

BS 6349-1-3:2012



BSI Standards Publication

Maritime works

**Part 1-3: General – Code of practice
for geotechnical design**

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Summary of pages

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Foreword

Publishing information

This part of BS 6349 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 September 2012. It was prepared by Technical Committee CB/502, *Maritime works*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

Together with BS 6349-1-1, BS 6349-1-2 and BS 6349-1-4, this part of BS 6349 supersedes BS 6349-1:2000, which will be withdrawn when all four of the new subparts have been published.

Relationship with other publications

BS 6349 is published in the following parts:

- Part 1-1: *General – Code of practice for planning and design for operations*; ¹⁾
- Part 1-2: *General – Code of practice for assessment of actions*; ¹⁾
- Part 1-3: *General – Code of practice for geotechnical design*;
- Part 1-4: *General – Code of practice for materials*; ¹⁾
- 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 intended to be read in conjunction with BS EN 1997-1 and BS EN 1997-2.

Information about this document

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

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

The principal change in respect of the geotechnical content is that the document has been edited to be compatible with relevant Eurocodes.

The new BS 6349-1-3 is split into two main sections covering site investigation and geotechnical design, with annexes containing informative text regarding site investigation and testing procedures and typical ground properties.

¹⁾ In preparation.

Use of this document

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

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

Presentational conventions

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

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

Contractual and legal considerations

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

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

Section 1: General

1 Scope

This part of BS 6349 gives recommendations for geotechnical activities associated with the design and implementation of maritime works. It covers site investigation and geotechnical design, and gives additional guidance on testing procedures and typical ground properties.

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.

BS 6031 *Code of practice for earthworks*

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

BS 8006-1, *Code of practice for strengthened/reinforced soils and other fills*

BS EN 1538, *Execution of special geotechnical works – Diaphragm walls*

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

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

BS EN 1997-2, *Eurocode 7 – Geotechnical design – Part 2: Ground investigation and testing*²⁾

BS EN 1998 (all parts), *Eurocode 8 – Design of structures for earthquake resistance*

BS EN 14731, *Execution of special geotechnical works – Ground treatment by deep vibration*

BS EN ISO 22475-1, *Geotechnical investigation and testing – Sampling methods and groundwater measurements – Part 1: Technical principles for execution*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

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

3.1.1 extreme high water (EHW)

highest level that can be predicted to occur as a combination of astronomical tides, positive or negative surges, seiches and freshwater flow

3.1.2 extreme low water (ELW)

lowest level that can be predicted to occur as a combination of astronomical tides, positive or negative surges, seiches and freshwater flow

3.1.3 highest astronomical tide (HAT)

highest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions

²⁾ This standard also gives informative references to BS EN 1997-2.

3.1.4 lowest astronomical tide (LAT)

lowest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions

NOTE It is often the level selected as the datum for soundings on navigational charts.

3.1.5 mean high water springs (MHWS)

average, over a long period of time, of the heights of two successive high waters at springs

3.1.6 mean low water springs (MLWS)

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

3.1.7 mean sea level (MSL)

average level of the sea surface over a long period

NOTE This is preferably 18.6 years (one cycle of the moon's nodes), or the average level that would exist in the absence of tides.

3.1.8 neap tide

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

3.1.9 range

difference in height between one high water and the preceding or following low water

3.1.10 return period

period that, on average, separates two occurrences

3.1.11 spring tide

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

3.2 Symbols

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

B_e	breadth of earth-retaining structure
c_u	undrained shear strength of soil
c'	effective cohesion
d_p	depth of pile toe from dredge level
d_t	depth of tension crack
H_R	retained height of structure
K_A	coefficient of active earth pressure
K_p	coefficient of passive earth resistance
P_A	total active force
P_p	total passive force
z	depth at which a calculation is to be made
γ	density of soil
γ_s	effective bulk weight density of saturated soil
γ_w	weight density of groundwater
$\delta_{\max}$	maximum angle of friction between soil and structure

φ_r	angle of soil shearing resistance
φ'	effective angle of soil shearing resistance

3.3 Abbreviations

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

DGPS	differential global positioning system
ELW	extreme low water
EHW	extreme high water
GPS	global positioning system
GWL	groundwater level
HAT	highest astronomic tide
LAT	lowest astronomic tide
MHWS	mean high water springs
MLWS	mean low water springs
RQD	rock quality designation
SCR	solid core recovery
SLS	serviceability limit state
SPT	standard penetration test
TCR	total core recovery
ULS	ultimate limit state

Section 2: Site investigation

4 General

A study of the surface and subsurface conditions at and near the site of proposed works should be carried out as an essential preliminary to the design of maritime structures. Much can be learnt from an early assessment of the basic geology of the area, with particular attention to existing morphological processes. This study should provide a basis for determining the extent of geotechnical investigation and laboratory testing required and aid in the interpretation and evaluation of the information obtained.

