

Maritime structures —

Part 5: Code of practice for dredging and land reclamation

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Committees responsible for this British Standard

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- Association of Consulting Engineers
- British Ports Federation and the National Association of Ports Employers
- British Steel Industry
- Concrete Society
- Department of the Environment (Property Services Agency)
- Department of Transport (Marine Directorate)
- Federation of Civil Engineering Contractors
- Health and Safety Executive
- Institution of Civil Engineers
- Institution of Structural Engineers
- Oil Companies International Marine Forum

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Publication(s) referred to	Inside back cover

Foreword

This Part of BS 6349 has been prepared under the direction of the Civil Engineering and Building Structures Standards Policy Committee.

This code of practice contains material which is both for the information and guidance of engineers and material which forms recommendations on good practice. As such, conformity with its recommendations is not obligatory and variations from its recommendations may well be justified in special circumstances and engineering judgement should be applied to determine when the recommendations of the code should be followed and when they should not.

A code of practice is intended for the use of engineers having some knowledge of the subject. It embodies the experience of engineers successfully engaged on the design and construction of the particular class of works so that other reasonably qualified engineers may use it as a basis for the design of similar works.

It is not intended that it should be used by engineers who have no knowledge of the subject nor that it should be used by non-engineers.

A code of practice represents good practice at the time it is written and, inevitably, technical developments may render parts of it obsolescent in time. It is the responsibility of engineers concerned with the design and construction of works to remain conversant with developments in good practice, which have taken place since publication of the code.

Following suggestions from the Maritime and Waterways Board of the Institution of Civil Engineers, the Standards Committee for Civil Engineering Codes of Practice set up an ad hoc panel to make further studies. The panel's report, presented in 1975, concluded that existing British codes were inadequate for the special aspects of maritime structures and that there was a need for such a code.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

The standard will be issued in seven Parts as follows:

- *Part 1¹⁾: General criteria;*
- *Part 2⁴⁾: Design of quay walls, jetties and dolphins;*
- *Part 3⁴⁾: Design of dry docks, locks, slipways and shipbuilding berths, shiplifts and dock and lock gates;*
- *Part 4⁴⁾: Design of fendering and mooring systems;*
- *Part 5⁴⁾: Code of practice for dredging and land reclamation;*
- *Part 6⁴⁾: Design of inshore moorings and floating structures;*
- *Part 7²⁾: Guide for the design and construction of breakwaters.*

In BS 6349-1 recommendations are given to assist clients and engineers to obtain the basic data relevant to the design of any maritime structure.

The full list of the organizations which have taken part in the work of the Technical Committee responsible for BS 6349-5 is given on the inside front cover. The Chairman of the Committee was Mr J T Williams OBE, CEng, FICE, FIStructE and the following were members of the Technical Committee.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to viii, pages 1 to 126, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1.1 Scope

This Part of BS 6349 gives guidance and recommendations on dredging and land reclamation. It is intended principally for use in respect of dredging operations that involve the use of floating plant, although many of the recommendations apply to the use of plant operated from the land.

Owing to the nature of dredging, most of the text is descriptive. Much of the practice of dredging is dependent on the characteristics of the particular plant employed. For this reason, considerable space is devoted to describing the character and mode of operation of dredging and ancillary plant. A general description is given in the main text with further detail given in Appendix A.

Site investigations, particularly ground investigation, are also covered at length. Dredging operations are highly sensitive to site conditions, particularly soil and rock conditions. In the past, inadequate or inaccurate information concerning these matters has frequently been a serious source of disruption and dispute. It is therefore important that these matters receive proper attention from the moment of conception of any work that involves dredging or land reclamation.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover. The numbers in square brackets used throughout the text relate to the bibliographic references given in Appendix C.

1.2 Definitions

For the purposes of this Part of BS 6349 the following definitions apply.

1.2.1

agitation dredging

the practice of lifting sediment from the sea bed and into suspension for dispersion by local currents

1.2.2

bucket capacity

the maximum volume of liquid that can be contained in the bucket when filled to the level of the cutting edge

1.2.3

bulking factor

a factor representing the increase in volume of dredged material relative to its volume before dredging

1.2.4

capping

the use of a clean dredged material as cover for contaminated dredged material disposed of in open water as a means of isolating the contaminated material from the marine environment

1.2.5

diffuser

a device placed at the outlet of a discharge pipeline to reduce the velocity of outflow and to reduce turbulence

1.2.6

draught

the vertical distance from the waterline to the deepest point on the keel of a vessel

1.2.7

dredger (or dredge)

Mechanical, hydraulic or electrical plant used for dredging

1.2.8

dredging

the removal from beneath water and raising through water of soil, rock or debris

1.2.9

haul distance

the one-way distance that a vessel has to travel to a disposal area

1.2.10

hopper capacity

the maximum total capacity of the hoppers of a hopper dredger or hopper barge

1.2.11

in situ density

the unit mass of bottom materials in their undisturbed state

1.2.12

land reclamation

the exclusion of the sea, or other mass of water, from areas that were previously submerged, or subject to inundation, by the raising of land levels primarily using materials recovered by dredging processes

1.2.13

maintenance dredging

dredging to restore or maintain a depth that existed previously, but has been reduced by the deposition of sediments

1.2.14

overdredging

the dredging of material from levels below that specified or required

1.2.15

sea bed

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

1.2.16

siltation

the process of the deposition of sediments in water

1.2.17

spuds

devices for holding a dredger in position and about which the dredger swings

Section 2. Site surveys and investigations

2.1 General

The performance of any dredger is directly related to the characteristics of the soil or rock to be dredged and the environment in which the work is to be carried out. Only with an adequate knowledge of these can the most appropriate type of plant be selected and the rate of production and duration of the work be estimated.

This applies to all types of dredging, including maintenance dredging. It follows that an adequate knowledge of the site conditions is a prerequisite of any dredging or reclamation work. Some information may exist as a result of earlier work on or in the vicinity of the site, and if so it should be evaluated by means of a desk study. Often, however, adequate information is not available and should be obtained by means of a site investigation.

In addition to the more obvious requirement to determine the site bathymetry and soil conditions, there are other matters that should be investigated. These include checks for the following:

- a) excessive debris or foreign matter;
- b) services;
- c) munitions;
- d) sensitive structures or installations;
- e) possible air draught or width restrictions to the passage of dredging or ancillary plant;
- f) as an extension of the soils investigation, the possible presence of boulders, which may have an excessively disruptive effect on dredging operations.

2.2 Hydrographic survey

2.2.1 General

The purpose of a hydrographic survey in relation to dredging work is to provide detail of sea bed levels. Sea bed levels have to be known before dredging work can be properly planned and quantities estimated. The choice of dredging plant, its working times and safe navigation are all affected by sea bed levels. A hydrographic survey may also include the measurement of currents, waves, water properties, sea bed characteristics, etc. Where appropriate, these matters are dealt with in subsequent clauses. In this clause, only the determination of sea bed levels at specific locations is considered.

General detail of the sea bed is given on Admiralty Charts, published in the UK by the Hydrographer of the Navy [1]. Where these charts are prepared from surveys of UK origin, more comprehensive information may be obtainable from the Hydrographer who may also hold additional information on wrecks, etc. beyond that shown on the published chart. Admiralty charts are prepared for navigation rather than for engineering purposes. Inshore detail is often sparse and the survey information may be many years out of date. For engineering purposes, a suitably detailed survey should be made.

The general principles of a hydrographic survey are covered in 8.1 to 8.7 of BS 6349-1:1984. More detailed information is to be found in [2]. In this clause, only matters of special relevance to dredging are considered.

2.2.2 Bathymetric detail

Survey detail or density should reflect the principal purpose of the survey. If the objective is to show that the minimum design depth for navigation has been achieved, particularly when dredging in rock is involved, survey lines should be very close. The actual distance apart will depend upon water depth and the beam angle of the echo sounder involved. The objective should be to achieve signal overlap at the sea bed. When rock dredging is involved, other additional survey methods, such as side-scan sonar or bar sweeps, should be employed (see 2.2.6 and 12.12).

If the objective of the survey is to provide a basis for the measurement of quantities for the payment of a contractor, the line spacing should be sufficiently close to identify any significant variation in section or level. This may involve survey lines at centres of between 10 m and 25 m, or perhaps wider line spacing on large-scale works. If the objective of the survey is simply to provide broad detail for the guidance of navigation of dredging and construction plant, survey lines at centres of 100 m or more may be adequate. In such instances, a check for possible upstanding features between lines of survey should be made using side-scan sonar (see 2.2.6). Such a low density of survey is not appropriate for measurement purposes.

If practical, survey lines should be sailed approximately perpendicular to the main sea bed contours, channels or slopes.

Table 1 — Probable error in depth measurement

Condition	Lead line	Survey echo sounder
	m	m
A. Due to sea bed material		
Rock bed	± 0.05	± 0.05
Sand bed	± 0.10	± 0.10
Clay bed	± 0.15	± 0.15
Soft silt bed	± 0.30	± 0.20
B. Due to current		
Current velocity		
1.0 knot	± (0.05 × <i>d</i>)	0.00
2.0 knot	± (0.20 × <i>d</i>)	0.00
C. Due to significant waves		
Wave height		
0.3 m: assuming small boat	± 0.20	± 0.20
0.5 m: assuming 10 m boat or larger	± 0.30	± 0.25
1.0 m: assuming 15 m boat or larger	± 0.50	± 0.30
NOTE 1 Accuracy will deteriorate with decreasing or varying bed density and bed gradients. Also affected by frequency of echo sounder used. Accuracy may be improved by use of dual frequency sounder.		
NOTE 2 Echo sounders are not affected by currents. Accuracy of lead lines in current dependent on skill of user. Error may be greater than shown in unskilled hands. Lead lines not recommended when water depth exceeds 10 m. <i>d</i> is the water depth in metres.		
NOTE 3 The error of recorded results will be greater than shown, especially in swell, but can be improved by skilled interpretation of continuous analogue record when sea bed is plane and wave period is short. Accuracy of echo sounder record in waves or swell can be improved by using filters and swell compensators.		
NOTE 4 All of these effects and others may combine to produce errors larger than shown.		

2.2.3 Depth measurement

2.2.3.1 General

Sea bed level is normally determined by measuring the depth of water above the sea bed and simultaneously recording the sea level close by, relative to an appropriate datum. Sea level should be recorded accurately throughout the period of survey at a location where the sea level at any given time is the same as, or not significantly different from, that in the area of survey. Sea conditions at the recording point should be compatible with accurate measurement.

Water depth may be measured with a sounding line, sounding pole or echo sounder. The most rapid and convenient method is by echo sounder. When sounding close alongside structures, many echo sounders are affected by side echoes, and a lead line or sounding pole should be used in preference.

The accuracy that can be achieved in determining sea bed levels is inferior to that normally attainable in land survey.

The accuracy and consistency of depth measurement, by whatever means, are affected by the characteristics of the sea bed material. When the sea bed is soft or disturbed, as may occur subsequent to and during dredging, accurate measurement is difficult and particular care is necessary to achieve good results. In soft silts, echo sounding may not be practicable for some time after the cessation of dredging. For consistent results, the method of sounding should not vary, e.g. the same type of echo sounder should be used throughout.

