BRITISH STANDARD

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1991

Maritime structures —

Part 5: Code of practice for dredging and land reclamation

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Civil Engineering and Building Structures Standards Policy Committee (CSB/-) to Technical Committee CSB/17, upon which the following bodies were represented:

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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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 1*1)*: General criteria;*

— *Part 2*4)*: Design of quay walls, jetties and dolphins;*

— *Part 3*4)*: Design of dry docks, locks, slipways and shipbuilding berths, shiplifts and dock and lock gates;*

— *Part 4*4)*: Design of fendering and mooring systems;*

— *Part 5*4)*: Code of practice for dredging and land reclamation;*

— *Part 6*4)*: Design of inshore moorings and floating structures;*

— *Part 7*2)*: 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 × d)	0.00
2.0 knot	± (0.20 × d)	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. d 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).

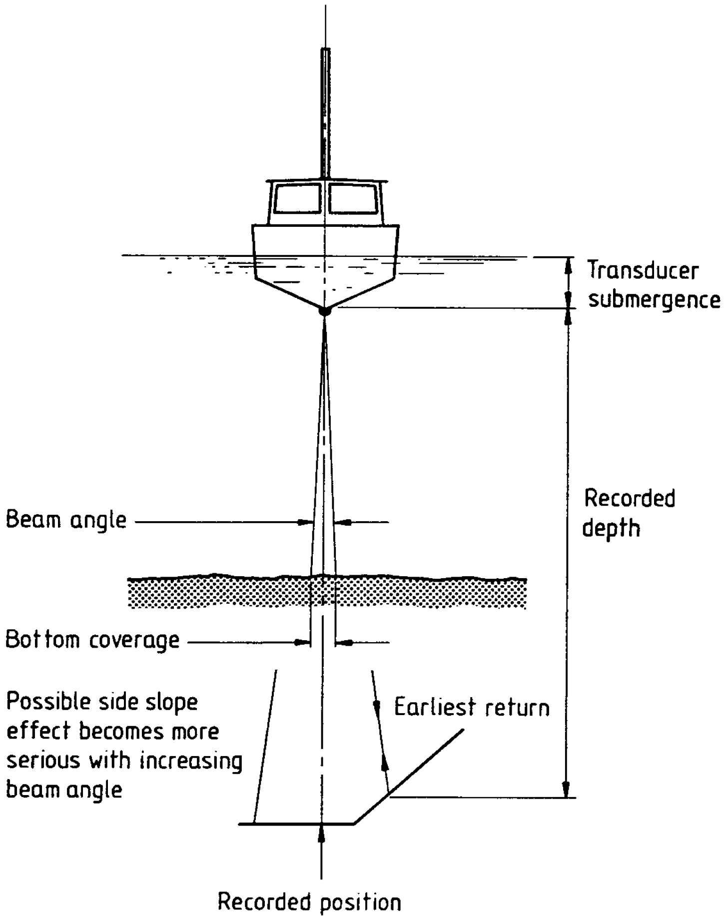


Figure 1 — Echo sounder with transducer beam angle and side echo from slopes

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:

a) power source suitability and stability;

b) depth of transducer below water surface (may vary with boat displacement or speed);

c) horizontal displacement of transducer position relative to position-fixing system;

d) alignment of analogue chart paper;

e) echo sounder calibration (bar check);

f) sea bed characteristics;

g) signal frequency;

h) paper speed;

i) proposed direction of sailing of lines;

j) 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:

a) alongside structures, where reflected signals may have an adverse effect on an echo sounder;

b) to check an echo sounder, particularly in areas where the sea bed is soft;

c) 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

d) 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.