The study should include assessment of the characteristics of soil or rock formations, which can be retained by structures or provide their foundations, or which can be incorporated in or affected by earthworks in the form of dredging and reclamation. It should also include the collection of data on locally available materials for use in constructing the works, including the long-term durability of these materials in the particular maritime environment.

NOTE 1 Site investigation prior to the planning, design and construction of dry docks is of greater importance than for many other structures of similar value or size. The subsoil conditions can greatly influence the choice of construction method.

NOTE 2 Ground investigation practice is described in BS EN 1997-2. Many of the methods and tools widely employed in the investigation of ground on land can be adapted to marine applications. The geology of the coastal margins is almost invariably complex. The apparent savings that can result from carrying out a reduced ground investigation are in many cases outweighed by increased disruption of the works due to unforeseen ground conditions. Preliminary guidance is given in Annex A.

NOTE 3 Information on geophysical surveying techniques is provided in CIRIA Report C562 [1].

These studies all form part of a site investigation for the works, and the geological, geophysical and geotechnical aspects of the investigation should be carried out in accordance with Clause 5, Clause 6 and Clause 7. The collection of data for the site should be followed by the selection of design parameters (see Clause 12) from which the behaviour of soils and rocks can be predicted. The next stage in the geotechnical design process is the calculation of earth pressures and earth resistance, which should then be used, with other actions, to check the adequacy of the proposed works.

NOTE 4 Appropriate methods of calculation, drawing attention to the interdependence and interaction of different types of structure and their surrounding soil masses, are described in general terms in Clause 10.

NOTE 5 Descriptions of particular methods of construction are not appropriate to this part of BS 6349, and the effects of constructional methods and procedures are normally referred to only where these could affect stability or design actions. However, because of its essentially geotechnical nature, the use of support fluids in excavations has been included and is described in 16.2.3.

Maritime structures will normally fall within geotechnical category 2 as defined in BS EN 1997-1, but in situations where complex or unusual engineering is involved, structures or parts of structures should be assumed to be in geotechnical category 3. The ground investigation requirements will normally be at least those indicated in BS EN 1997-2, but additional investigations and more advanced tests might be required, dependent upon the circumstances that place the structure or structural element in geotechnical category 3.

5 Planning of ground investigations

5.1 Existing data sources

The first stage of the site investigation should be a desk study of available published and unpublished information.

NOTE Sources of information relevant to maritime structures include:

- Admiralty charts and handbooks (the Pilot series) [2];
- Ordnance Survey maps and old maps;
- meteorological data;
- national and local government records;
- geological maps and memoirs;
- aerial and satellite photographs;
- information on existing works in the locality.

Admiralty charts and Ordnance Survey maps covering a long period of years should be studied for evidence of changes in seabed levels and in the configuration of the foreshore that can indicate areas of erosion or accretion.

5.2 Site reconnaissance

A thorough visual examination of the site should be made. Exposures of soil or rock on the foreshore or coastal cliffs should be examined to obtain preliminary information on the geology of the site and to obtain any evidence of erosion, accretion or instability. The appearance of existing structures and earthworks should be examined for signs of subsidence or ground heave.

The landforms of the foreshore should be studied in relation to seabed contours and information on littoral currents, in order to delineate areas of active erosion and accretion and to provide a basis for predicting changes that can result from construction of the new works.

NOTE 1 Many maritime sites are areas of recent geomorphological development, and such processes are more active if the site is nearer to the shore. The timescale of these changes is often comparable with the lifespan of the project and they can often be the most significant feature of the ground conditions affecting many maritime works.

NOTE 2 It is important to recognize characteristic features of coastal sediments. Those laid down in estuarine conditions are commonly flocculated silts and clays, although the flocs can also entrap coarser sediments brought into the estuary by coastal currents. Thus estuarine deposits are often characterized by great depths of very fine soils. Deltaic deposits have been laid down seasonally and therefore usually contain alternating bands of coarse and fine sediments corresponding to the variation in transporting power of the river in winter and in summer. Beach deposits often result from coastal rather than river transport and are usually of medium to coarse size. They can arise from small embayments and would therefore be very local, whereas they can occasionally be from long lengths of foreshore.