Depth measurements made from a moving vessel when crossing slopes are dependent on the true position being known. Sounding lines that cross significant slopes should ideally be sailed normal to the slope at the minimum speed necessary to maintain a true course. All lines should be sailed in the same direction for consistent results.

Accurate depth measurement is normally only possible when the sea is calm. Accuracy deteriorates as the height of waves or swell increases (see Table 1).

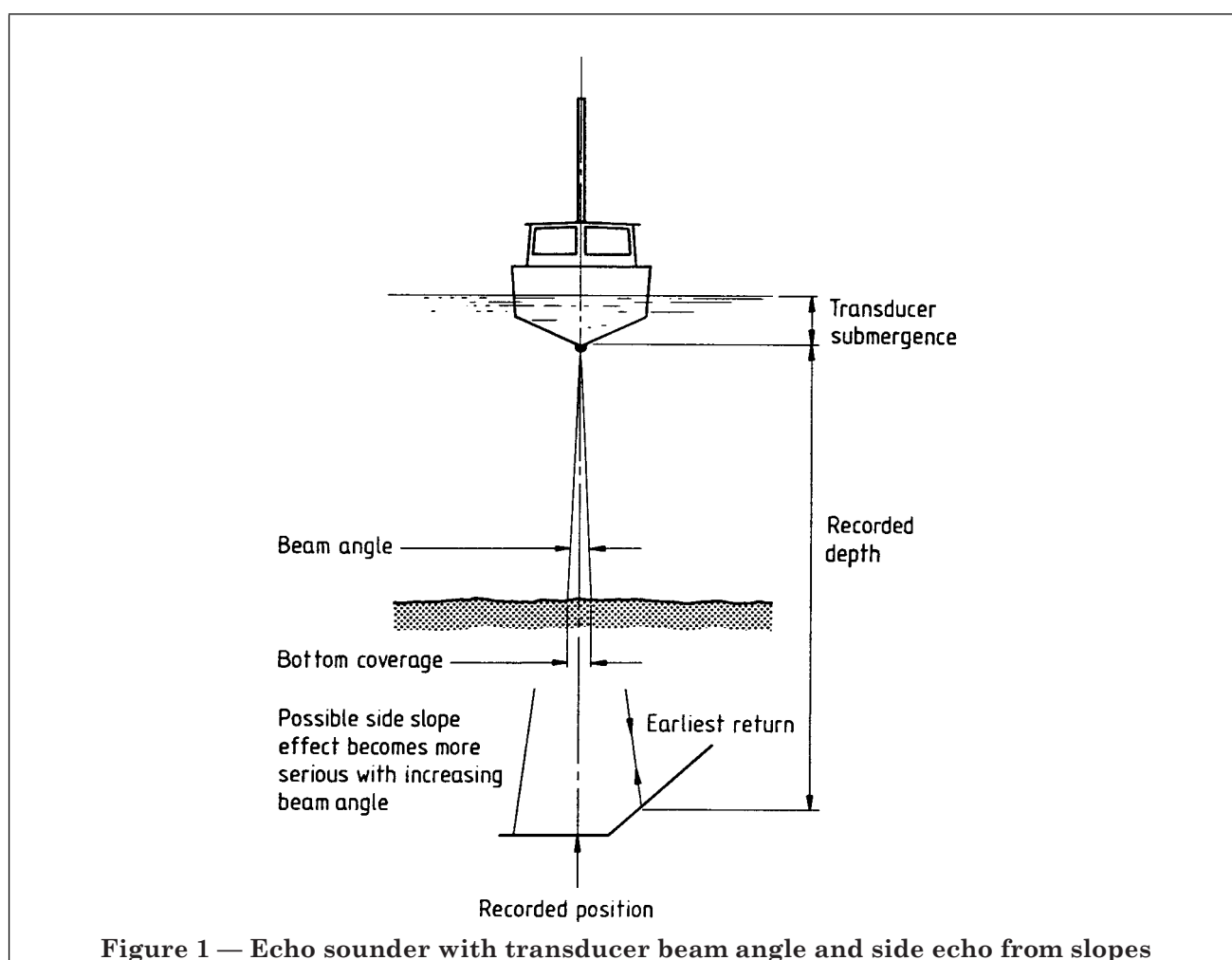


Figure 1 — Echo sounder with transducer beam angle and side echo from slopes

2.2.3.2 Echo sounder

The general principles of echo sounders and their use are described in 8.2 of BS 6349-1:1984. Greater detail, specific to the use of echo sounders in ports, is given in [3].

Different echo sounders operate with different signal frequencies and beam angles. The beam angle is the included angle of divergence of the signal transmitted from the transducer (see Figure 1). Echo sounders that operate at a comparatively high frequency but low energy are normally relatively lightweight and have a modest energy demand. They are therefore very convenient for hydrographic surveys, particularly where portability is important. The signal from echo sounders of this type may reflect from sea bed materials of quite low density. Conversely, echo sounders that operate at lower frequencies and higher energy may penetrate low density surface layers and the signal may be reflected by a sub-bottom layer. As the echo sounder characteristics may affect the survey results, careful consideration of the choice of echo sounder in relation to the main objectives of the survey should be made. Some echo sounders provide a choice of frequencies (see Table 2).

Table 2 — Frequency and penetration of echo sounders

Frequency	Penetration	
	Silt	Sand
kHz	m	m
10	2.0 to 5.0	0.5 to 1.5
15	1.0 to 3.0	0.5 to 1.0
50	0.5 to 2.0	0.1 to 0.5
100	0.1 to 1.0	0.0 to 0.5
200	0.0 to 0.2	0.0 to 0.1

Echo sounders may record the measured depth as a continuous trace on a chart in analogue form, or in digitized form on a magnetic tape, or disc. When analogue recording is used, the vertical scale of the chart should be sufficient to allow accurate interpretation. A scale of 1 : 100 will normally allow a reasonable interpretation. When digitized recording is used some selection of data takes place. The selection process may influence the results. The selection process should be thoroughly understood and any bias which is contrary to the objectives of the survey should be eliminated.

It is necessary to carry out regular recalibration of the echo sounder by means of a bar check. Calibration should be checked at the commencement and completion of each period of survey and, when appropriate, at intervals between. The following listed field checks should be made when using echo sounding equipment:

- power source suitability and stability;
- depth of transducer below water surface (may vary with boat displacement or speed);
- horizontal displacement of transducer position relative to position-fixing system;
- alignment of analogue chart paper;
- echo sounder calibration (bar check);
- sea bed characteristics;
- signal frequency;
- paper speed;
- proposed direction of sailing of lines;
- water level in survey area.

2.2.3.3 Lead line

The lead line consists of a flexible, non-elastic line, usually of wire or chain, attached to a lead or steel weight. The line is marked in divisions of length, normally at 0.1 m intervals.

The lead line is used to plumb the bottom manually and is therefore rather slow and laborious, particularly as water depth increases. With experience, the nature of the bottom can be gauged, i.e. soft, very soft, firm or hard, but care has to be taken in evaluating the indications obtained.

It is not normal to use a lead line as a general survey tool in water depths exceeding 10 m or where there are moderate or strong currents. The speed of the survey vessel should be as slow as is practical to maintain course.

The lead line may be used to advantage in the following situations:

- alongside structures, where reflected signals may have an adverse effect on an echo sounder;
- to check an echo sounder, particularly in areas where the sea bed is soft;
- to determine navigable depth, on the assumption that the depth reached by a lead line with a weight of appropriate dimensions, sinking under its own weight, is a navigable depth; or
- within small or shallow areas where the use of an echo sounder is not justified.

Lead lines, particularly those of chain construction, may break and be rejoined, perhaps with some reduction in length. It is therefore recommended that the overall length and the position of the intermediate division marks are checked before use with a good quality steel tape measure.

2.2.4 Density measurement

2.2.4.1 General

If the level of the sea bottom can not be satisfactorily determined by conventional methods, as in areas of soft or fluid mud, it may be more appropriate to determine the level of material of a particular density and perhaps define that level as the basis of the ruling depth for navigation purposes. Such measures can serve to reduce both the frequency and quantity of dredging in ports and waterways. The density meter, which measures the density of the sea bed material at the elevation at which the instrument is located, can provide a means of doing this. It is necessary that the user is properly experienced and that the objectives are clearly understood.

2.2.4.2 Gamma radiation based systems

There are at present two types of gamma radiation density meter, the “backscatter” and the “transmission”. The backscatter meter, which has a radiation source and radiation counter arranged vertically within a cylindrical housing, is generally the more convenient in use. Both types are calibrated by immersion in a medium of known density.

In use, the instrument is lowered into the sea bed material and the count rate variation with depth is recorded. Variation of the density of the sea bed material with depth can be determined by reference to a calibration curve. This is suited only to spot readings or depth profiles.

For the continuous measurement of density in areas of fluid mud, systems are available in which a gamma ray transmission gauge is mounted within a towed “fish device”. The depth and position of this device are measured by conventional methods.

2.2.4.3 Sonic methods

Various systems are available that continuously measure sea bed density in areas of fluid mud by sonic methods. The sound source and receiver are mounted within a streamlined “fish device”, which is towed through low density sea bed layers. The system requires calibration against a medium of known density. It is necessary to know the composition of the mud layer, including an analysis of particle size and organic content by conventional sampling and laboratory analysis. The system can also be used from a fixed position to produce a depth profile of density.

In those systems that provide a continuous measure of density, the towed “fish device” is automatically raised and lowered through the layer of fluid mud, continuously recording variations in density with depth. Subsequent analysis can provide information concerning the elevation of a particular density throughout the area surveyed.

2.2.5 Position fixing

2.2.5.1 General

The methods and accuracy of determining position over water are inferior to established methods on land. A hydrographic survey is conducted from a moving vessel on a moving surface, and position-fixing systems are therefore of a dynamic nature. If the various components of the measurement of position are not perfectly coordinated in time, a source of error is established. Unless the sea bed is horizontal, an error in position will also produce an error in depth. It should be noted that in inland waters and other suitable sea bed positions, simple surveying methods may be appropriate. The general principles of position fixing are described in 6.3 of BS 6349-1:1984.

Accurate position fixing is most important during the execution of dredging (see 11.3) and its measurement (see section 12). It can be advantageous, but may not be practicable, for the method of position fixing used during the site investigation and survey to be the same or similar to that to be used during the work. The level of accuracy and the shore control requirements will then be consistent throughout.

2.2.5.2 Sextant angles

The use of survey sextants is described in 6.3.2 of BS 6349-1:1984. More detailed information is given in [4] and [5].

The sextant provides the simplest and most economic method of position fixing over water, provided that the sight distances are modest, visibility is good, great accuracy is not required and suitable coordinated shore marks exist or can be easily provided. An abundance of shore control marks is required to maintain reasonable accuracy when surveying long, confined areas, such as estuarial or river channels. This may be impractical or uneconomic.

The sextant is normally suitable for fixing the position of stationary dredgers (see 4.3 and 4.7 to 4.11). It is not normally practical for trailing suction hopper dredgers (4.2).

The sextant is not suited to very accurate surveys unless the distance to the shore control marks is relatively short.

2.2.5.3 Electronic range-range

The general principles of radio positioning systems, which include range-range systems, are described in 6.3.3 of BS 6349-1:1984. Greater detail is given in [5].