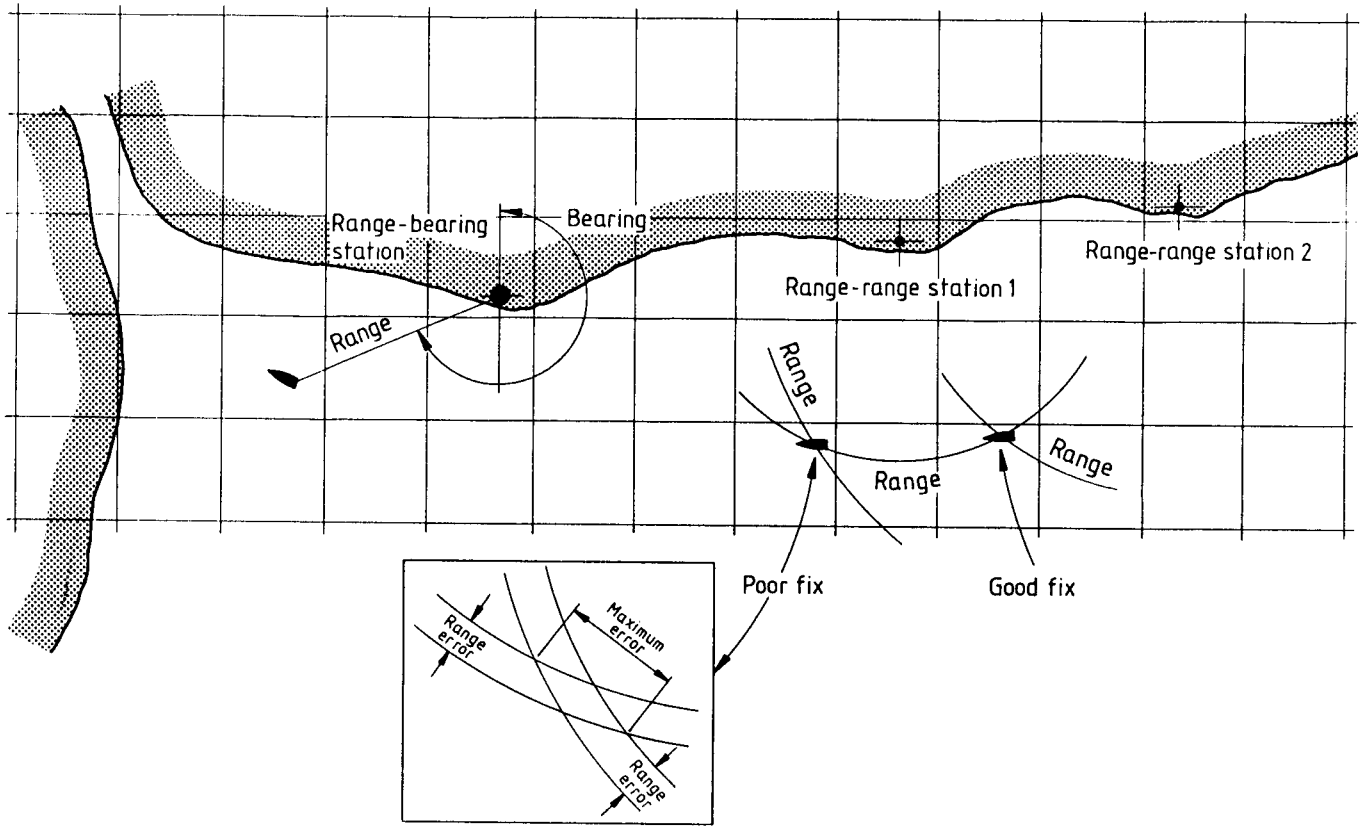
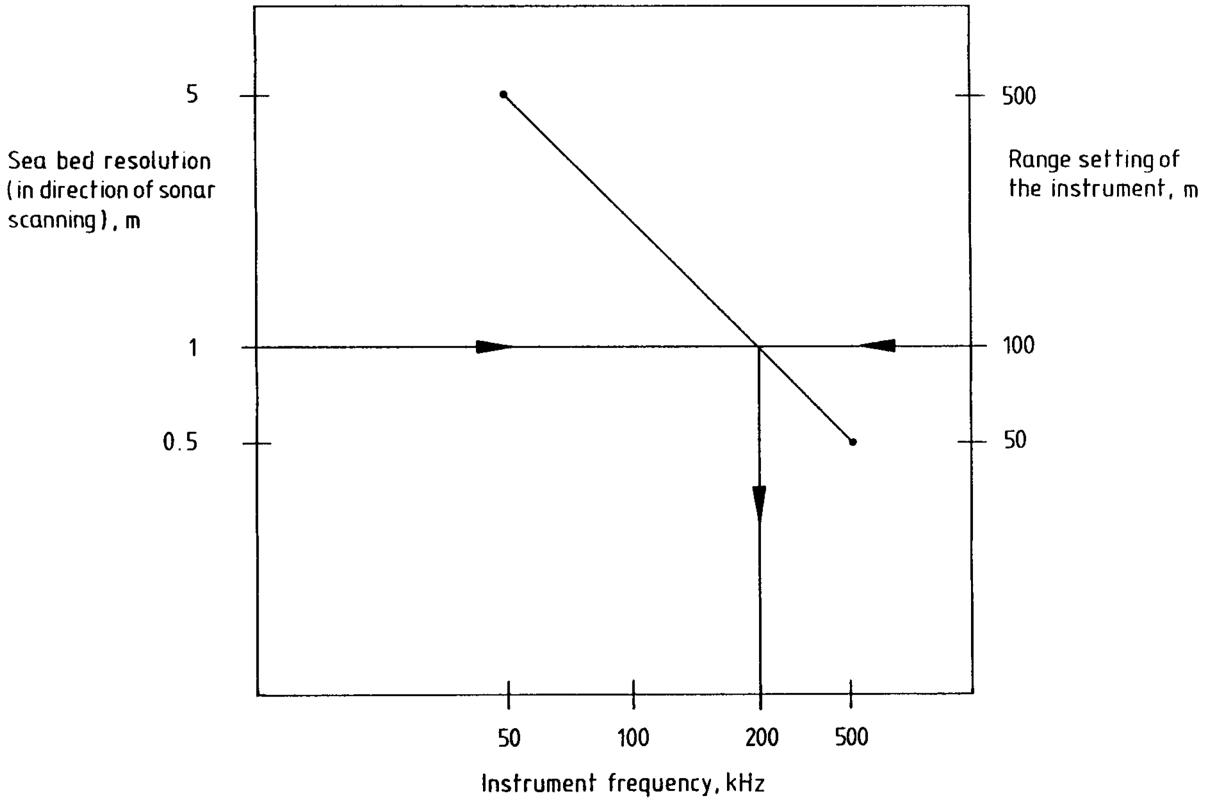


Figure 2 — Illustration of range-bearing and range-range electronic positioning systems and source of error if only two poorly located range-range stations are used



Use of graph

Decide on the seabed resolution required and follow the graph across to see the corresponding range. Alternatively, decide on the range setting from the line spacing and see if the resolution is acceptable. When both values are acceptable, take the vertical intersection with the axis to give the optimum frequency of operation of the sonar "fish device".

This graph is only valid if the directions of the arrows are followed.

NOTE 1 Sea bed resolution is based on the paper width, which is normally 127 mm (5 in) per channel.

NOTE 2 Higher frequencies give greater resolution but the signal is more quickly attenuated with range.

NOTE 3 The graph covers the side-scan sonar "fish devices" in general use. If they do not meet the requirements of the work a more specialized sonar "fish device" and/or recorder may be required and it is recommended that an engineering geophysicist or hydrographic surveyor is consulted.

Figure 3 — Selection of side-scan sonar "fish device"

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 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.