Organically formed deposits are frequently of significance. They are mainly calcareous, of which coral and calcite – excluding algae that cement detrital material – are two examples. All such materials are subject to leaching and therefore caverns can form. Particular attention should be given to such a possibility, especially where major structures such as breakwaters or dry docks are proposed. Sedimentary rocks formed by induration are also subject to cavernous formation, so a site investigation programme arranged to locate such features should be adopted in these types of soils.

Similarly, attention should be paid to carbonaceous organic deposits such as peat or inorganic soils with a modest organic content, as these materials are compressible and can be difficult to work with.

5.3 Selection of sampling methods

The quality of a soil, rock or groundwater sample is influenced by the geological and hydrogeological conditions, the choice and execution of the drilling and/or the sampling method, handling, transport and storage of the samples. The selection of drilling and sampling methods for soil and rock, and measurement of groundwater, should be in accordance with BS EN ISO 22475-1.

5.4 Layout of boreholes and trial excavations

The layout of exploratory boreholes, trial pits and shafts should cover the full longitudinal and lateral extent of the works. Boreholes for wharves and quay walls should be spaced at intervals along the waterside frontage of the structure. In a transverse direction, the boreholes should be sited to include exploration of the ground conditions for any anchorages on the landward side. The possible risks for instability due to a rotational slip should also be investigated.

NOTE 1 This encompasses the shoreside works and any dredging of the seabed for berths on the water side of the site (see Figure 1).

NOTE 2 General guidance on the spacing of boreholes is given in BS EN 1997-2.

Boreholes for jetties should be sited along the line of the berthing heads and mooring structures and along the line of the approach structures. At least one borehole should be close to the planned position of each major component of the structure and, in general, boreholes should not be more than 50 m apart.

For dry docks, the number and layout of boreholes cannot be defined with certainty before the investigation work is started, but ten equally spaced along the line of each dock wall and along the centre if dewatering works are envisaged should be the minimum. If variations in level, in thickness or in the properties of various layers of subsoil are revealed, the number of the boreholes should be increased until a sufficient understanding of the subsoil conditions can be attained.