The range-range systems consist of two or preferably more coordinated shore stations and a single master station on board the survey vessel. Position is given by the simultaneous measurement of two or more ranges with position being that of the intersection of the range arcs.

The ranges may be displayed on a console integral with the master station. If required, a microcomputer can be interfaced to convert the ranges to X-Y coordinates, which can in turn be fed to a track plotter or VDU, which provides a visual guide to the position in plan of the survey vessel. Such a system is also an important aid to the efficient deployment of trailing suction hopper dredgers (see 4.2).

The much shorter range sampling period compared with sextant fixing allows higher vessel sailing speeds to be maintained without a serious deterioration in the density of information collected. The use of range-range equipment also allows the position to be determined with accuracy over greater distances and with closer detail. Employment of a track plotter allows the survey to be carried out at predetermined lines, which can be properly aligned, such as in the taking of cross sections.

The absolute accuracy of individual measured ranges varies according to the specific system employed but may be between ± 1 m and ± 5 m. The absolute accuracy of position is always less than the individual range accuracy as it is a function of the geometry of the range arc intersection. Even assuming a perfect (90°) angle of intersection, the maximum error in position may be three times greater than the maximum range error (see Figure 2). The magnitude of the maximum potential error increases as the angle of range arc intersection deviates from 90° (see Table 3).

Table 3 — Approximate error in position due to poor intersection angle using range-range equipment

Angle of range arc intersection	Approximate error in position	
	Maximum range error ± 1 m	Maximum range error ± 3 m
degrees	m	m
90	3	8
80	3	9
70	3	11
60	4	12
50	5	14
40	6	18

Most range-range systems require a clear line of sight between the shore stations and the system master on board the survey vessel, and shore stations have to be appropriately sited for this purpose. The individual range accuracy may be affected by atmospheric conditions, weather, reflections from large, hard surfaces, such as ships and buildings, and by interference from other radio transmitting equipment such as radar.

The position of all shore stations should be properly coordinated with the national, or local, grid. At commencement and on completion of each period of survey, the survey vessel should be positioned alongside known coordinated points within the survey area and the indicated ranges should be compared with the calculated ranges.

Alternatively, a second measurement system, such as an electronic distance measurer (EDM), can be used to check ranges. For small, regular survey areas, checks made at two points are normally sufficient to demonstrate whether or not the system is properly calibrated and free from interference. A further check may be made when crossing a known transit, such as the line of leading lights.

The following checks should be made before the survey commences:

- a) coordination of positions of shore stations;
- b) geometry of range arc intersection throughout the survey area (generally not less than 60°);
- c) calibration of equipment (static and dynamic);
- d) equipment free from interference;
- e) correction for horizontal position between receiver aerial and echo sounder transducer;
- f) correction of the range due to any difference in elevation of the master and shore station aerials if necessary.

2.2.5.4 Electronic range-bearing

Range-bearing systems consist of a single, coordinated shore station and a shipboard master station. Position is determined by the simultaneous measurement of range and bearing. Range and bearing are displayed on a console on board the survey vessel. If required, a microcomputer can be interfaced to convert range and bearing to X-Y coordinates. These in turn can be fed to a track plotter or VDU to provide a continuous indication or record of the vessel position relative to the national, or local, grid. This facility can be used to sail predetermined survey lines marked on to the track plotter chart.

The accuracy of the range-bearing systems is constantly improving with a maximum range approximately equal to visibility on the line of site. Unlike the range-range systems, the quality of fix is not influenced by the system geometry. Accuracy is directly related to range and the system is therefore most appropriate to relatively short-range applications. The use of a single shore station simplifies the setting up procedure, provided that the entire site is within range and enjoys a clear line of sight from the shore station.

The system should be calibrated over known ranges similar to the minimum and maximum site requirements and should be checked at the commencement, and on completion, of each period of survey.

Some systems measure vertical as well as horizontal angles, which allows the determination of the elevation of the survey vessel relative to the shore station.

The following checks should be made before the survey commences:

- a) coordination of position of shore stations;
- b) calibration of equipment (static and dynamic);
- c) possible interference to equipment;
- d) correction for horizontal position between receiver aerial and echo sounder transducer;
- e) correction of the range due to any difference in elevation of the master and shore station aerials if necessary.

2.2.5.5 Laser The laser provides a visual indication of the required position and with some systems may also measure distance from the shore station and indicate this on an on-board display. Simpler systems employ a single shore station, which is set up on the fixed bearing along which the dredging has to proceed. However, some systems provide for the simultaneous measurement of range and bearing. Performance depends on a clear line of sight and good visibility.

In use, the fixed laser has greater application to dredging (particularly the dredging of trenches for pipes and outfalls) than to site investigation and survey. Lasers may be used effectively to control the levelling of fill in reclamation works.

2.2.6 Side-scan sonar

The general principles of the side-scan sonar are described in 8.3 of BS 6349-1:1984.

Side-scan sonar can be described as a sideways looking echo sounder. Normally, two opposing transducers are mounted within a “fish device”, which may be towed behind the survey vessel. Alternatively, in dedicated vessels the transducers may be mounted within the bottom of the vessel. The transducer signals are directed at shallow angles below the horizontal on either side of the path of the vessel. The width of coverage depends on the water depth and the signal strength but for most dredging applications, should be 75 m in shallow water or 150 m in deeper water, both dimensions being each side of the centreline of the track sailed. As a general rule, lines should be sailed at a distance apart that is slightly less than the range setting, thereby giving 100 % overlap. In this way, every feature can be seen from two directions including those directly beneath the “fish device”.

The height of the “fish device” above the sea bed can be varied by lengthening or shortening the tow cable or by changing the speed of the towing vessel. The “fish device” is normally towed at a height above the sea bed equal to approximately 10 % of the range. However, there is better textural definition of the sea bed when the “fish device” is towed closer to the sea bed.

The three frequencies in general use are 50 kHz, 100 kHz and 500 kHz. The 50 kHz frequency is usually used for reconnaissance work, typically to a range in excess of 200 m on each side of the survey vessel, 100 kHz is usually used for more general survey work, typically at ranges up to 200 m, and 500 kHz is usually used for detailed inspection, typically at 50 m range. (See Figure 3 for selection of frequency.)

Side-scan sonar provides a graphic record of the sea bed surface in which any irregularities or outstanding features are generally indicated by a darker shading on the record. The darker shading is the result of the greater reflectivity of the outstanding features resulting in a stronger return signal. With experienced interpretation and good records, different sea bed features, such as mud, sand or gravel, can be identified.

The system is also particularly useful for identifying outstanding features that may be a hazard to navigation, such as wrecks or rock outcrops.

Side-scan sonar also provides a useful method for determining the satisfactory completion of dredged channels.

Sonar data can be stored on magnetic tape. The latest sea bed mapping recorders can correct for changes in vessel speed and distortion of record to give a record that is to a chosen scale. By further computer processing, individual records can be assembled to provide a mosaic picture of the sea bed.

Because side-scan sonar offers a simple method of covering large areas of sea bed quickly and inexpensively, it should be deployed on all occasions when the resulting records may be of use in the design or control processes of dredging works. Normally, it is possible to deploy side-scan sonar at the same time as echo sounding or sub-bottom profiling.

The main disadvantage of the sonar method is the uncertainty of the true position of the “fish device” relative to the towing vessel. Where an object of interest has been identified, the sideways swing of the “fish device” can be corrected by the object arc method [6]. It is good practice to run lines on the four sides of a square around an object of particular interest to improve its identification and position. However, a compass attachment and transponder can be attached to the “fish device” to give actual orientation and position.

A picture guide [7] has been published giving examples of the most common sea bed features and objects, and this provides a useful aid to identification.