[a] 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

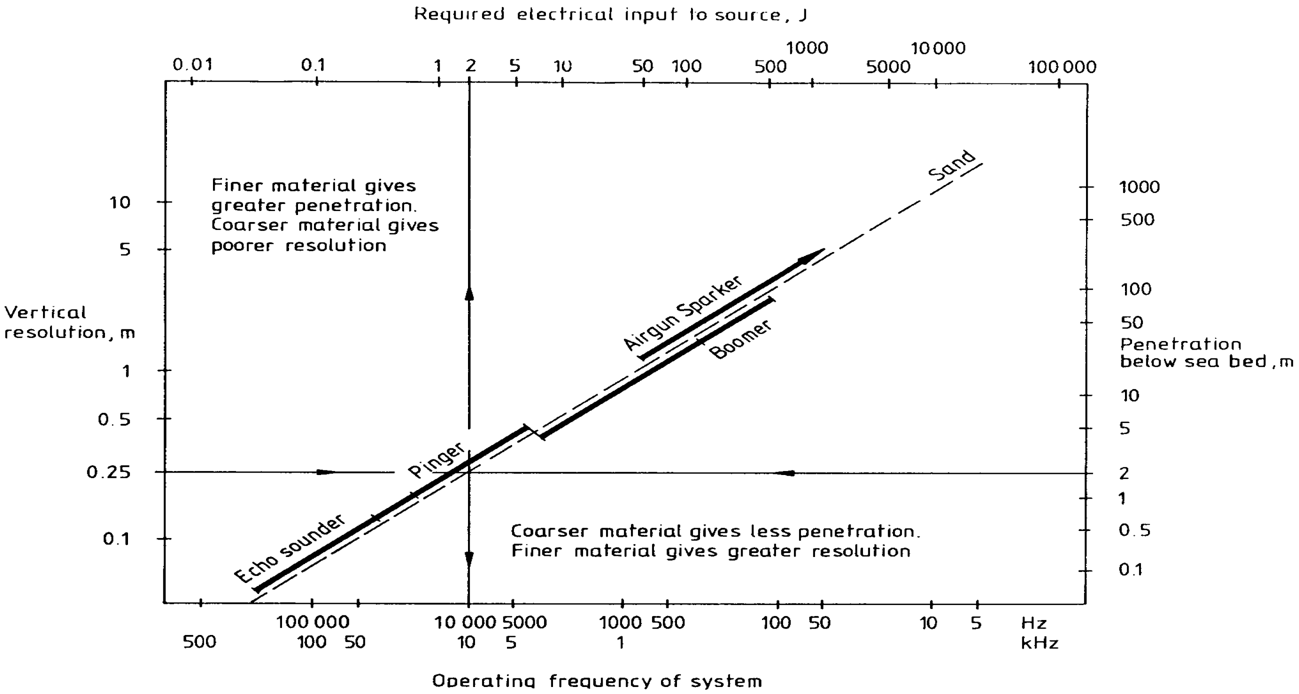
Most of the sampling and investigation procedures have been derived from land-based techniques. Some techniques have been adapted and are under further development for underwater operation on the sea bed using a diver or using remote control from the surface. Mention should be made of vibrocorers and 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.



Use of graph

Decide on the required penetration below the sea bed and follow the graph across to see the resolution that can normally be obtained in sand. Alternatively, decide on the resolution and see what penetration in sand is normally possible. When both values are acceptable, take the intersection with the graph to give the profiling system and the vertical intersection with the axes to give the operating frequency and power at which the profiling system should be used.

This graph is only valid if the directions of the arrows are followed.

NOTE 1 If coarser sediments than sand are anticipated, expect less penetration, poorer resolution and more power needed to penetrate the sea bed.

NOTE 2 If finer sediments than sand are anticipated, expect more penetration, better resolution and less power needed to penetrate the sea bed.

NOTE 3 Gravel or coarser material on the sea bed surface scatters the energy and needs significantly more power and perhaps a sparker or airgun energy source to achieve penetration.

NOTE 4 Clays containing organic matter and gas absorb energy and it may not be possible to penetrate below them.

NOTE 5 The graph is a generalization of seismic reflection profiling and covers the broad concepts of data recovery. If a more detailed assessment is required, it is recommended that an engineering geophysicist is consulted.

Figure 4 — Selection of seismic reflection profiling system (based on equipment in common use in sandy materials)

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
	mm			
Boulders Cobbles	Larger than 200 200 to 60	Visual examination and measurement (see note 1)	*Particle shape* Rounded Irregular Angular Flaky Elongated Flaky and elongated	Not applicable
Gravels	Coarse 60 to 20 Medium 20 to 6 Fine 6 to 2	Easily identifiable by visual examination		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	*Textures* 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:

a) structure (e.g. resistance to penetration, compactness);

b) for granular soils, quantitative distribution of grain sizes, preferably indicated as a grading curve, and a descriptive indication of the shape of the grains;

c) for cohesive soils, shear strength;

d) smell and colour;

e) 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:

i) stiff, fissured, grey clay;

ii) loose, yellow, rounded, fine medium gravel and course sand containing shells;

iii) soft, grey/blue, sandy silt;

iv) soft, black, clayey, fibrous, strong-smelling peat;

v) brown, rounded, slightly compact, fine sand;

vi) compacted, coarse, angular sand mixed with scattered, irregular gravel;

vii) 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 desctiption 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:

Till type	***Boulder content***
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 Cobbles (see note 2)	Visual in field	Visual inspection	NA[a]	Laboratory test (on fragments)	NA	NA	NA	NA	NA	NA
Gravel	***Laboratory test***	*Laboratory test*	NA	Laboratory test	***In situ test***	NA	NA	NA	Laboratory test (see note 3)	NA
Sands	***Laboratory test***	*Laboratory test*	Laboratory test on undisturbed samples (see note 4)	Laboratory test	***In situ test***	Laboratory test	NA	NA	*Laboratory test*	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***	*Laboratory test* (see note 6)	*Laboratory test*	*Laboratory test*	Laboratory test	Laboratory test
Clays	Laboratory test (see note 7)	NA	***Laboratory test on undisturbed samples***	NA	*In situ test or laboratory test on undisturbed samples*	***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	*Laboratory test on undisturbed samples*	NA	*In situ test*	Laboratory test	Laboratory test	*In situ and/or laboratory test*	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.

[a] 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	*Laboratory* BS 1377-2 *In situ* 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 soom 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
Visual inspection	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
Bulk density	Volume/mass relationship	Wet and dry test	L	*Int. Journal for Rock Mech. Min. Sci.*, 1979, **16**, 141-156 [14]
Porosity	Measure of pores expressed as percentage ratio voids/total volume	To be calculated directly from wet and dry bulk density	L	
Carbonate content	Useful for identification of limestone, chalks, etc.		L	BS 1377-3 ASTM[a] D 3155
Surface hardness	Determination of hardness	Graded according to Moh's scale from 0 (talc) to 10 (diamond)	L	Reference set commercially obtainable
Uniaxial compression	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]
Brazilian split	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]
Point load test	Strength indication	Easy and fast test but should be matched with uniaxial compressive strength test	L	*Int. Journal for Rock Mech. Min. Sci.*, 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 intrepretation of test results on soft rocks, especially coarse-grained conglomerates	L	See note 2
Standard penetration test (SPT)	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 *Annual book* 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.

Term	*Description*
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.

Term	*Compressive strength* **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.