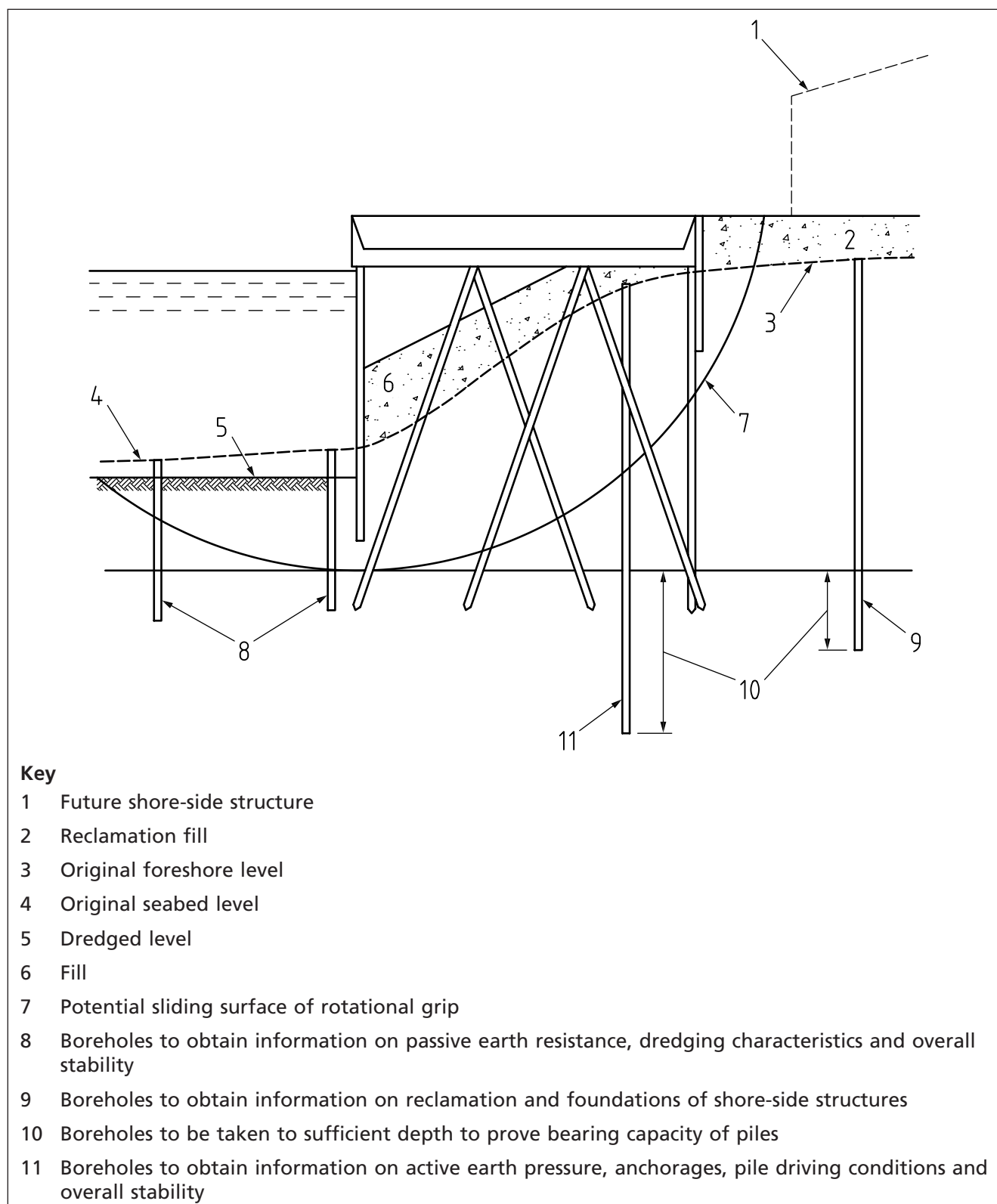
For a simple ship building berth there might be a need for a retaining wall at the lower end to provide deep water, so the site investigation should take into account that sheet piling might be needed at that location.

The remainder of the site should be investigated to ascertain whether the allowable ground pressure is sufficient to support shipyard hard standing areas by direct loading, or whether bearing piles will be required and if so, the site investigation should establish the likely length of such piles.

For a shiplift, the boreholes should be positioned on the lines of the piers so that the size and length of the piles, which might be heavily loaded, can be determined.

The layout of boreholes for dredging and reclamation work should be based on the extent of the operations required and on the variability of the subsoil.