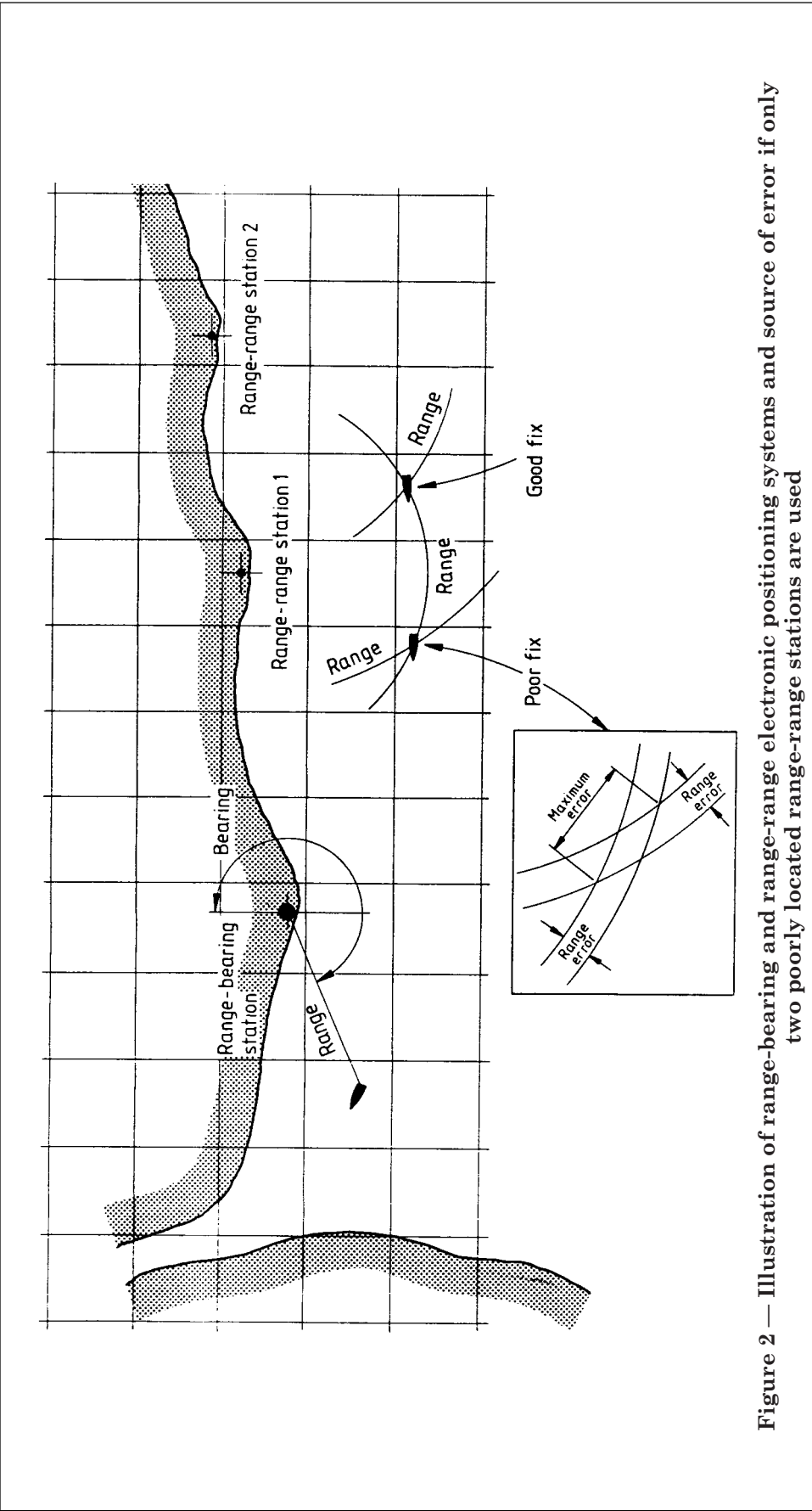
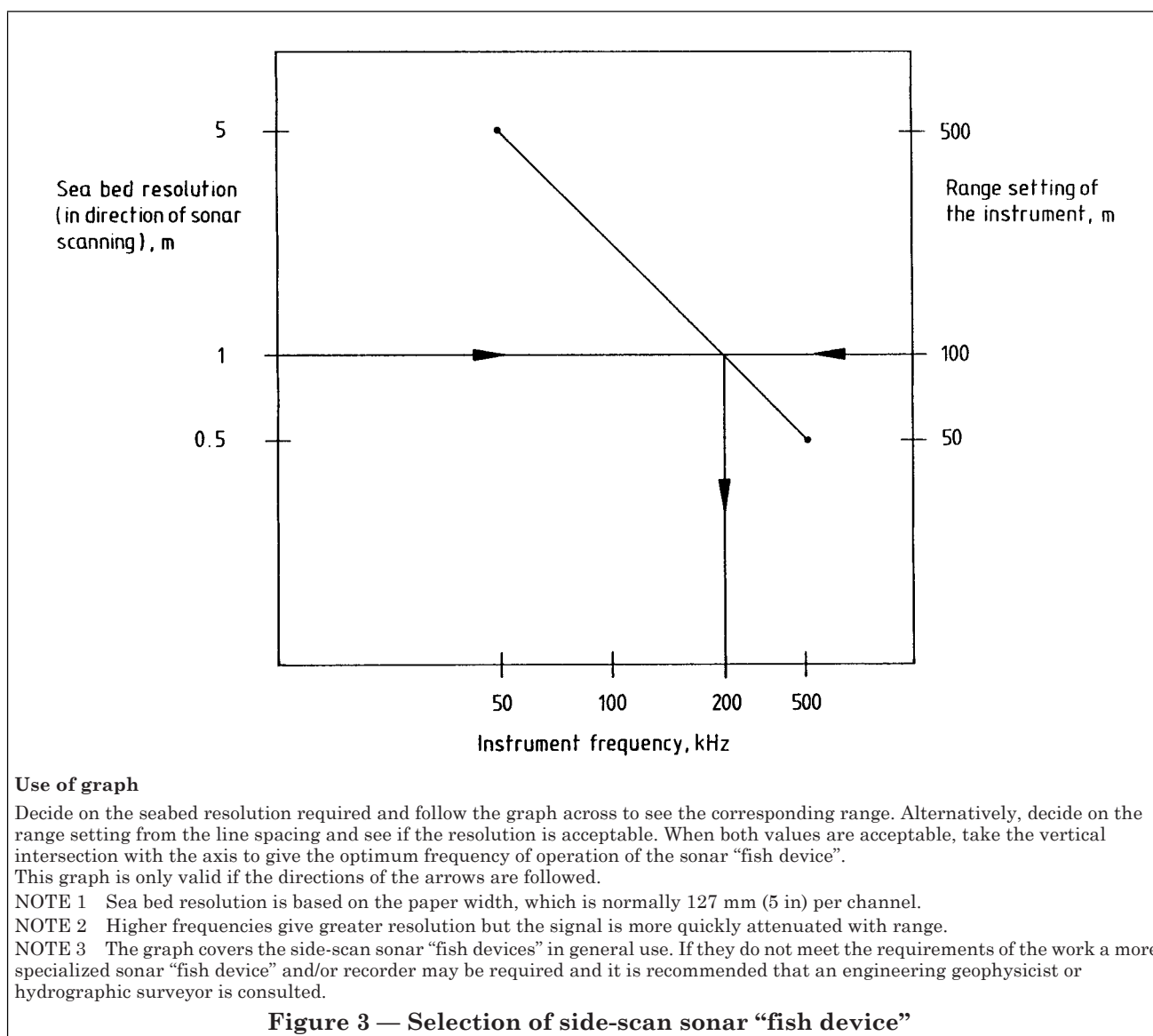


Figure 2 — Illustration of range-bearing and range-range electronic positioning systems and source of error if only two poorly located range-range stations are used



2.2.7 Automated survey systems

With modern electronics a very high degree of automation is possible. For small survey areas such sophistication is not normally justified, but for the repetitive survey of large areas positive benefits may result.

Fully automated systems are most useful to port authorities which are responsible for the maintenance of depths by dredging over large areas of port or approaches, and to contractors engaged on large-scale dredging works. However, caution is necessary when any automated system is employed.

Within the software that interprets the measurements and manipulates the data, adjustments may be made that can affect the final figures. For example, a programme that has been designed for use in the measurement of navigable depth may be heavily biased towards the minimum depths recorded and therefore may be unreliable for the computation of quantities. Some degree of selectivity or bias may also occur during the digitizing of echo sounder depth measurement.

A check for possible bias in the measurement of depth can be made by the manual interpretation and plotting of the echo sounder analogue record and of tide levels (assuming these have been recorded) for a random area of survey.

2.3 Sea bed conditions

The nature of the sea bed is important to both the design of works that involve dredging and the selection of dredging plant.

Some characteristics of sea bed condition may be measured remotely by instruments, such as side-scan sonar (see 2.2.6) and echo sounder (see 2.2.3.2). Others may require a visual inspection by a diver.

An indication of the texture of the sea bed can be provided by side-scan sonar. This also indicates 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 sea bed at depths from 3 m to 25 m, depending upon water clarity.

Generally it is necessary to confirm the more important features by diver or remote-camera inspection.

2.4 Current measurement

The speed and direction of the flow of water at different depths and times can be measured by a variety of techniques, which are described in clause 11 of BS 6349-1:1984.

The determination of current speed and direction is important in order to assess the likely distribution of any sediments in suspension, the dredger performance and the sea bed stability.

Variations in current speed and direction occur from sea bed to sea surface at different states of the tide, in fluctuating river discharges and at different seasons of the year.

Current meters may be suspended from a vessel or may be fixed by means of an anchored buoy and left to record automatically on station. Records that embrace spring and neap tides should be obtained over a period of at least 2 weeks in order to gain an indication of current velocity and direction. In most cases, current velocity is greatest at times of the greatest tidal range.

Current measurement may also be made by other methods, such as float tracking or dye tracing.

2.5 Wave height and direction

Wave height, period and direction are important to the operation of dredging plant and, in many instances, to the final performance of works created through dredging. (See section 4 of BS 6349-1:1984.)

Wave records should be gathered over as long a period as is practicable, in advance of any significant dredging works. Where this is not practicable, records over any winter period, or period that normally includes the most hostile wave conditions, should be obtained. Exceptionally, when it is known that any work will only be undertaken during the summer, summer records should be obtained. Records should provide details of wave height, wave period, wave direction, and their duration, particularly during extreme conditions.

Wave height and period may be measured by means of wave-sensing buoys or bottom-mounted, pressure-sensitive, wave-recording devices. The more sophisticated of these instruments can also measure wave direction. Where complex wave conditions exist, wave direction may, as an alternative, be measured by radar mounted on the shore or by satellite [8].

2.6 Tides

Since most dredging works are located within a narrow coastal margin where shallow water normally exists, the variations in sea level resulting from tidal fluctuations are important. Generally, for Standard Ports, tide records are available and tide predictions will have been published in tabular form. Corrections can be made by basic methods to the tide predictions for the Standard Ports to determine predicted tide levels at Secondary Ports [9].

Where no records or predictions are available, tidal levels have to be observed over a number of tidal cycles to represent the true relation between local conditions and those that exist at the nearest Standard Port. As a minimum, such tidal observations should extend over the lower neap tide periods for at least 24 h and again over the higher spring tide periods for at least 24 h. Ideally, continuous tidal observations should be made for a period of at least 2 weeks and preferably 4 weeks.

Tide records can be obtained by the installation of a simple paper chart, float or pneumatically operated, tide-recording gauge, which should be levelled to an established datum.

2.7 Water temperature and salinity

For works within the UK, water temperature and salinity may not be important, but in tropical regions the effects of relatively high water temperatures and high salinity may be important in relation to the operation of dredging plant.

Water temperature and salinity also have an effect on the density of the water and consequently on the displacement of floating plant and on the performance of certain survey instruments such as the echo sounder.

Site investigations for projects within tropical areas or areas of high temperature should therefore include regular measurements of water temperature and salinity, particularly during the more extreme seasonal phases.

2.8 Suspended solids

Sediment in suspension may affect the design aspects of dredging works. Any dredged formation which intercepts the passage of mobile deposits will be exposed to potentially heavy rates of siltation and therefore high maintenance costs.

Sediment concentrations should be measured by sampling the water column throughout the tidal cycle.

Normally, it is necessary to sample at a number of locations within the area of the projected works in order to establish the pattern of local variations that may occur and primary sediment transport routes.

2.9 Sediment transport

NOTE See 14.2 of BS 6349-1:1984.

In addition to sediment that is transported in suspension, there may be significant movements at or near the sea bed. This is particularly true for granular sediments located in the surf zone or within the area of wave influence.

Near-bed or on-bed sediment transport does not normally affect the working of dredging plant. However, it has an important effect on the feasibility of maintaining dredged channels and other dredged areas.

Particular problems may arise in the near-shore zone where littoral drift is intercepted by navigation channels or harbour works. If the rate of drift is particularly high, it will be expensive and perhaps impracticable to maintain an adequate channel depth. Further problems may arise if the dredging activity necessary to maintain channel depth deprives the downdrift shore-line of renourishment material with subsequent shore-line regression.

2.10 Ground investigations

2.10.1 General

The geotechnical properties of the ground to be dredged fundamentally affect the performance of all dredging plant. The proper definition of these properties in advance of dredging works is therefore paramount. (See clause 49 of BS 6349-1:1984).

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 vibrocoring, may 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.

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.

The geology of the coastal margins is almost invariably complex. The apparent economic savings that may result from an inadequate ground investigation are in many cases outweighed by the increased costs arising from disruption of the works due to unforeseen ground conditions. Preliminary guidance is given in Table 4.

2.10.2 Survey and site investigation methods

2.10.2.1 General

Many of the methods and tools widely employed in the investigation of ground on land can be adapted to marine applications. In soils, the most common method used is the shell and auger. Ground investigation practice is described in BS 5930. Some of the methods that may be useful for marine ground investigation, but are not fully covered in BS 5930, are described in 2.10.2.2 to 2.10.2.9.

2.10.2.2 Seismic refraction profiling

In the refraction method, the various velocities of propagation of acoustic energy through the sea bed 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 sea bed. 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. 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 velocity of refracted energy is reduced when it passes through fault or fracture zones. This allows rock quality to be assessed horizontally along an array of hydrophones.

The refraction method complements the reflection method (see **2.10.2.3**) and may give satisfactory results when the reflection method has poor penetration or resolution due to organic sediments, coarse granular sea bed surface, poor quality reflectors, variable geology or disturbance from shallow-water multiple reflectors.

The main disadvantage of the method is the difficulty in placing the acoustic energy source and the hydrophone array on the sea bed 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 are not instantly amenable to interpretation. They should be computer processed for the best results.