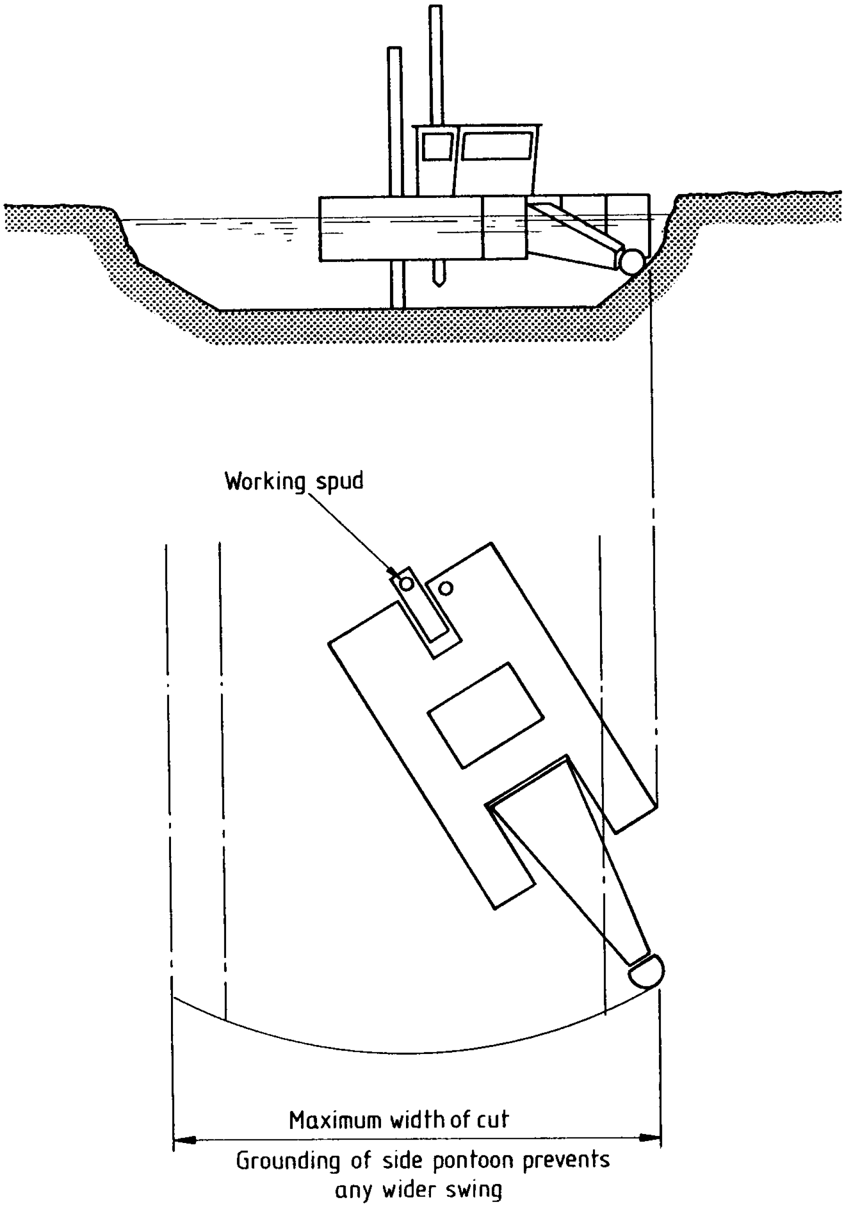


Figure 5 — Cut width limitation which affects dredgers that swing while working in shallow water

3.2.3 Channel or trench width

The minimum and maximum widths of cut that can be made economically depend upon the type of dredger to be employed and the depth of water in the working area. When water is at times less than the draught of the dredging plant, the final width of cut has to be not less than the width of the dredger itself (plus barges when necessary). In the case of dredgers that swing from side to side to operate, such as cutter suction dredgers, the width of cut has to be such that at the extremity of the cut the suction head or cutterhead extends beyond the outside leading corner of the hull (see **3.5.2** and Figure 5).

When bucket-type dredgers are employed, which normally achieve spoil disposal through the loading of hopper barges, the minimum width of cut in shallow water has to be sufficient to accommodate not only the dredger but also one or more barges moored alongside.

Regardless of water depth, there is an optimum width of cut, which affects the efficiency of the dredging operation.

For cutter suction dredgers, it is not normally practical to swing the dredger through more than 45° either side of the centreline of the cut. Therefore, if the channel width is a few metres greater than the maximum practical angle of swing for the particular dredger employed, it will be necessary to make a second cut parallel to the first to achieve the desired width. This second cut may be very uneconomic. Even if the total width of cut to be achieved is divided into two equal cuts, the overall efficiency of the operation will still be reduced.

Similar considerations apply to grab and backhoe dredgers due to limitations of outreach.

3.2.4 Soil strength

The strength of the soil or rock to be removed by dredging is an important factor affecting dredger production.

The strength may manifest itself in a number of ways. In sands a high degree of consolidation has an adverse effect on the dredgeability of the soil. In clays, high shear strengths also result in much lower productions. In weak rocks, greater crushing strengths limits production.

With increasing rock strengths, the point will be reached when the rock can no longer be dredged economically without pretreatment. The pretreatment process (see **9.4**) greatly increases the cost of dredging.

Generally, it may be preferable to remove greater quantities of more easily dredged material rather than relatively small quantities of rock. The removal of rock will almost certainly involve the mobilization of specialist equipment so that even for small quantities costs will be relatively high.

Where rock is anticipated, a thorough soil investigation with adequate sampling and laboratory testing of recovered rock cores is essential if the works are to be fully assessed at the design stage (see **2.10** and **2.12**).

Where materials other than rock are expected, the importance of determining the strength of the in situ material may be less obvious. Vibrocoring, which is less expensive, may give little indication, particularly in sands or gravels, of the in situ strength or degree of consolidation of the material. Where possible, in situ testing of the penetration type (see **2.10.2**) should be undertaken in addition to the recovery of samples in order that additional knowledge concerning in situ soil strength can be gained. Relatively small differences in strength may have a significant effect on dredging production.

Soil strengths also influence the stability of side slopes, which may be of particular importance in the dredging of temporary trenches for the laying of pipes, outfalls or other services (see Table 11). Very weak or mobile bed materials may result in rapid infill of the trench, and hence a need for regular dredging up to the point of the pipe launching or placement with a consequent substantial increase in the cost.