Figure 1 Location and depth of boreholes for piled wharf



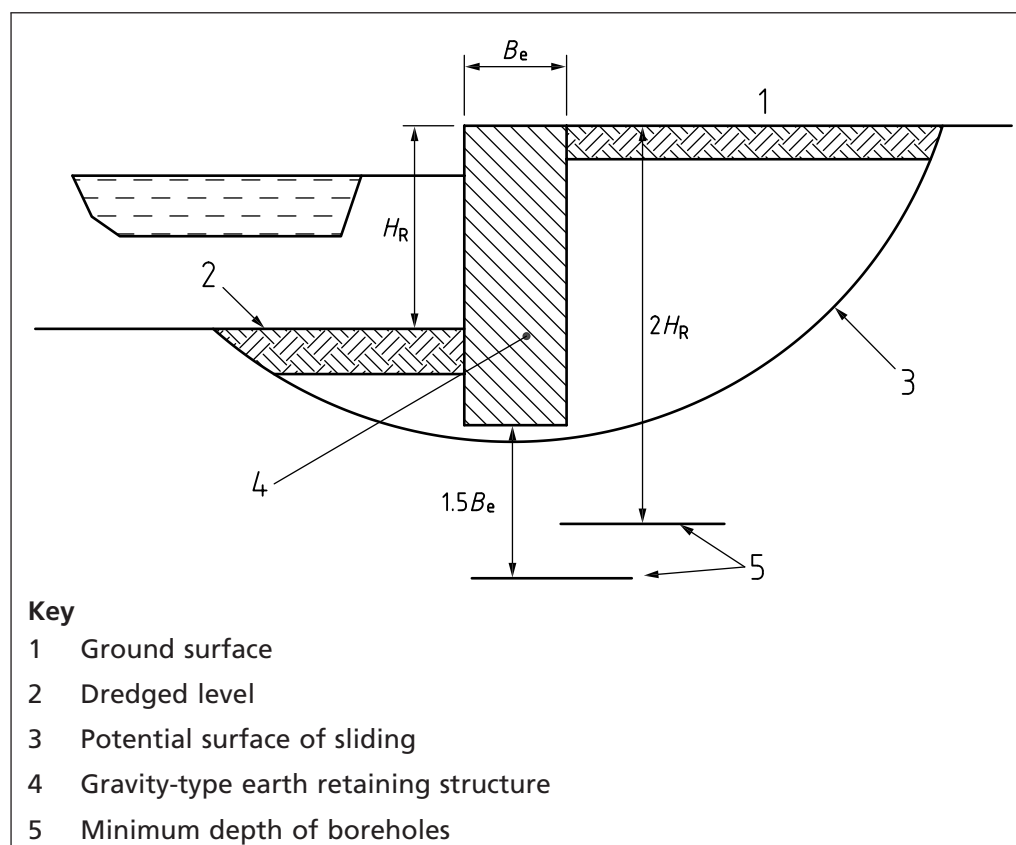
5.5 Depth of boreholes

NOTE Guidance on the depth of boreholes is given in BS EN 1997-2.

In order to obtain soil parameters to form the basis of slope stability analyses, the depth of the boreholes should cover the likely maximum depth and lateral extent of slip surfaces (see Figure 1).

Boreholes should be drilled to sufficient depth to investigate the foundation conditions and stability against a rotational shear slide (see Figure 2).

Figure 2 **Depth of boreholes in relation to retained height of soil and width of quay wall**



In order to obtain information on the stability and deformation of the foundations of gravity-type quay walls such as sheet pile cellular structures, or monoliths, the boreholes should be drilled to a depth below the base of the structure of 1.5 times the width of the structure or pile group supporting the structure (see Figure 2).

Boreholes drilled in rock formations should be taken to a depth sufficient to explore the thickness and characteristics of any weathered rock that could affect the behaviour of slopes and foundations. Where heavily loaded structures depend for their stability on the strength of fresh unweathered rock, the boreholes should be drilled to a depth of at least 3 m into such material to prove its quality and continuity.

In most cases where dredging is required, the depth of ground to be removed is limited to a few metres. In these instances, a relatively simple method of ground investigation, such as vibrocoreing, might be adequate. In contrast, where difficult materials such as rock have to be removed by dredging, samples should be obtained by drilling from a floating or fixed structure.

Dredging below the seabed can involve removal of soil from below the designed dredge level to conform to the requirements of a particular excavation technique, and the possibility of future deeper dredging should be taken into account. Therefore boreholes in dredging areas should be extended below design dredge level until a stratum of known geological characteristics is encountered or to a depth of 5 m below design dredge level, whichever is the lesser. 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.

Deep excavations can involve a risk of uplift of the base, due to shear failure in soft to firm clays, or to the occurrence of groundwater under pressure in pervious layers underlying impervious soils or rocks at the base of the excavations; the possibility of heave of the floor of the excavation due to swelling of clay soils might also need to be taken into account. Boreholes should be taken to a sufficient depth to investigate the presence or absence of such hazards.

Where groundwater lowering schemes for excavations, or installations to cut-off inflow into excavations, are proposed, the boreholes should be drilled completely through the water-bearing formation to locate the underlying impervious horizon, and far enough into the stratum to prove continuity.

5.6 Sealing of boreholes

Where boreholes are required in the area of a deep excavation for structures such as drydocks or other deep basins, they should be properly sealed before being abandoned, to prevent leakage into the excavation and contamination of or connections between aquifers. Sealing should be in accordance with BS EN ISO 22475-1, with a material of equal or less permeability than the original ground but preferably concrete.

NOTE There have been cases of leakage into dock excavations from abandoned boreholes which have been extremely difficult to seal.

5.7 Ground investigations over water

5.7.1 General

Site investigations conducted over water are more difficult and time-consuming than comparable investigations conducted on land, and there might be a temptation to economize by reducing the scope of the investigation. The extent of the requirement for ground investigations should be realistically assessed, since economies in this direction can turn out to be false. Geophysical surveys are extensively used at the planning stage to provide additional geological information for the ground beneath the construction site and the positioning of the investigation boreholes.