An advantage of the method is that it may provide a guide to whether the ground materials can be dredged directly or may require pretreatment [10].

2.10.2.3 Seismic reflection profiling

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

Acoustic energy is released by a piezoelectric or electromechanical transducer, sparker, airgun, etc. having the generic names “echo sounder”, “pinger”, “boomer”, “sparker” and “airgun” and progressively increasing from weakest to strongest 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 passed to a paper recorder, or digitized.

The sub sea bed is presented graphically by the recorder 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. Figure 4 shows a general relation between a number of these factors that can be used to assist in the initial selection of an acoustic source (see also Table 5).

Higher frequencies are attenuated with depth so that penetration is achieved only with lower frequencies. The lower the frequency, the lower is the resolution of thin strata. The coarser the sub sea bed materials, the greater is the energy absorption and the lesser the penetration.

An echo sounder signal will not penetrate the sea bed measurably unless it is a soft mud. A pinger signal will penetrate sand, but its low energy will be quickly absorbed and give only a few metres of penetration, although of high resolution and accuracy.

A boomer signal will penetrate sand to depths of several tens of metres with an acceptable resolution and accuracy, and is the best compromise between cost, mass and performance for most site investigation and survey work.

A sparker can give greater power than a boomer and achieve greater penetration; although at the expense of resolution.

As no single system can generally provide a full interpretation it is customary to use two or more simultaneously. A common combination for deeper penetration is echo sounder, boomer and sparker, and echo sounder, pinger and boomer for shallow penetration.

Sea trials of a few hours' duration are desirable to determine the vessel speed, propeller revolutions, towing configuration and instrument settings that give the clearest possible seismic record.

Table 4 — Sampling and investigation procedures for dredging purposes

Rock or soil type	Rotary drilling (see note 1)	Shell and auger boring	Underwater (sea bed) devices	Undisturbed sampling (see note 2)	Disturbed representative samples (see note 2)	Dynamic penetration tests (see note 3)	Static penetration test (e.g. Dutch and Swedish)	In situ vane testing	Geophysical methods
Rocks	Best method of obtaining core samples of intact rocks in situ condition for examination and test	NA ^a	Useful for obtaining core samples of limited penetration	Cores represent undisturbed samples of intrinsic rock	Cutting in drill fluid may be used for identification of non-recovered layers	Used only in soft or weathered rock and in corals	NA	NA	Useful to establish the likely geology over a large area. It will assist to both "set out" a borehole grid, and to "fill in" details between borings and drillings. However, such methods still require careful interpretation. Very useful where relatively simple soil/rock conditions exist (i.e. soft alluvium over rock). Where only slight changes in strata density occur, great care is needed in interpretation
Boulders Cobbles	May be used to penetrate and obtain core samples	Chiselling required to penetrate strata	NA	Cobbles retained as undisturbed samples	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	Used with cone gives reasonable in situ compactness estimate	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 for in situ compactness estimate at the same time as sample is obtained	Useful method for determining in situ properties and "hard" strata levels. In areas with very wide soil variation may be useful to supplement borehole information	NA	
Silts	NA		If cohesive in nature can use undisturbed core samplers for clay, otherwise see Sands			Can be used, but interpret with care		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 days	
Peats, etc.	NA		Variety of undisturbed core samplers available					Used for estimate of shear strength but great care needed in interpretation	

NOTE 1 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.

NOTE 2 Care should be observed 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. Care in labelling samples is paramount.

NA = Not applicable.

Comments on Table 4

General comments

Generally, site investigations have to be carried out by a reliable specialist. These range from government research based organizations to specialized geotechnical contractors. Whoever undertakes the work it is of prime importance that the work is supervised by well-qualified and experienced geotechnical engineers or engineering geologists and that the field work in particular is undertaken by skilled drilling crews with well-maintained equipment.

Investigations for dredging projects normally involve work over water and it should be noted that engineers and drillers who may be experienced on land-based operations do not always adapt to operations from floating craft with its many additional hazards.

It is advisable to obtain as much information as possible on the levels and the configuration of the deposits and on their origin. Deposits of complex structure need more detailed investigations than deposits having very regular profiles and structures. The amount of investigation also depends on the size of the area to be dredged.

Test borings should reach some distance below the depth to be dredged; this should be done with a view to both redredging and any future deepening work. In sand searches (e.g. for reclamation purposes) borings have to penetrate to adequate depths.

Investigation procedures

Most of the sampling and investigation procedures have been derived from land-based techniques. Some techniques have been adapted and are under further development for underwater operation on the sea bed using a diver or using remote control from the surface. Mention should be made of vibrocorers and gravity samplers as sampling methods for superficial layers of soft sediments. Recently, specific underwater samplers have been developed for dredging investigations. These include remote-controlled devices either to carry out a cone penetration test or to take soil and rock samples by coring or penetration.

Self-elevating platforms

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.

Test dredging

There may be some projects on which the complexity of the geology or other special circumstances warrant the use of test dredging or even make test dredging desirable. In other cases the results of previous dredging contracts might be useful. In all cases, details of all relevant circumstances should be provided, including quantitative and qualitative information on the spoil and where appropriate a description of the dredger previously used. Great care should be taken by the employer in providing reliable information and by the contractor in interpreting this information.

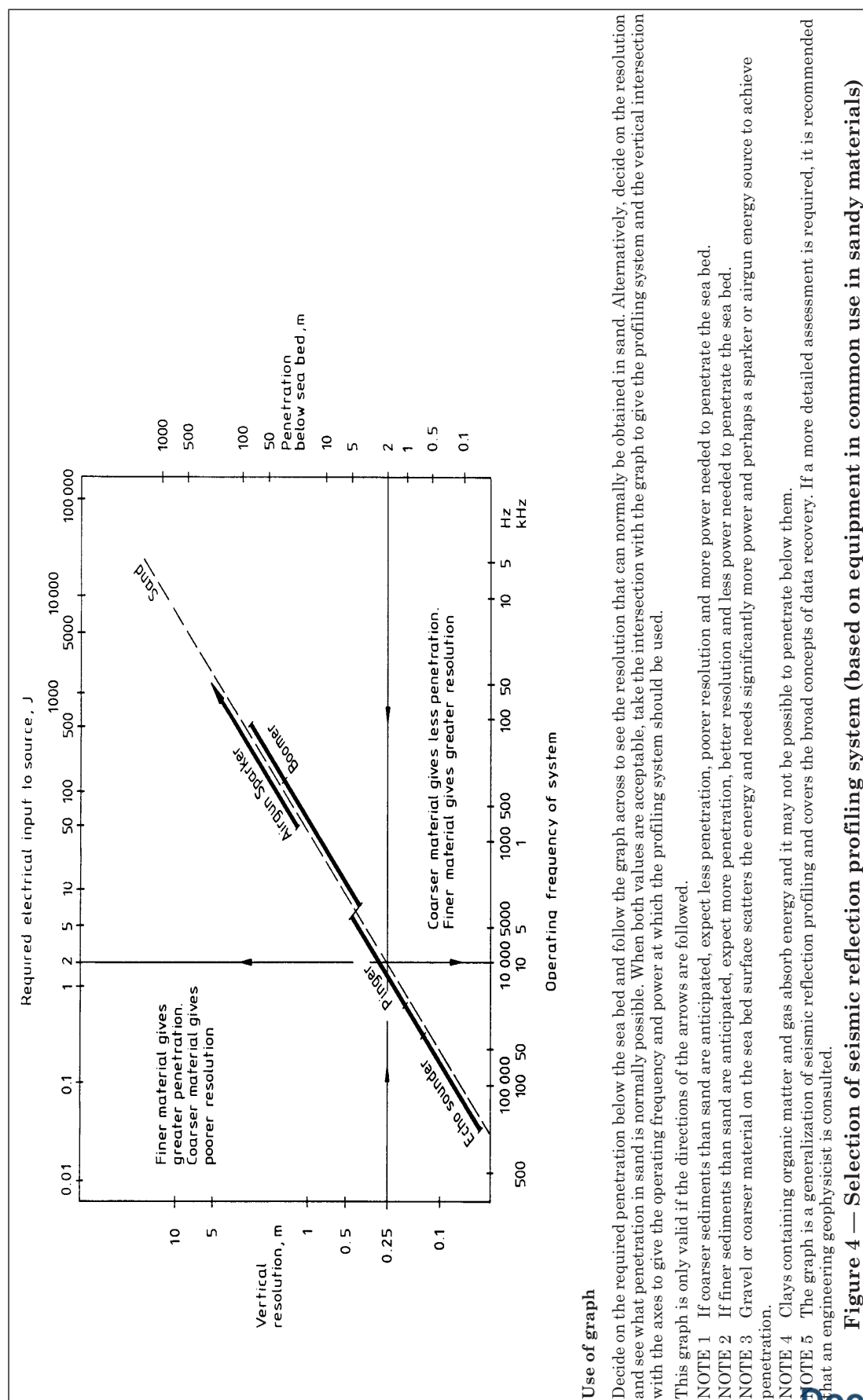


Table 5 — Typical applications of geophysical systems

Purpose of survey	Systems that may be used	Line spacing	Horizontal control	Vertical control	Correlation sampling and in situ testing
Sand and gravel prospecting	Echo sounder Boomer Sparker Side-scan sonar	500 m square grid	Long-range radio positioning Satellite navigation Radar	Predicted tides at standard ports	Air lift Vibrocore Grab
Dredging for approach channels	Echo sounder Boomer Sparker Side-scan sonar Magnetometer	50 m to 100 m with cross lines at 200 m to 500 m	Medium-range radio positioning Optical	Observed tides at convenient tide gauge	Grab Vibrocore Borehole Dutch cone
Trenching and route selection for pipelines, sea outfalls and cables	Echo sounder Pinger Boomer Side-scan sonar Magnetometer	20 m with cross lines at 100 m	Medium-range radio positioning with computer processing	Observed tides at convenient tide gauge or installed tide gauge every 20 km along route	Gravity Vibrocore Borehole Dutch cone Pressuremeter

Sea conditions, especially waves, have an appreciable effect on record quality. Work can not be executed satisfactorily using surface-towed equipment when the sea state exceeds 3 on the Beaufort scale. 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.

Correlation boreholes should later be sunk at selected positions to prove the geophysics.

2.10.2.4 Marine magnetometer profiling

The marine magnetometer detects and records the total magnetic field of the earth near the sea bed. Ferrous metal objects on or just below the sea bed will interfere with this magnetic field and cause magnetic anomalies, which the magnetometer can detect.

Magnetic anomalies can be caused by iron-rich dykes and similar geological features, but in UK waters are mainly caused by pipelines, shipwrecks, cables and other civil and military debris.

As a general rule, a magnetometer should register a measurable anomaly from 100 kg of iron at a distance of 10 m from the tow “fish device”. However, there are many factors that can affect this.

The method for search purposes has to be regarded as qualitative and all measurable anomalies have to be inspected by a diver. Where no anomalies are visible, it may be necessary to jet away the sediments to expose shallow buried objects.

2.10.2.5 Side-scan sonar

The side-scan sonar can be a valuable tool for site investigation as well as for bathymetry (see 2.2.6).

2.10.2.6 Gravity sampling

The gravity sampler is a heavily weighted, open-tube sampler, which is lowered to the sea bed on a cable or allowed to fall freely so that it enters the sea bed with a momentum that forces a sample into the tube.