Table 11 — Typical side slopes for various soil types: underwater slopes

Soil type	Side slope	
	Still water	Active water
Rock	Nearly vertical	Nearly vertical
Stiff clay	45°	45°
Firm clay	40°	35°
Sandy clay	25°	15°
Coarse sand	20°	10°
Fine sand	15°	5°
Mud and silt	10° to 1°	5° or less

3.2.5 Particle size

Particle size considerably influences the rate of production that can be achieved by each type of dredger. Very fine particles can usually be easily dredged, but may cause problems due to their very slow rate of settlement. Trailing suction hopper dredgers (see **4.2**) will normally remove loose deposits of very fine material from the sea bed at high rates, but the load that can be achieved in the hopper will be relatively small unless the concentration rate of solids in the incoming water mixture is very high.

If cutter suction dredgers or other types of suction dredger that discharge through a pipeline are employed in the removal of very fine materials, problems may be created subsequent to the discharge of the material through the difficulty of achieving settlement rapidly within the disposal or containment area. Fines may cause siltation of adjoining areas if lost through the sluices.

Generally, bucket-type dredgers do not suffer the same disadvantages when handling fine materials as, in most cases, these materials exhibit some degree of cohesion, which assists in achieving good bucket filling and hence relatively high production rates. However, if the material to be dredged consists of very fine materials with little cohesion, losses of fines from the buckets or grabs rising through the water column may be significant.

With coarser grained materials, more rapid settling from suspension allows a high percentage retention of the material in the hopper or within an onshore filling area.

Increasing particle diameter while still within the sand range has little effect on bucket-type dredgers but may have an important effect on dredgers that discharge the spoil by pumping through a pipeline, such as the cutter suction dredger. The increasing settling velocity of the particle requires higher mixture velocities in the pipeline in order to keep all particles in motion. Higher velocities result in higher friction head, possibly a larger number of pumps or increased horsepower to drive the pumps and much greater wear on pumps and pipelines.

The effect of increasing particle size on those dredgers that rely on pumping for part of the disposal process is shown in Figure 6.

Gravel can be pumped over significant distances but only with higher than usual flow velocities. The resultant high pump head and increased horsepower necessary, coupled with the much higher wear rates, all combine to increase costs.

Cobbles and boulders are particularly critical to dredging operations. Boreholes are too small in diameter to allow satisfactory recovery of samples. Reference should be made to the drillers' logs for references to obstructions and chiselling. If it is suspected that cobbles and boulders exist, comparison should if possible be made with local cliff exposures, land boreholes, nearby beaches and divers' reports to make a more realistic estimate of the frequency of disposition that could be expected. This should then be included as a note on all the test sheets and in the covering report.

3.2.6 Transport distance

Regardless of the type of dredging process that is involved, the greater the distance that the dredged spoil has to be transported, the greater is the cost of the work. When pumping methods are to be employed, careful phasing of the work may permit pipeline lengths to be minimized by ensuring that the area of dredging is as close as is practical to the area of filling.

Where it is proposed to dispose of spoil at sea, careful consideration should be given to the location of the area of the spoil disposal. The designer is unlikely to be free to select an area for spoil disposal that is necessarily ideal for his purposes. The effects upon other users of the sea, particularly the fishing industry, have to be considered before any final decision concerning disposal sites can be made (see **3.7.1**).

Pumping long distances over water should be avoided where possible. Floating pipelines are extremely vulnerable to wave attack.

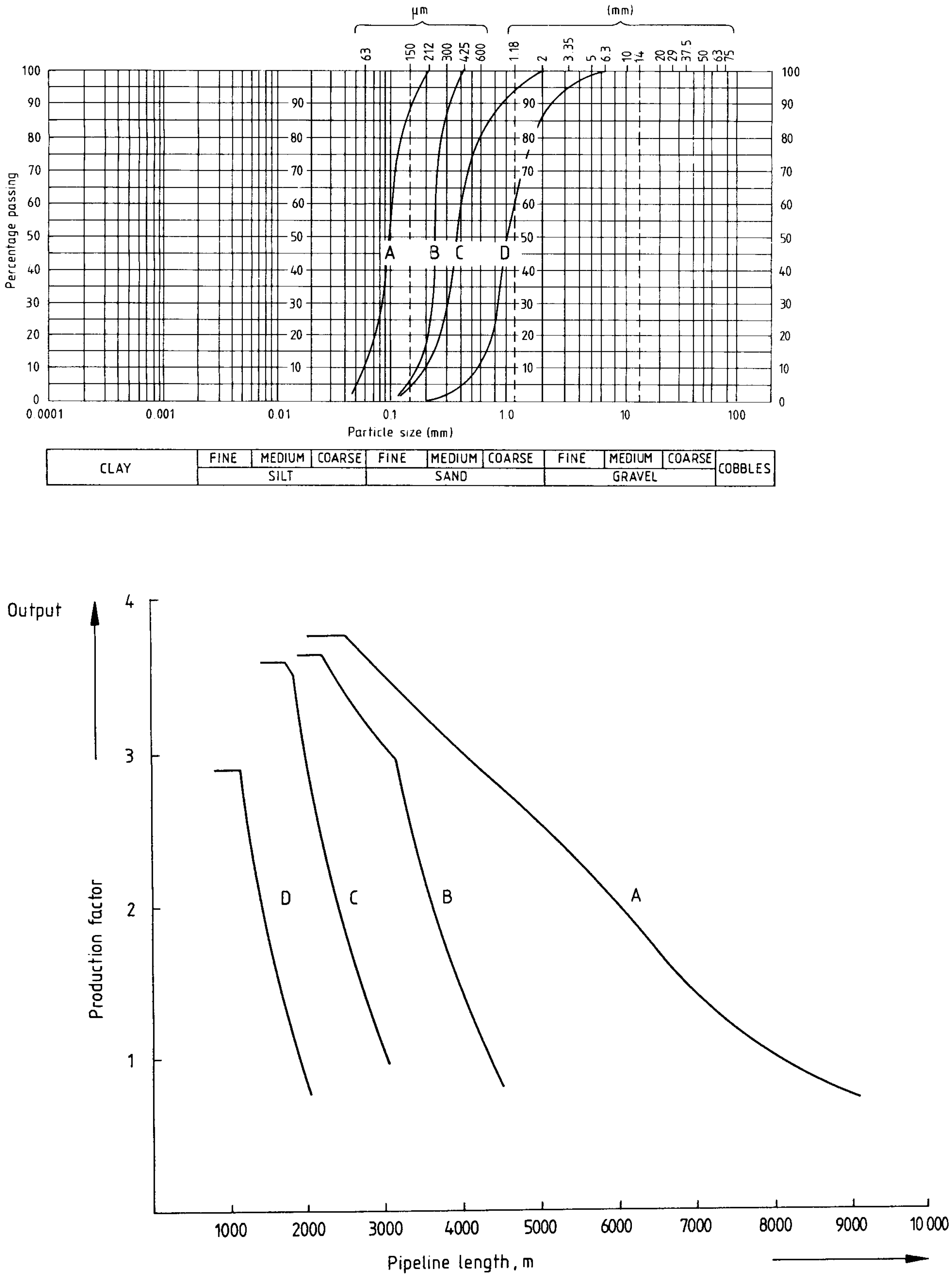


Figure 6 — Decrease in output with increasing material particle size and increasing pipeline length for a particular dredger

