 1377-2
			Sedimentation test	BS 1377-2
		Verify that the fill material meets the specified fill criteria	Comparison with standard samples and photographs	ASTM D2488
			Flakiness index	BS EN 933-3
			Shape index	BS EN 933-4
	Minimum and maximum dry density	Calculate the relative density	Minimum dry density test	ASTM D4254
			Proctor test	BS 1377-4
			Vibrating hammer	ASTM D7382
			Vibrating table	ASTM D4253
	Mineralogy	Evaluate wear and tear during construction and fill mechanical behaviour	Visual examination	Not standardized
			X-ray fluorescence or x-ray diffraction, microscopy	BS 5930:2015
Fill properties	Shear strength	Evaluate/monitor the resistance to shear stress failure.	Vane shear test	BS 1377-9
			Cone penetration test	BS 1377-9
		Verify bearing capacity to support applied loads and stability of installed slopes	Standard penetration test	BS EN ISO 22476-3, ASTM D1586
			California bearing ratio	BS 1377-9
			Plate loading test	BS 1377-9
			Zone load test	Not standardized
			Trial embankment	Not standardized
			Electrical piezometer	Monitoring instrument for excess pore pressure
			Inclinometer	Monitoring instrument for lateral deformation

Table 18 **Overview of reclamation properties to be measured and monitored during construction** *(2 of 2)*

Characteristic and property to measure and monitor		Purpose of measurement	Test or monitoring technique	Reference/Note
Fill properties *(cont.)*	Stiffness	Estimate/monitor deformation and settlement	Oedometer test	BS 1377-5
			Triaxial test	BS 1377-7
			California bearing ratio	BS 1377-9
			Settlement plate	Tool to monitor vertical settlement
			Extensometer	Tool to monitor vertical settlement
			Settlement hose	Tool to measure settlement distribution curves
	Density	Estimate other geotechnical parameters correlated with density, to calculate the relative compaction or the relative density	Weight in water and water displacement method	BS 1377-2
			Sand replacement or sand cone method	BS 1377-9
			Water replacement method	BS 1377-9
			Core cutter method or drive cylinder method	BS 1377-9
			Nuclear measurements	BS 1377-9
			Rubber balloon method	ASTM D2167
	Permeability	Estimate the consolidation time, the effects on shear strength and stability	Constant-head method	BS 1377-5
			Hydraulic consolidation cell	BS 1377-6
			Triaxial test	BS 1377-6

Annex A (informative) Seismic geophysical investigation techniques

A.1 Seismic refraction profiling

In the refraction method, the various velocities of propagation of acoustic energy through the seabed strata are measured. In order to achieve this, a pulse of acoustic energy is released by high explosive, sparker, air gun, etc.

The acoustic energy source can be attached to the hydrophone array, towed between the hydrophones or independently placed on the seabed. The choice of acoustic energy source and hydrophone array depends upon site conditions and needs careful consideration at the planning stage.

The apparent velocity recorded between any two hydrophones is the velocity of propagation in the stratum from which that energy has been refracted (this is typically referred to as seismic velocity). In this way a vertical profile can be derived and depths to points of velocity changes calculated.

A benefit of the method is that the seismic velocity of rocks depends upon their degree of weathering and fracturing (the velocity of refracted energy is reduced when it passes through fault or fracture zones). This therefore allows rock quality to be assessed horizontally along an array of hydrophones.

The refraction method complements the reflection method (see **A.2**) and might give satisfactory results when the reflection method has poor penetration or resolution due to organic sediments, coarse granular seabed surface, poor quality reflectors, variable geology or disturbance from shallow-water multiple reflectors. All seismic methods might achieve poor results where gas is present within the soils or rocks.

The main disadvantage of the method is the difficulty in placing the acoustic energy source and the hydrophone array on the seabed in a known position. Waves, currents, winds and water depths, etc. make field work slower than for the seismic reflection method. A further disadvantage is that the field data in their raw form are not instantly amenable to interpretation and for best results require a further level of processing than is typically required for the reflection method (in the case of single-channel seismic reflection profiling).

An advantage of the method is that it might provide a guide to whether the ground materials can be dredged directly or might require pre-treatment.

A.2 Seismic reflection profiling

In the reflection method, a pulse of acoustic energy is reflected off the seabed and those sub-seabed strata that give an acoustic impedance contrast resulting from increased density and/or velocity.

Acoustic energy is released by a piezoelectric or electromechanical transducer, sparker, airgun, etc. The following types of seismic source or sub-bottom profiler are available:

- echo sounder;
- pinger;
- chirper;
- parametric;
- boomer;
- sparker;
- airgun.

The order in which these are given corresponds loosely to progressively increasing acoustic energy output. These sources are attached to, or towed astern of, the survey vessel.

The reflected energy signal is detected by the transducer or by a hydrophone array towed astern of the vessel and subsequently digitized.

The sub-seabed is presented graphically as a deep echo sounding or geophysical time section with some seismic reflectors identifiable as geological strata.

The main advantages of the method are the speed of data recovery and the real-time presentation of data as a section.

For this reason, it is necessary to appreciate the relations between acoustic energy, signal frequency, resolution and penetration to select the optimum equipment for the site.

Higher frequencies are attenuated with depth so that penetration is achieved only with lower frequencies. However, the lower the frequency, the lower the vertical resolution. The coarser the sub-seabed materials, the greater the energy absorption and the lesser the penetration (see Table A.1).

Table A.1 **Indicative penetration depths for a range of soils**

Seismic source	**Typical operating frequency range**	**Indicative penetration below seabed**		
		Gravel	**Medium sand**	**Silt**
	kHz	m	m	m
Sparker	0.1 to 2	≤15	15 to 50	75 to 100+
Boomer	1 to 4	≤5	5 to 20	30 to 100
Parametric echo sounder	4 to 10	<1	≤5	5 to 30
Pinger	4 to 15	<1	≤5	5 to 30
Chirp	3 to 20	≤2	≤10	5 to 50

NOTE There are many variables that affect the effective sub-seabed penetration that can be achieved with a sub-bottom profiler system, such as masking by gas or multiple reflections. The values given in the table above are therefore to be treated as indicative only.

Sea conditions, especially waves, have an appreciable effect on record quality. When the transducer is towed below the surface the effect of waves is much reduced, although snatching and heaving from an unstable survey vessel reduce record quality to below acceptable levels. Swell compensators can be used to extend the working conditions for surface-towed equipment.

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