The main advantages of the system are low cost, rapid deployment and, in very soft alluvial silt, the potential to penetrate and perhaps recover up to 6 m of material.

The main disadvantages of the system are that penetration in anything other than soft materials is very small and that the sample may be very disturbed.

2.10.2.7 Vibrocoring

This method of open-tube sampling utilizes the fact that granular materials liquefy when vibrated, allowing the casing to penetrate more easily. In this way, relatively undisturbed samples of granular or soft materials can be recovered quickly.

Lack of control over positioning of the vibrocorer in the sea is a disadvantage. Further disadvantages are its limited penetration and that recovery can not be guaranteed and the density of the recovered sample may have been modified by vibration.

The over-riding advantages of the vibrocorer are that it recovers samples relatively quickly and cheaply compared with shell and auger boring and that it can be used to complement a few boreholes to gain a wider knowledge of the site at relatively low cost.

2.10.2.8 Jet probing

A jet probe is a thin pipe emitting air or water at high pressure, which is lowered through the soft sea bed with lengths of pipe being added until the probe reaches refusal. The portable version is generally fabricated from water or gas pipe with a terminal nozzle.

It can be useful to determine the interface level where soft alluvial sediments are known to overlie denser or harder material.

The main advantages are low cost and usually its ease of operation from a small boat. One disadvantage is that refusal may occur on, for example, a thin bed of shells or equally unimportant feature. Depending on water depth and sediment thickness, it may deviate out of vertical and therefore give an overestimate of the thickness of soft material. Further disadvantages are that no samples can be recovered and there is a complete lack of standardization as to applied power/pressure. Due to these limitations the method should only be used to complement other and better investigative methods.

2.10.2.9 Grab sampling

The grab sampler is a spring-loaded or weighted sampler, which is lowered by cable to the sea bed. On contact with the sea bed, it grabs a disturbed sample of the surface material and retains it during recovery to the vessel.

It is relatively quick to operate and small samplers may possibly be used from a small boat in shallow water. The operator can sense the difference between soil and rock/boulder sea bed conditions, and this can be useful in confirming sea bed texture in conjunction with side-scan sonar and seismic reflection profiling.

By using a large grab for sampling it may be possible to recover cobbles and boulders, which are particularly relevant in the selection of dredging plant. Other sampling tools are deflected by boulders and can not satisfactorily sample them or may not detect them.

2.10.2.10 Trial dredging

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

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, a pattern of sampling by boreholes or some other method may not provide a truly representative picture of the overall condition. Trial dredging should then be considered.

Where trench or channel formations that would cut across deposits of doubtful stability or across the paths of substantial sediment transport routes are proposed, the formation of a trial section by dredging and the careful monitoring of the performance of that trial section may 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 gravel, cobbles and boulders, typically of glacial origin.

The performance of the dredger and of the dredged formation should be properly monitored throughout the trial and key parameters should be preselected and carefully recorded during execution.

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

2.10.3 Soil classification

Soil classification is the arrangement of soils into groups that have similar properties.

The British Soil Classification System (BSCS) for Engineering Purposes is given in Table 8 of BS 5930:1981.

The Permanent International Association of Navigation Congresses (PIANC) has produced a soils classification specific to dredging [11], which includes soil strength and structural characteristics (see Table 6).

For dredging purposes, it is recommended that the PIANC or BSCS classification is used.

All soil classifications have their merits and particular applications and it is important to name the classification used to describe the soil sample.

Table 6 — General basis for identification and classification of soils for dredging purposes

Main soil type	Particle size identification range of size	Identification	Particle nature and plasticity	Strength and structural characteristics	
Boulders Cobbles	mm Larger than 200 200 to 60	Visual examination and measurement (see note 1)	<i>Particle shape</i> Rounded Irregular Angular Flaky Elongated Flaky and elongated	Not applicable	
	Gravels Coarse 60 to 20 Medium 20 to 6 Fine 6 to 2			Possible to find cemented beds of gravel, which resemble weak conglomerate rock. Hard-packed gravels may exist intermixed with sand	
Sands (see note 2)	Coarse 2 to 0.6 Medium 0.6 to 0.2 Fine 0.2 to 0.06	All particles visible to the naked eye Very little cohesion when dry	<i>Textures</i> Rough Smooth Polished	Deposits vary in strength (packing) between loose, dense and cemented. Structures may be homogeneous or stratified. Intermixture with silt or clay may produce hard-packed sands	
Silts (see note 2)	Coarse 0.06 to 0.02 Medium 0.02 to 0.006 Fine 0.006 to 0.002	Generally particles are invisible and only grains of a coarse silt may just be seen with the naked eye. Best determination is to test for dilatancy (see note 3). Material may have some plasticity, but silt can easily be dusted off fingers after drying and dry lumps powdered by finger pressure	Non-plastic or low plasticity	Essentially non-plastic but characteristics may be similar to sands if predominantly coarse or sandy in nature. If fine, approximates to clay with plastic character. Very often intermixed or interleaved with fine sands or clays. May be homogeneous or stratified. The consistency may vary from fluid silt through stiff silt into "siltstone"	
Clays	Less than 0.002 Distinction between silt and clay should not be based on particle size alone since the more important physical properties of silt and clay are only related indirectly to particle size	Clay exhibits strong cohesion and plasticity, without dilatancy. Moist sample sticks to fingers, and has a smooth, greasy touch. Dry lumps do not powder and there is shrinking and cracking during drying process with high dry strength	Intermediate plasticity (lean clay) High plasticity (fat clay)	Strength	Shear strength (see note 4)
				Very soft	May be squeezed easily between fingers Less than 20 kN/m ²
				Soft	Easily moulded by fingers 20 kN/m ² to 40 kN/m ²
				Firm	Requires strong pressure to mould by fingers 40 kN/m ² to 75 kN/m ²
				Stiff	Can not be moulded by fingers, intended by thumb 75 kN/m ² to 150 kN/m ²
				Hard	Tough, indented with difficulty by thumb nail Above 150 kN/m ²
				Structure may be fissured, intact, homogeneous, stratified or weathered	

Table 6 — General basis for identification and classification of soils for dredging purposes

Main soil type	Particle size identification range of size	Identification	Particle nature and plasticity	Strength and structural characteristics
Peats and organic soils	Varies	Generally identified by black or brown colour, often with strong organic smell and presence of fibrous or woody material		May be firm or spongy in nature. Strength and structure may vary considerably in horizontal and vertical directions. Presence of gas should be noted
NOTE 1 Although only visual examination and measurement are possible, an indication should be given with respect to the particles as well as to the percentages of different sizes. NOTE 2 “Sands” and “silts” are terms denoting a particle size. Sands are not necessarily restricted to quartz sands but may include lime sands, iron ores, etc. Also silts denote a grain size, not a consistency. Therefore consistency terms such as “fresh harbour silts, muds”, etc. should not be used. NOTE 3 Dilatancy is the property exhibited by silt as a reaction to shaking. If moistened sample is placed in an open hand and shaken, water will appear on the surface of the sample giving a glossy appearance. A plastic clay gives no reaction. NOTE 4 Shear strength is defined as the undrained (or immediate) shear strength ascertained by the applicable, in situ or laboratory test procedure.				

Comments on Table 6

Describing soils

General

In practice, no soil falls precisely within a single, predetermined main type, so combinations of types have to be described accurately and intelligibly.

It is possible to do this by using a noun to denote the chief constituent of the complex soil and adjectives to denote other constituents that are present in smaller quantities. The noun should be regarded as denoting the principal constituent, i.e. the one that determines the behaviour of the soil.

Every description of soil should contain some indication as to the following characteristics:

- structure (e.g. resistance to penetration, compactness);
- for granular soils, quantitative distribution of grain sizes, preferably indicated as a grading curve, and a descriptive indication of the shape of the grains;
- for cohesive soils, shear strength;
- smell and colour;
- for peats, the extent of decomposition.

Furthermore, for composite soils, the major characteristics should be given, depending on the predominant nature of the soil.

Whenever possible, a full grading curve should be provided, but if grading curves are not given or are limited in extent, the percentage by mass of the several soil fractions should be stated.

Clear descriptions should be given, e.g. the following:

- stiff, fissured, grey clay;
- loose, yellow, rounded, fine medium gravel and coarse sand containing shells;
- soft, grey/blue, sandy silt;
- soft, black, clayey, fibrous, strong-smelling peat;
- brown, rounded, slightly compact, fine sand;
- compacted, coarse, angular sand mixed with scattered, irregular gravel;
- hard, brown clay containing sand and gravel.

Even though a full soil description is made, representative samples should be kept in airtight containers so that further examination can be carried out at a later date on fresh samples.

Fine soil

In fine soil, the engineering behaviour is better related to a description that takes account of marked influence of the silt and clay fraction. For example, a small proportion of clay-sized material can confer cohesive properties to a composite soil and can then be sufficient to warrant description of the soil as a clay. Distinction between the silt and clay fractions is important since they behave differently. The property most indicative of the relative proportions of silt and clay in a fine soil is its plasticity.

In this respect fine soil may often be categorized according to plasticity properties, on a basis of the relation between plastic limit and liquid limit of the soil. Use may then be made of the well-known plasticity chart where mineral and organic soils fall on either side of a dividing "A" line (after Casagrande). Soils that plot below the "A" line are predominantly silt and those that plot above it are predominantly clay. For further details see BS 5930.

Estimation of boulder and cobble content

In many cases (particularly in Scandinavia) the inclusion of boulders and cobbles causes problems in dredging work. Unfortunately, the investigation of such deposits is difficult and the correct prediction and assessment of the boulder and cobble content are therefore important.

Indirect estimations of the boulder and cobble content can be assisted by considering the mode of formation, composition of laboratory samples and sounding results.

In this respect reference should be made to [12] which covers the following points.

a) Mode of formation. The mode of formation provides a good indication of the boulder and cobble content of a soil. For example, the boulder content of tills (i.e. material transported by the ice sheet and deposited when the ice has melted) can be assumed to be as follows:

<i>Till type</i>	<i>Boulder content</i>
Coarse-grained	High
Mixed-grained	Medium to high
Fine-grained	Low to medium

It should be noted that fine-grained tills can have a high cobble content even if a boulder content is low. For a full discussion on guiding values for the division of mineral soils on the basis of the contents of the various fractions, reference should be made to [12] (especially to Table 5, Table 6 and Table 7 of that publication)

b) *Composition of laboratory samples.* The composition of laboratory samples can also improve the estimation of the boulder content. Due to the limited capacity of the sampling device, the samples give no direct indication of the possible presence of boulders or cobbles in the soil. However, it is possible to draw some indirect conclusions.

If a soil sample is classified as gravelly or if it contains small cobbles, there may be reason to suspect the presence of larger cobbles and boulders. Without special investigation and designation (e.g. aeolian sand), even sand can not be assumed to be completely free from cobbles. However, the boulder content is usually very low.

If the uniformity coefficient C_u (i.e. $\frac{D_{60}}{D_{10}}$) is high (greater than 10),

however, the possible presence of gravel cobbles and boulders may be suspected even in a sand deposit.

c) *Results of penetration tests.* Light, sounding probes are stopped by boulders and large cobbles. The following can therefore indicate the presence of boulders and cobbles:

- 1) if the probe stops at varying depths in adjacent holes;
- 2) if increased resistance occurs irregularly (necessitating impact driving);
- 3) if the probe stops at a lesser depth than the assumed bedrock.