3.2.7 Interaction with other navigation

3.2.7.1 *General*

The effects of dredging operations on other navigation in the area depend almost entirely on the type of dredging plant. Normally, the trailing suction hopper dredger, by virtue of the fact that it dredges while on the move, will not create problems provided that there is an adequate working space for shipping to pass alongside the dredger, which when dredging will normally be moving slower than most other vessels (see **4.2**).

Dredgers provided with spuds, such as backhoes (see **4.10**) and some grabs (see **4.8**), which although stationary do not require mooring wires, do not normally cause serious problems for navigation.

Cutter suction dredgers (see **4.4**) which normally work and moor using a combination of spuds and anchor wires and employ only two side wires and these, only when the dredger is working, normally lie on the sea bed. Provided that under keel clearance is adequate these dredgers will not create a hazard to passing navigation.

The discharge pipelines from cutter suction dredgers or other pumping dredgers may cause problems. Care should be exercised to ensure that the pipeline is routed in such a way as to minimize interference with navigation. Where the crossing of navigable waterways by pipelines can not be avoided, it may be necessary to lay a section of the pipeline on the sea bed. The alternative of breaking the pipeline each time that a shipping movement is necessary is only practical in situations where shipping movements are very infrequent.

The bucket chain dredger (see **4.9**), which relies on a pattern of six anchors and mooring wires in order to work, creates the greatest problem where other navigation is involved. Not only is the number of wires greater but the wires have to rise from the sea bed to the dredger and consequently result in reduced water depth for the passage of navigation. Many bucket chain dredgers are fitted with underwater fairleads to increase the depth of submergence of the mooring lines at the point of departure from the dredger.

In some instances, the conflict between dredging operations and normal navigation can be avoided by careful planning and phasing of the work. For example, movement of vessels in and out of yacht harbours tends to be a summer activity and winter movements are generally very light. If the dredging operations can be scheduled for winter, the effect upon the general operation of the harbour will be greatly reduced. Similar considerations may apply in the case of ports with heavy ferry traffic. It is standard practice for the port authority to issue notices to mariners to give advance warning of any dredging operation within a particular area.

3.2.7.2 *Lights and signals to be displayed*

There are established international conventions and standardized signals to draw the mariner's attention to dredging operations and the correct methods of navigation when passing through an area where dredging is taking place.

All stationary dredging craft that are unable to move to avoid collision while working are legally bound to display appropriate lights or signals. The requirements for dredgers in UK waters are laid down in Statutory Instrument No. 1525, 1972 Merchant Shipping and Civil Aviation Safety, the Collision Regulations (Ships and Seaplanes on the Water) and Signals of Distress (Ships) Order 1965.

3.3 Vertical tolerances

3.3.1 General

In all dredging works, some vertical tolerance is necessary. The amount of tolerance depends on the type of material to be dredged, the nature of the dredging equipment and the likely wind and wave activity in the area. The imposition of unreasonably narrow vertical tolerances may cause operational difficulties.

In general, those dredgers that, by their method of operation, sweep the bottom of the sea bed are likely to produce the most accurate finish. These include the bucket chain dredger and the cutter suction dredger.

The vertical accuracy of working that is readily achievable reduces as the flexibility of the dredging system increases. Consequently, the grab dredger can not be expected to work to high degrees of accuracy under normal conditions, especially when working in cohesive materials.

The following factors influence the accuracy of the dredged formation that can be achieved:

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

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

c) the type and size of the dredging equipment;

d) the experience of the operating personnel;

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

f) the rate of change of tidal level;

g) the strength of tidal or river currents;

h) the extent of automated control of the dredging.

The range of vertical accuracies that are normally achieved by different types of dredging plant under varying site conditions is given in Table 12.

A suitable tide board to provide an indication of the required depth of dredging is shown in Figure 7.

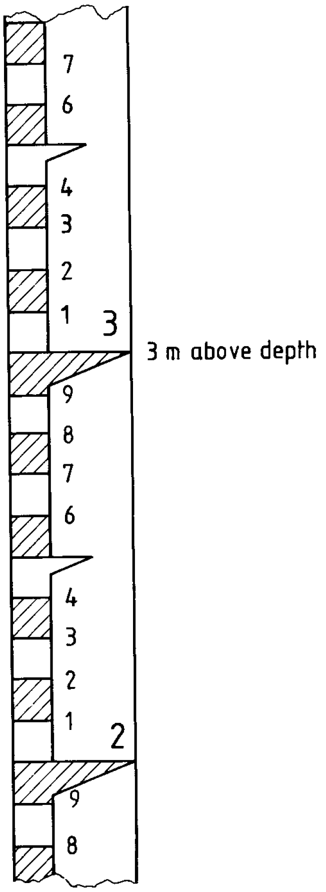


Figure 7 — Tide board markings to provide clear indication to dredger crew of required depth of dredging relative to tide level

The final decisions concerning the magnitude and arrangement (i.e. plus and minus, or minus only) of vertical tolerances depends upon the intended objective. Where the object is to create the minimum water depth for the navigation of shipping, it is normally most appropriate to specify a level above which all material has to be removed. A lower limit below which no material may be removed may be specified if necessary. This would be required, for example, if excessive depth could have an adverse effect on the stability of side slopes or adjacent structures. It has to be recognized that some overdredging is inevitable, it being impossible for any dredger to produce a given level with no plus or minus tolerance at all.

3.3.2 Overdredging

Overdredging is that depth of material removed from below the level specified by the design. It is important to limit overdredging alongside structures such as quay walls and caissons. If it is desired to specify particularly small tolerances, it should be recognized that certain types of plant may not be suitable for the work. In other areas, overdredging may not be important.