The sinking of boreholes below water presents special difficulties, particularly with regard to rotary diamond core drilling. Working platforms can be fixed, floating or heave-compensated. A conductor pipe should be suspended from the platform to protect the flexible investigation string from the force of currents. Percussion boring and rotary drilling techniques, both conventional and wireline, may be employed. Geophysical logging techniques are often employed to augment the information obtained from the borehole programme.

Overwater work is always subject to a risk of delay because of unsuitable weather. For any given weather condition, the amount of delay depends on the type and size of the installation. In general, the larger the staging or floating craft, the smaller the risk of delay due to weather but, on the other hand, the greater the operating costs. When planning an overwater investigation, a realistic allowance should be made for the possible cost of weather delays.

Sinking boreholes between high and low tide levels may be achieved using scaffold stagings or platforms (see 5.7.2), by using flat-bottomed pontoons or shallow draft jack-up rigs or by moving boring rigs to the location during periods permitted by the tides.

NOTE 1 The scope of the work, including the methods of boring, sampling and in-situ testing, requires careful consideration depending on the particular difficulties of the site. Attention is drawn to health and safety requirements, navigational warnings, and the regulations of governmental departments and other authorities that might be relevant when working over water.

NOTE 2 General guidance on geotechnical investigation and testing is given in BS EN ISO 22475-1.

5.7.2 Stages and platforms

NOTE 1 Where stable working platforms are available or can be provided, such as oil drilling platforms and jetties or purpose-built scaffold stages and drilling towers, it is normally possible to use conventional dry-land site investigation boring equipment and conventional methods of sampling and in-situ testing. When working from existing structures, it might be necessary to construct a cantilever platform over the water on which to mount the boring rig.

When boring close to the shore in relatively shallow water, the convenience of constructing a scaffold or other tower at the borehole location to avoid working in water should be considered, although a means of transporting the boring equipment to the tower should be provided.

NOTE 2 Some towers are so constructed that they can be moved from one borehole location to another without having to be dismantled. Jack-up platforms and special craft fitted with spud legs can be floated into position and then jacked out of the water to stand on their legs. These fulfil the requirement for a fixed working platform and provide manoeuvrability.

The design of all staging, towers and platforms should take into account the capability of the sea-bed strata to withstand the foundation actions. The design should also include the effects of the fluctuating water levels due to tides, waves and swell conditions, and it is essential that such constructions be sufficiently strong for the boring operations to resist waves, tidal flow, other currents and floating debris.

5.7.3 Floating craft

The suitability of floating craft as an operating platform should be based on:

- the geotechnical properties of the sea bed;
- the likely weather conditions;
- the depth of water;
- the strength of currents;
- whether the water is sheltered or open; and
- whether accommodation is required on board for personnel.

In inland water, a small anchored barge might suffice, but in less sheltered waters a barge should be of substantial size, and anchors should be correspondingly heavy.

NOTE In offshore conditions, a ship is often employed, and it might then be possible to accommodate the personnel on board, reducing the need for auxiliary supply vessels.

In order to achieve high quality coring, constant pressure should be maintained between the drill bit and the bottom of the hole. For the deeper waters, particularly with swells, special techniques of heave compensation should be adopted. The types of sample to be recovered and in-situ tests to be performed should be selected on the basis that special equipment is employed when boring from floating craft and that the working platform might move.

5.7.4 Setting-out and locating borehole positions

Modern positioning systems, such as the global positioning system (GPS) and the differential global positioning system (DGPS) should be adopted where practicable, because they are simple to operate, provide accurate surveying data and eliminate unnecessary risks to personnel in terms of health and safety. Close inshore, it is often possible to set out boreholes satisfactorily by using measurements to features onshore or by lining in from previously placed shore markers. Where necessary, theodolite observations can be taken from land-based stations.

Further offshore, it is necessary to use electronic methods of position fixing. Electronic methods are also advantageous in poor visibility conditions.

5.7.5 Determination of reduced level of bed and strata boundaries

For correct interpretation and reduction to an appropriate datum level, tidal corrections should be applied to the data obtained, particularly in the near-shore environment. Standard tide tables for the area of interest may be used, but reduced levels may also be transferred to a boring vessel from shore by setting up a tide gauge close inshore; this is read at frequent intervals throughout the tidal cycles, and readings of water depth are taken at the same time on the operating platform.

NOTE Corrections might be necessary to allow for tidal variations when the tide gauge reading and the one from the vessel vary significantly. Some methods of heave compensation on the drilling vessel automatically make this correction. The depth of water can be difficult to determine where the seabed is very soft, and reduced levels of strata boundaries would then become less accurate.