The probe is unlikely to encounter cobbles or boulders if they only occur to a minor degree. Just a few stops can therefore be taken to indicate a considerable content of cobbles and boulders.

2.11 Laboratory and in situ tests for soils

The testing of soils should be in accordance with BS 1377.

See Table 7 and Table 8 and BS 5930 for tests of particular importance for dredging work.

Table 7 indicates the most commonly adopted laboratory and in situ tests to be carried out for classification purposes. Laboratory testing has to be undertaken on fresh samples and great care has to be taken that samples are fully representative.

2.12 In situ and laboratory tests for rock

2.12.1 General

Due to the many properties of rock that affect how it may be drilled, blasted or dredged, it is essential that rock is properly classified and that tests are carried out to identify the properties [13].

2.12.2 Laboratory tests

NOTE For outline details see Table 9.

The following rock properties are important in providing the information necessary to assess whether, or how, rock can be dredged, with or without pretreatment:

- a) density;
- b) hardness;
- c) abrasiveness;
- d) porosity;
- e) tensile strength;
- f) compressive strength.

Some of the tests for these properties are described in BS 1377 and BS 5930. The qualities that are particularly important in dredging are hardness, abrasiveness and strength. Specialist geotechnical advice should be sought on what tests are most appropriate for providing information for dredging projects and how this information should be interpreted.

2.12.3 Field tests and descriptions

The accurate assessment and description of the condition of rock in relation to fracture state and rock quality is essential when the dredging of rock, with or without pretreatment, is intended.

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 the following:

- borehole logging;
- 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 methods are described in BS 5930.

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, pretreatment may not be necessary. If pretreatment is necessary, fractured rock may 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.

Table 7 — Classification of soils for dredging purposes by in situ and laboratory testing (see note 1)

Main soil type	Particle size distribution	Particle shape	In situ density or bulk density	Relative density of the solid particles	Compactness (in situ)	Natural moisture content	Plastics and liquid wastes	Shear strength	Lime content	Organic content
Boulders	Visual in field	Visual inspection	NA ^a	Laboratory test (on fragments)	NA	NA	NA	NA	NA	NA
Cobbles (see note 2)										
Gravel	Laboratory test	<i>Laboratory test</i>	NA	Laboratory test	In situ test	NA	NA	NA	Laboratory test (see note 3)	NA
Sands	Laboratory test	<i>Laboratory test</i>	Laboratory test on undisturbed samples (see note 4)	Laboratory test	In situ test	Laboratory test	NA	NA	<i>Laboratory test</i>	Laboratory test
Silts (see note 5)	Laboratory test	Laboratory test	Laboratory test on undisturbed samples	Laboratory test	In situ test or laboratory test on undisturbed samples	<i>Laboratory test</i> (see note 6)	<i>Laboratory test</i>	<i>Laboratory test</i>	Laboratory test	Laboratory test
Clays	Laboratory test (see note 7)	NA	Laboratory test on undisturbed samples	NA	<i>In situ test or laboratory test on undisturbed samples</i>	Laboratory test (see note 6)	Laboratory test	In situ and/or laboratory test (see note 8)	NA	Laboratory test
Peats and organic soils	NA	NA	<i>Laboratory test on undisturbed samples</i>	NA	<i>In situ test</i>	Laboratory test	Laboratory test	<i>In situ and/or laboratory test</i>	NA	Laboratory test

Key

Tests in bold italic type are considered to be of first priority for assessment of soil characteristics for dredging purposes; tests in italic type are of second priority. Tests in non-italic type can be restricted to a few representative samples of each soil type.

NOTE 1 For testing procedures see Table 8.

NOTE 2 To be tested as rock.

NOTE 3 Applicable to dredged aggregates for construction purposes.

NOTE 4 Determination of the maximum and minimum dry density is also recommended.

NOTE 5 Silts often contain an appreciable amount of clay particles, which have a strong influence on the soil characteristics. In such cases the tests for silts as well as clays should be performed.

NOTE 6 Tests should be performed on samples in natural condition by preference using undisturbed samples.

NOTE 7 It may be useful to carry out particle size distribution on any sand/silt fraction within the clay sample but also expressing the percentage relative to the total sample.

NOTE 8 Tests should include sensitivity performed on representative samples.

NA = Not applicable.

Table 8 — In situ and laboratory testing procedures for soils for dredging purposes

Soil properties or characteristics	In situ test	Laboratory test (site or central laboratory)	Reference
Particle size analysis	NA ^a	Sieving on granular soils Sedimentation on cohesive soils Combination on composite soils such as sandy clays A rough evaluation by comparison with standard soil samples, by microscope or with grid counter	BS 1377-2
Particle shape	NA	Comparison with standard samples and photographs	BS 812-102 and BS 812-105
Bulk density or in situ density	NA over water except for measurement of boulders and cobbles	The unit mass of soil as found in situ and expressed as the ratio between total mass and total volume of soil	<i>Laboratory</i> BS 1377-2 <i>In situ</i> BS 1377-9
Particle density (PD) of the solid particles	NA	PD determined as the ratio between unit mass of solid particles and unit mass of water	BS 1377-2
Compactness (in situ)	May employ several in situ tests, e.g. the following: a) Standard penetration test (SPT) b) Static cone penetration test (CPT) c) Dynamic probing (DP)		a), b) and c) BS 1377-9
Moisture content	a) Radioactive meter method on land	b) Moisture content determination	a) BS 1377-2 b) BS 1377-9
Plasticity	NA	Determination of liquid and plastic limits	BS 1377-2
Shear strength	May employ several in situ tests, e.g. the following: a) Hand penetrometer or hand vane b) Vane tests c) Static cone penetration test (CPT) d) Dynamic probing (DP)	e) Laboratory vane f) Unconfined compression apparatus g) Triaxial compression	a) Not standardized b), c) and d) BS 1377-9 e) and f) BS 1377-7 g) BS 1377-7 and BS 1377-8
Lime content	NA	a) Measurement of carbonate content b) Visual test by applying dilute hydrochloric acid to specimen to indicate effervescence	a) BS 1377-3
Organic content	NA	Determination of organic content	BS 1377-3

^a NA = Not applicable.

Comments on Table 8	
In situ and laboratory testing	
The table indicates the range of in situ and laboratory tests that may be used to determine various soil properties or characteristics.	
Laboratory testing has to be undertaken on fresh samples and tests should ideally be carried out very soon after samples are obtained. However, since practical and logistical difficulties sometimes cause delay in samples being received at the laboratory, it is essential, where this may occur, that the simpler field tests (e.g. hand penetrometer or hand vane) are undertaken on site for later comparison with laboratory tests.	
The in situ compactness may be determined by using one of several tests including the standard penetration test (SPT).	
An important value used in geotechnical work is the relative density of sands and gravels, which has been developed by the use of this test. A commonly used scale in terms of N-values is as follows:	
Term	SPT N-values blows/300 mm penetration
Very loose	0 to 4
Loose	4 to 10
Medium dense	10 to 30
Dense	30 to 50
Very dense	over 50
Other testing	
It should be noted that, especially in relation to environmental aspects, it may be necessary to carry out chemical tests on selected samples. The precise tests will be related to the circumstances of the project and the specific requirements.	

Table 9 — In situ and laboratory testing procedures for rocks for dredging purposes

Name of test	Purpose of test	Remarks	Laboratory (L) or in situ (S)	Reference
<i>Visual inspection</i>	Assessment of rock mass	Indicates in situ state of rock mass (see note 1)	S or L	BS 5930
Thin section	Identification	Aid to mineral composition	L	Geotechnical textbooks } <i>Int. Journal for Rock Mech. Min. Sci.</i> , 1979, 16 , 141-156 [14]
<i>Bulk density</i>	Volume/mass relationship	Wet and dry test	L	
<i>Porosity</i>	Measure of pores expressed as percentage ratio voids/total volume	To be calculated directly from wet and dry bulk density	L	
<i>Carbonate content</i>	Useful for identification of limestone, chalks, etc.		L	
Surface hardness	Determination of hardness	Graded according to Moh's scale from 0 (talc) to 10 (diamond)	L	Reference set commercially obtainable
<i>Uniaxial compression</i>	Ultimate strength under uniaxial stress	Test to be done on fully saturated samples. Dimensions of testpiece and direction of stratification relevant to stress direction are to be stated. Recommend 1 : 2 length/diameter ratio for cylindrical specimens	L	International Society for Rock Mechanics Commission Committee on Laboratory Tests. Publication 135, September 1978 [15]
<i>Brazilian split</i>	Tensile strength (derived from uniaxial testing)	As for the test immediately above except length/diameter ratio recommendation	L	International Society for Rock Mechanics Commission Committee on Laboratory Tests. Publication 8, March 1977 [13]
<i>Point load test</i>	Strength indication	Easy and fast test but should be matched with uniaxial compressive strength test	L	<i>Int. Journal for Rock Mech. Min. Sci.</i> , 1972, 9 , 669-697 [16]
Protodiakonov	Indication of crushing resistance under dynamic load	Test has been devised for the harder type of rocks. Care should be taken with the execution and interpretation of test results on soft rocks, especially coarse-grained conglomerates	L	See note 2
<i>Standard penetration test (SPT)</i>	Strength indication	Applies to corals and highly weathered rocks	S	BS 1377-9

Table 9 — In situ and laboratory testing procedures for rocks for dredging purposes

Name of test	Purpose of test	Remarks	Laboratory (L) or in situ (S)	Reference
Seismic velocity	Indication of stratigraphy and fracturing of rock mass	Useful in extrapolating laboratory and field tests to rock mass behaviour	S	ASTM <i>Annual book</i> 1975 340-347 [17]
Ultrasonic velocity	Longitudinal velocity	Tests on saturated core samples	L	ASTM Spec. Tech. Publication No. 402 (1966) 133-172
Static modulus of elasticity	Stress/strain rate	Gives an indication of brittleness	L	
Drillability	Assessment of the rock mass	Measurement of drilling parameters including penetration rate, torque, feed force fluid pressure, etc., and statement of drill specification and technique	S	
Angularity	Determination of particle shape	May be by visual examination compared to standard specimens	L	BS 812-1
Key Tests in bold italic type are considered to be of first priority for assessment of soil characteristics for dredging purposes; tests in italic type are of second priority. Tests in non-italic type can be restricted to a few representative samples of each soil type. NOTE 1 Colour photography for record purposes can be very useful. NOTE 2 Concise records are not available for the Protodiakonov test. A reference that gives a slight modification of this procedure in order to overcome some of the disadvantages of the original method, such as rebonding of pulverized material is Evans and Pomeroy [18]. See [19, 20, 21, 22]. ^a ASTM = American Society for Testing and Materials.				

Comments on Table 9

Engineering characteristics of rock

The current approach is to recommend consideration of both rock material and rock mass characteristics.

However, especially in relation to dredging works, where the rock to be excavated is underwater, it is usually necessary to describe and assess the rock by an examination of cores obtained from site investigations, which essentially indicate the nature of the rock material. Rock mass can only properly be examined by mapping natural and artificial exposures and excavations on land. Although it is valuable to examine land outcrops that are local to the dredging works, great care is needed, since isolated, natural exposures are not necessarily representative of the rock mass at the site of future excavation.