Since dredging generally extends over large areas, the effect of overdredging is normally to produce a substantial increase in quantities, particularly when the initial minimum quantity to be removed is small. Any assessment of quantities at the design stage of dredging works has to take account of the additional quantities that will arise from overdredging. This is particularly important when considering the quantities that have to be disposed of, especially if that disposal is to an onshore containment area. The increase in quantities arising from overdredging may also increase the duration of the works.

Table 12 — Typical working vertical accuracy for dredging plant under various site conditions

Site conditions	Standard trailer	Light trailer	Cutter suction	Bucket wheel	Grab hopper	Grab pontoon	Bucket	Backhoe	Dipper
Bed material	mm	mm	mm	mm	mm	mm	mm	mm	mm
Loose silt	200	200	200	200	200	200	200	150	200
Cohesive silt	300	300	150	150	250	250	150	150	150
Fine sand	200	200	150	150	200	200	150	150	150
Medium sand	200	200	150	150	200	200	150	150	150
Gravel	200	200	150	150	200	200	150	150	150
Soft clay	250	250	150	150	250	250	150	150	150
Medium clay	300	300	150	150	300	300	150	150	150
Stiff clay	250	250	150	150	250	250	200	150	200
Very weak rock	300	N[a]	300	250	N	300	300	350	300
Weak rock	N	N	300	250	N	350	300	350	300
Moderately weak rock	N	N	300	N	N	N	N	350	350
Pretreated rock	350	N	350	350	350	350	350	350	375
Adjustments for site conditions									
Sea conditions									
Sheltered water									
Small plant	125	150	150	150	175	175	100	100	100
Medium plant	100	150	125	125	150	150	100	100	100
Large plant	75	150	100	150	150	150	75	75	
Exposed water									
Small plant	300	350	N	N	500	N	N	N	N
Medium plant	250	350	350	350	400	400	350	300	300
Large plant	200	350	300	300	350	300	300	250	250
Currents									
Moderate (0.5 m/s)	0	0	0	0	100	100	0	0	0
Strong (1.0 m/s)	100	100	50	0	200	200	100	0	0

NOTE 1 Accuracies are plus or minus.
NOTE 2 Site condition adjustments should be added to "Bed material" figures.
NOTE 3 None of the figures are absolute limits, but difficulties may arise where lower limits are specified.

[a] N = Not usually appropriate.

When the purpose of dredging is channel maintenance, there may be benefits in permitting overdredging if, as a result, the interval between successive dredging campaigns can be extended.

3.3.3 Navigable depth

Navigable depth is the water depth necessary to permit safe navigation. The depth of channels is dealt with in **18.3** of BS 6349-1:1984.

After dredging, measurement has to be made to determine whether a navigable depth has been achieved. This measurement is normally made by echo sounder (see **2.2.3.2**).

Depending upon the characteristics of the echo sounder, the recorded depth may be significantly less than the actual depth that is available for navigation. This is because the signal from certain types of echo sounder, particularly those of high frequency and low energy, may be reflected from a surface of material that is of very low density. This may be particularly true upon the completion of dredging in areas of fine sediments, such as silts, clays and fine sands, since at this time the surface deposits may be in a semiliquid state. Shipping may be able to navigate through this material without any adverse effect on the handling characteristics of the ship.

Table 13 — Typical horizontal accuracy for dredging plant under various site conditions

Site conditions	Standard trailer	Light trailer	Cutter suction	Bucket wheel	Grab hopper	Grab pontoon	Bucket	Backhoe	Dipper
	mm	mm	mm	mm	mm	mm	mm	mm	mm
Bed material									
Loose silt	2 500	2 000	500	500	500	500	500	250	500
Cohesive silt	2 500	2 500	500	500	500	500	500	250	500
Fine sand	2 500	2 000	500	500	500	500	500	250	500
Medium sand	2 000	2 000	500	500	500	500	500	250	500
Gravel	2 500	2 000	500	500	500	500	500	250	500
Soft clay	2 500	2 500	500	500	700	700	500	250	500
Medium clay	2 500	2 500	500	500	700	700	500	250	500
Stiff clay	2 500	2 500	500	500	700	500	500	250	500
Very weak rock	2 500	N	500	500	N	700	700	700	700
Weak rock	N[a]	N	500	500	N	800	600	600	600
Moderately weak rock	N	N	600	600	N	N	700	800	700
Pretreated rock	2 500	N	1 000	800	1 000	1 000	1 000	700	800
Adjustments for site conditions									
Sea conditions									
Sheltered water									
Small plant	500	700	700	700	1 000	700	700	400	400
Medium plant	500	700	500	500	1 000	500	700	350	350
Large plant	500	700	500	500	1 000	500	700	300	300
Exposed water									
Small plant	2 000	2 500	N	N	2 000	N	N	N	N
Medium plant	1 750	2 500	1 000	1 000	1 750	1 500	1 500	700	1 000
Large plant	1 500	2 500	1 000	1 000	1 750	1 500	1 500	700	700
Currents									
Moderate (0.5 m/s)	1 000	1 500	500	500	1 500	1 000	1 000	200	300
Strong (1.0 m/s)	2 500	3 000	1 500	1 800	3 000	2 000	2 000	700	700

NOTE 1 Accuracies are plus or minus.
NOTE 2 Site condition adjustments should be added to minimum "Bed material" figures.
NOTE 3 None of the figures are absolute limits, but difficulties may arise where lower limits are specified.

[a] N = Not usually appropriate.

A judgement may be necessary at the design stage to determine the method by which the navigable depth available is going to be assessed and measured. If it is decided that any material or mixture with a density less than a predetermined figure, e.g. 1.2 t/m^3, does not present a hazard or restriction to navigation, the measurement of the available navigable depths has to be made with an instrument that measures the in situ density of the material comprising the sea bed (see **2.2.4**).

The proving of navigable depth upon completion of dredging is particularly important and may require special checks to be made (see **2.2.4**).

3.4 Horizontal tolerances

Under normal operating conditions, the horizontal accuracy that can be easily achieved with dredging equipment is significantly less than that which can be easily achieved with excavating equipment on land. The degree of accuracy that can be achieved is greater for those dredgers that are positively located by spuds than for those dredgers that are relatively free in their movement, particularly trailing suction hopper dredgers, in which there is no positive mooring system and the dredger is moving continuously while dredging.

The required horizontal accuracy should be decided at the design stage and taken into account when selecting appropriate plant.