6 Groundwater investigations

NOTE 1 General guidance on groundwater sampling and measurement is given in BS EN ISO 22475-1.

The piezometric head of pore water in soils is a critical factor in the analysis of the stability of excavated slopes and earth-retaining structures. Fluctuations in tidal or seasonal levels in the waterway can cause corresponding fluctuations in piezometric head in the groundwater. The effects on groundwater levels of meteorological surges in sea levels should also be taken into account. It is therefore important to establish the relationships by means of simultaneous observations of waterway levels and groundwater levels in piezometers, installed on the landward side at various distances back from the waterside face of a structure or slope. The observations should be made to cover periods of spring and neap tides, and if possible they should cover periods of seasonal peak conditions in waterway levels.

NOTE 2 Observations of the salinity of the groundwater at various positions back from the waterside face can indicate the relative influences of saline water and non-saline groundwater on piezometric levels.

The possible existence of groundwater under artesian or sub-artesian pressure within pervious soil layers confined by impervious strata should be investigated by observations in piezometers installed within the pervious layers.

Most borehole or drill holes require the addition of water to facilitate progress, but it is essential that care is taken to maintain water equilibrium in the boreholes during the drilling process, in order to obtain satisfactory samples and conditions for in-situ tests, such as the standard penetration tests (SPT). If artesian conditions are present, the top of the borehole tube should be maintained at a level at least equal to the artesian head. Any water added will mask zones of inflow and changes in pressure, and so the readings taken during drilling are often not representative of in-situ conditions. Water level or pressure monitoring instruments should be installed to determine the equilibrium conditions (see BS EN ISO 22475-1).

Where groundwater lowering schemes are proposed to enable the construction of dock basins or lock chambers, the groundwater investigations should include measurements of the permeability of the soil in situ.

NOTE 3 Information on permeability testing of soils is given in BS EN 1997-2.

7 Field tests in soil and rock

7.1 Planning

Field tests should be planned with the following in mind:

- geology/stratification of the ground;
- type of structure, the possible foundation and the anticipated work during the construction;
- type of geotechnical parameter required;
- design method to be adopted.

7.2 Normal field tests

The following field tests should be used as appropriate to obtain information about the site. They may be used individually or in combination:

- cone penetration test;
- pressuremeter and dilatometer tests;
- standard penetration test;
- dynamic probing;
- weight sounding test;
- field vane test;
- flat dilatometer test;
- plate loading test.

NOTE Information on the tests listed above is given in the various parts of BS EN ISO 22476. General guidance on testing methods is given in BS EN 1997-2.

7.3 Other field tests

7.3.1 Determination of earth pressure coefficient at rest

Where earth-retaining structures are to be formed directly against the soil to be retained, in-situ measurements of the coefficient of earth pressure at rest should be obtained.

7.3.2 Detection of underground movements at depth

Where maritime works are to be constructed on sites suspected of having suffered previous instability, movements should be monitored in the ground at various depths in advance of construction, followed by similar observations during, and for as long as possible after, construction of the project. This form of monitoring also forms part of investigations of instability, which might arise as a result of earthworks associated with shoreside structures.

Trial pits and trenches may be used to determine the location of existing shear surfaces at relatively shallow depths. This method becomes increasingly more difficult with depth, and where there is reason to believe that movement is actually taking place or it is feared that movement is imminent, inclinometers installed in boreholes should be used. Inclinometers, unlike simple slip indicators, can show the precise direction in which the soil has sheared between any two occasions of measurement. The equipment should be used for cases where the rate of movement is small or for installation in anticipation of movement. If used when movement is relatively rapid, the inclinometer probe is soon unable to pass the shear surface, and hence all measurement of movement below this level ceases to be possible.

The annular space between ground and the special casing should be grouted.

7.3.3 Field tests for dredging

Where possible, in-situ penetration testing should be undertaken in addition to the recovery of samples, in order that direct measurement of in-situ material strength can be carried out. Vibrocoring, which is less expensive, might give little indication, particularly in sands or gravels, of the in-situ strength or degree of consolidation of the material.

Relatively small differences in strength can have a significant effect on dredging production. In sands, a high degree of consolidation will adversely affect the dredgeability of the soil; in clays, high shear strengths will also result in much lower production, as will greater crushing strength in weak rocks.