Rock material

For dredging purposes it is important to assess the engineering characteristics. Geological examination will identify the material and will already provide valuable basic information concerning the rock type and its likely characteristics.

Information on weathering is extremely important from a dredging point of view, and it is suggested that a descriptive scale of weathering that relates to the breakdown of the rock material should be included.

The comments under "Weathering of rock material", "Strength of rock material" and "Fracture state" are included in BS 5930.

Weathering of rock material

A descriptive scheme for weathering of rock material may be established such as the following.

<i>Term</i>	<i>Description</i>
Fresh	No visible sign of weathering of the rock material
Discoloured	The colour of the original fresh rock material is changed and is evidence of weathering. The degree of change from the original colour should be indicated. If the colour change is confined to particular mineral constituents, this should be mentioned
Decomposed	The rock is weathered to the condition of a soil in which the original material fabric is still intact, but some or all of the mineral grains are decomposed
Disintegrated	The rock is weathered to the condition of soil in which the original material fabric is still intact. The rock is friable, but the mineral grains are not decomposed

The stages of weathering described may be subdivided using qualifying terms, e.g. partially discoloured.

Strength of rock material

It is valuable to relate the strength of rock material obtained in the uniaxial compression test to a general scale of strength as follows.

<i>Term</i>	<i>Compressive strength</i> MN/m ²
Very weak	< 1.25
Weak	1.25 to 5
Moderately weak	5 to 12.5
Moderately strong	12.5 to 50
Strong	50 to 100
Very strong	100 to 200
Extremely strong	> 200

It should be noted that the strength of a rock material determined in the uniaxial compression test is dependent on the moisture content of the specimen, anisotropy and the test procedure adopted.

For dredging assessment, the strength range within the descriptive term is rather large and therefore it is very important that when giving descriptive terms the test results should also be provided.

Fracture state

The state of the rock in situ is very important and so it is essential that the drilling method and size employed are stated. In addition, in order to assess the soundness of the rock, various criteria may be used to indicate the fracture state of rock cores; these are the total core recovery, solid core recovery, fracture log and Rock Quality Designation (RQD). All these should be included in the log of the borehole.

The total core recovery is expressed as the length of the total amount of core recovered as a percentage of the length of core run.

The solid core recovery is defined as the length of core recovered as solid cylinders expressed as a percentage of the length of core run.

A fracture log is a count of the number of natural fractures present over an arbitrary length, e.g. the number of natural fractures per metre of core run.

The determination of RQD is a quantitative measure of the fracture state of the rock. RQD is the sum length of all core pieces (100 mm or longer), measured along the centreline of the core, expressed as a percentage of core drilled.

Important aids, together with RQD determination, are colour photographs of the rock cores.

It is also possible that a ratio of field seismic velocity to the laboratory seismic velocity may be used as a quantitative fracture index of the in situ rock mass.

Section 3. Considerations affecting dredging works

3.1 Introduction

Matters that are fundamental to the operation of dredging plant are discussed in this section. Works that depend on dredging plant for their formation, such as navigation channels, are only discussed in relation to the design limitations that are due to dredging plant. The design of works in relation to their intended end use is described in BS 6349-1.

3.2 Factors affecting the use of dredging plant

3.2.1 Sea state

The normal limitations that apply to each of the various types of dredging plant are detailed in section 4 and Appendix A. For convenience, an indication of the limitations applying to all types of dredging plant is given in Table 10 to provide the means of identifying quickly those types of plant that are likely to be unsuited to particular situations. Table 10 is illustrative only as individual dredgers may not conform to the figures given.

Severe sea conditions may adversely affect the stability or security of a dredger in the same way as they may affect any other floating plant, vessel or structure. Generally, dredging plant is not designed to continue operating in severe sea conditions and these conditions are not covered in this Part of BS 6349.

The risk of damage occurring to a dredger due to impact with the sea bed depends on the nature of the sea bed and the amplitude of movement and acceleration of the dredger mass. These in turn depend on the amplitude, period and direction of the waves or swell.

The direction of working in relation to the prevailing sea direction is important, as a dredger that is end on to the sea may be unaffected and work safely while, if broadside on to the same sea, it may suffer from roll which may make operation impossible.

Wind, visibility and the effect of currents may create operational problems and it is essential that each should be considered when selecting plant and operating techniques.

Water currents, if significant, will affect dredging operations in a wide variety of ways. Strong currents may have an adverse effect on the mooring of stationary dredgers.

Each type of dredger may be affected in a different way, as follows.

- a) A cutter suction dredger may have to limit the angle of swing in order to avoid placing the dredger across the current with resulting high forces on the mooring system.
- b) Cross currents may make it difficult to control the dredging action of trailing suction hopper dredgers due to the relative freedom of the draghead in relation to the ship.
- c) For grab dredgers operating in any significant water depth, the current carries the grab out of position and the dredging process is difficult to control.

Wind effects are mainly confined to the sea conditions which are caused by high wind speeds, although operational problems may also arise. Poor visibility may also cause operating problems as well as increasing the risk of collision.

3.2.2 Water depth

There is a minimum and a maximum water depth in which any particular dredger is able to operate efficiently. With rare exceptions, dredging plant need to remain afloat in order to continue operating.

In the case where the existing water depth is shallow, the dredger may have to create sufficient water depth from which it can operate.

Not only is it essential that the main dredger remains afloat but it is also essential that access by loaded barges and hoppers is assured at all times if production is not to be interrupted.

For those dredgers that discharge to barges, it is essential that movement of the barges be assured at all times if production is not to be interrupted. When discharge is through a pipeline, if it becomes grounded by low water level this will restrict the movement of the dredger.

There are few dredgers that are able to dredge below a depth of 30 m. A small number have the capability to dredge down to depths of 40 m and a few to depths as great as 80 m. Such dredgers are normally only employed in specialized applications.

Where production requirements are small and the material to be dredged is loose and free flowing, submersible pumps or jet pumps with flexible hose discharge can be used down to depths greater than 100 m.

Table 10 — Guidance on the use of dredging plant

Operational parameters	Units	Type of dredging plant									
		Trailer suction	Suction	Cutter suction	Bucket wheel	Stationary suction	Grab hopper	Grab pontoon	Bucket chain	Hydraulic backhoe	Dipper
Minimum depth of water to operate	m	4	3	1	3	1.5	3	3	3	2	1.5
Maximum depth of water to operate	m	35	35	35	20	85	45	80	35	25	15
Maximum wave height to operate	m	3	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Maximum swell height to operate	m	2	1.5	1	0.6	1	1	1	1	0.7	0.7
Maximum cross current to operate	knots	3	2	2	2	2	1.5	1.5	1.5	1.5	0.5
Minimum cut width	m	NA ^a	NA	5	5	NA	5	5	10	2	3
Maximum cut width (single pass)	m	NA	NA	175	105	NA	15	70	200	50	25
Minimum turning circle	m	75	75	NA	NA	NA	75	NA	NA	NA	NA
Minimum water consumption	m ³ /h	NA	NA	300	350	450	NA	NA	NA	NA	NA
Maximum particle size	mm	500	200	500	450	150	450	3 500	2 500	3 000	2 500
Maximum soil shear strength	kN/m ²	75	NA	500	400	NA	100	300	350	450	500
Maximum rock crushing strength (see note 1)	kN/m ²	100	NA	30 000	10 000	NA	500	1 000	3 000	10 000	5 000
Maximum ice thickness to operate	mm	200	NA	200	200	NA	200	100	100	200	200

NOTE 1 Maximum rock crushing strength is very dependent on rock quality.

NOTE 2 Apart from cross currents, minimum figures apply to smallest plant type and maximum figures apply to largest plant type.

NOTE 3 None of the figures are absolute limits, but operation outside these parameters is unusual and may be difficult.

^a NA = Not usually applicable.

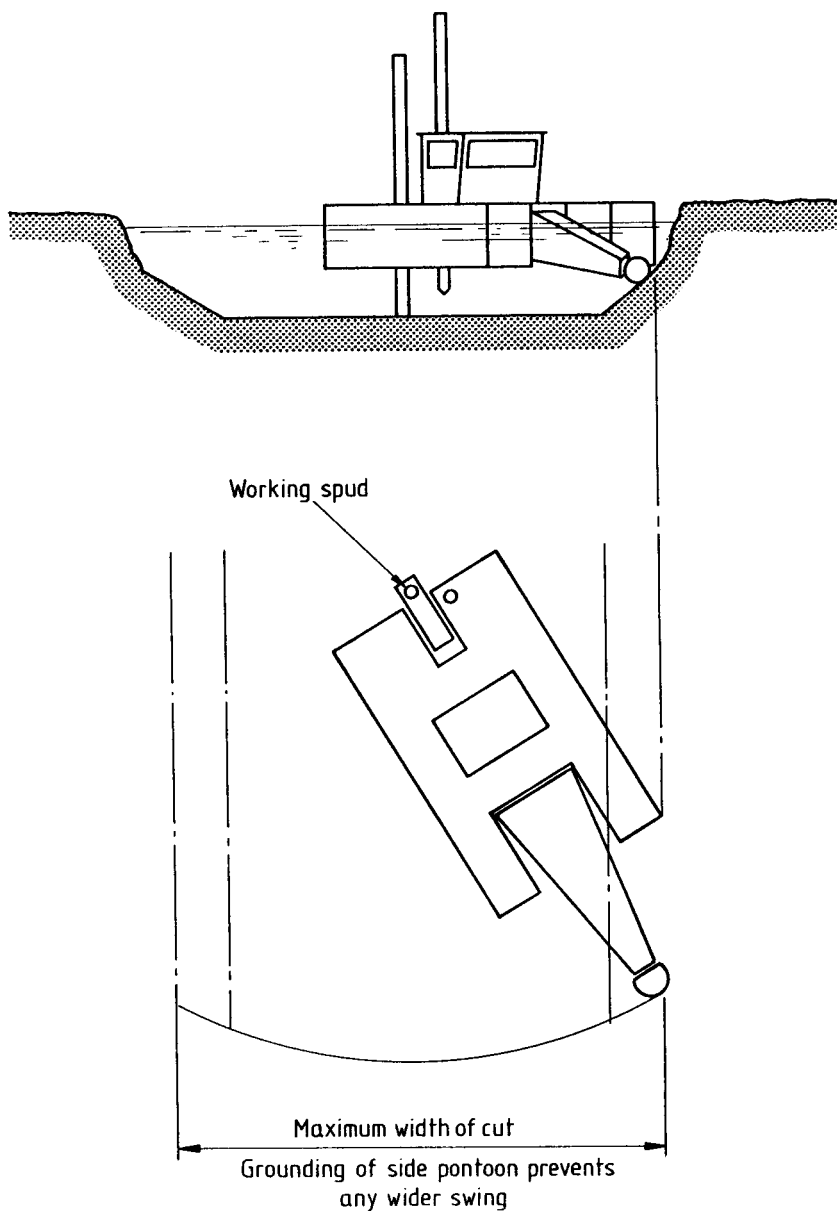


Figure 5 — Cut width limitation which affects dredgers that swing while working in shallow water