Soil strengths also influence the stability of side slopes, which can be of particular importance in the dredging of temporary trenches for the laying of pipes, outfalls or other services. Very weak or mobile bed materials can result in rapid infill of the trench, and regular dredging should therefore be undertaken up to the point of the pipe launching or placement, with a consequent substantial increase in the cost.

NOTE 1 The removal of rock by dredging will almost certainly involve the mobilization of specialist equipment so that even for small quantities, costs will be relatively high.

Where the dredging of rock, with or without pre-treatment, is anticipated, a thorough investigation with adequate sampling and laboratory testing of recovered rock cores should be undertaken, to allow an accurate assessment and description of the condition of the rock in relation to fracture state and rock quality to be made. Information about rock strength, which affects the energy required to achieve removal, and abrasiveness, which affects the rate of wear of dredger components, should be obtained.

NOTE 2 If fracturing is sufficiently close and open, pre-treatment might not be necessary. If pre-treatment is necessary, fractured rock can impede drilling by causing the drill to jam.

A number of in-situ tests or field assessments may be carried out, particularly in sedimentary rocks, to assess strength or resistance to cutting. These include:

- borehole logging;
- total core recovery (TCR);

- *solid core recovery (SCR);*
- *rock quality designation (RQD);*
- *drillability;*
- *velocity of propagation of sound;*
- *standard penetration tests.*

Further information on in-situ tests and assessments is given in BS EN 1997-2.

NOTE 3 Information on the testing procedures for soil and rock is given in Annex B.

7.4 Trial dredging

COMMENTARY ON 7.4

Trial dredging might be the only satisfactory way of predicting the performance of particular dredging plant on a particular site. The cost of trial dredging can be unacceptably high unless suitable plant is already available and located on the site, but there are situations in which it is recommended.

Trial dredging should be undertaken when the soil conditions within the area to be dredged are known to be extremely complex with a wide variety of soil types and strengths, and a pattern of sampling by boreholes or some other method might not provide a truly representative picture of the overall condition.

It should also be considered where trench or channel formations are proposed that would cut across deposits of doubtful stability or across the paths of substantial sediment transport routes. In such cases, the formation of a trial section by dredging, and the careful monitoring of the performance of that trial section, might provide the best means of accurately forecasting the performance of the finished formation.

Trial dredging should also be employed in situations where there is no satisfactory conventional soil investigation method that is capable of sampling the true ground conditions. This includes sites that contain particle sizes too large to be recovered intact by normal sampling methods. Hence trial dredging is appropriate in areas known to contain very coarse soils, namely cobbles and boulders, typically of glacial origin.

The performance of the dredger and of the dredged formation should be monitored throughout the trial, and key parameters should be pre-selected and carefully recorded during execution.

Account should be taken of changes in weather conditions during these trials to assess plant performance.

7.5 Sampling of soils, rock and groundwater

The sampling of soils, rock and groundwater should be carried out in accordance with BS EN ISO 22475-1, in the context of geotechnical testing as described in BS EN 1997-1 and BS EN 1997-2.

8 Laboratory tests on soil and rock

The testing of soils and rock should be carried out in accordance with BS EN 1997-2.

NOTE CEN ISO/TS 17892-1 to CEN ISO/TS 17892-13 are currently in preparation, and will give methods for determining many of the properties listed below.

- a) *The following properties are important when determining the engineering performance of soil and rocks.*
- *bulk density;*
 - *water content;*
 - *particle density;*
 - *consistency limits;*
 - *organic content;*
 - *plasticity;*
 - *particle size grading;*
 - *chemistry;*
 - *compressive strength;*
 - *tensile strength;*
 - *drained/undrained shear strength;*
 - *compressibility;*
 - *permeability;*
 - *porosity.*
- b) *The following rock properties are important in providing the information necessary to assess whether, or how, rock can be dredged, with or without pre-treatment:*
- *density;*
 - *hardness;*
 - *abrasiveness;*
 - *porosity;*
 - *tensile strength;*
 - *compressive strength.*

9 Geotechnical design report

NOTE Recommendations concerning the geotechnical design report are given in BS EN 1997-1.

The geotechnical design report should include the geotechnical investigation report, details of which are given in BS EN 1997-1, and should indicate the datum adopted for any geotechnical investigation, design calculations and the scheme drawings. It should also indicate the relationship between ordnance datum and chart datum.