In some situations it may be necessary to restrict dredging within tight tolerances. Careful selection of plant and survey methods will assist in achieving higher degrees of accuracy, but usually at the expense of reduced production and hence increased unit costs.

The following factors influence the degree of accuracy that can be achieved:

a) the type of the dredging equipment;

b) the height, length and direction of the prevailing waves and the strength of tidally induced currents or river currents;

c) the method of position fixing and quality of survey control;

d) the experience of the operating personnel;

e) the instrumentation available for determining the position of the cutting mechanism or suction intake relative to the water surface;

f) the degree of automation available on board the dredger;

g) the maximum depth of dredging below water level;

h) the type of material to be dredged.

An indication of the horizontal accuracies that can be achieved without seriously affecting the economic operation of the dredging is given in Table 13.

3.5 Side slopes

3.5.1 General

With a few exceptions, the accurate formation of side slopes using dredging equipment is difficult.

There are basically three options available for the formation of side slopes and these are as follows.

a) A rectangular dredged section can be produced and side slopes can be allowed to collapse to take up their natural angle of repose.

b) The stable slope can be estimated at the design stage and an approximation of this slope can be achieved by a series of stepped or “boxed” cuts (see **3.5.2**).

c) The stable slope can be estimated at the design stage (see **6.2** of BS 6031:1981) and this slope can be cut in the dredging process by a combination of swinging the dredger and raising the cutterhead simultaneously. Reasonable results are possible by this method when an experienced operator is employed, or when the dredger is fitted for profile cutting under computer control.

3.5.2 Stepped cuts

For practical reasons it is often necessary to form underwater slopes by the dredging of a series of steps that approximate to the required slope. In weak soils, the vertical face of each dredged step soon collapses. This failure destroys the soil structure with the result that the final stable slope may be significantly flatter than could have been achieved by the initial formation of a slope with an angle a little less than the critical value. The final slope angle that results from the dredging of steps in weak soils may be less than half of that theoretically possible.

In most cases the additional cost of creating slopes without steps may be difficult to justify.

When slopes are to be formed by the dredging of steps, there are a number of considerations in relation to the size and configuration of steps that should be taken into account to ensure that economic execution is achieved.

Cutting the steps will generally not present problems in deep water, but in shallow water the pontoon of a dredger that swings from side to side when dredging may come into contact with the dredged slope or the side of the channel before the actual cutting mechanism reaches the point at which the slope has to be cut (see Figure 5).

Normally, step heights should not be so small as to reduce seriously the production of the dredger.

The heights of steps should also be limited to avoid creating an excessively high vertical face, which may collapse resulting in the burial of the suction intake or bucket ladder of the dredger.

As a general guide, step heights should be not less than 0.75 m and not greater than 2.5 m. Each particular case has to be examined on its merits with consideration being given to the type of plant to be employed, the particular characteristics of the sea bed soils and the wave climate in which the plant has to operate.

3.5.3 Side slope stability

The stability of underwater slopes resulting from dredging depends on the characteristics of the sea bed soils and of the dynamic environment that prevails in the area.

Side slopes in areas subject to significant wave activity, strong currents or propeller wash or slopes that traverse intertidal zones are likely to stabilize at much flatter slopes than those formed in similar materials in more stable conditions. In this situation, slopes can be better estimated by a comparison with local natural sea bed or beach profiles in similar materials.

For economic reasons it is normally desirable to achieve the steepest slope that has long-term stability. Care should be taken to avoid specifying slopes that are unrealistically steep and that will ultimately collapse, resulting in a reduction of the formation width.

Where temporary formations are required for the placing of pipes or structures, deterioration of the side slopes can result in a trench that is too narrow, preventing placement of the structure.

Typical side slopes in a variety of different soil conditions are given in Table 11.

The stability of side slopes in still water can be estimated using normal slip circle methods, but allowance should be made for the reduction in the disturbing forces due to the reduced mass of submerged soils. This may result in stable slopes that are much steeper than is possible above water.

Submerged soil deposits may not be fully consolidated. Underconsolidated deposits are normally characterized by excess pore water pressure. Such deposits have a lower strength and are not stable at slopes as steep as more fully consolidated deposits of otherwise similar character.

3.6 Disposal of dredged material

3.6.1 General

The method of disposal of material arising from dredging is one of the most important considerations at the design stage of any dredging work [23]. When the engineer has decided upon a particular method for disposal, it will be necessary to obtain the relevant licences and consents before the operation can proceed (see **3.7**).

In any disposal operation careful thought has to be given to the means by which the dredged material is to be transported to the point of disposal. When disposal is on land, attention to the method of connection between floating and sea bed pipelines is particularly important.

3.6.2 Contaminated material

Special precautions are necessary for the disposal of contaminated material. The London Dumping Convention (see **3.7**) does not permit the dumping at sea of seriously contaminated material. When harmful substances are to be disposed of the method of disposal has to provide for the isolation of the material from the surrounding environment [24]. This may involve disposal on land within containment areas designed to prevent the escape of harmful substances, or dumping at sea within predredged pits with subsequent capping with a stable blanket of inert material. The development of satisfactory methods of disposal is not yet definitive and it is recommended that each particular case is carefully considered.

3.6.3 Disposal at sea

Disposal at sea is a common practice for material arising from both capital work and maintenance dredging. It is normal for the dredged material to be disposed of within a specified area.

In the UK, as in many other parts of the world, disposal at sea is controlled by legislation (see **3.7.1**).

When selecting a disposal site for capital works allowance has to be made for the progressive increase in sea bed levels that may result from the deposition.

Sea bed levels within the disposal site should provide for an adequate under keel clearance for the disposal vessel at all tidal and sea states during which work will take place.

When granular sediments are removed by dredging from the coastal sediment transport system, such as in the maintenance of channels that intercept and trap littoral drift, every effort should be made to return the dredged sediment to an area within the downdrift sediment system. In this way, potentially harmful effects on the downdrift coastline may be avoided or at least alleviated. This process is referred to as sand bypassing. In the UK, if the sand bypass method is not direct and continuous, a licence or licences are normally required (see **3.7**).

A locally established practice of disposal of dredged material within a particular closely defined area may not be the most economic nor the most environmentally satisfactory solution.

3.6.4 Side casting

3.6.4.1 *General*

Spoil disposal by side casting involves the discharge of dredged material alongside the area of dredging by direct discharge of the dredger bucket or by pumping.

The system may be used in certain maintenance dredging situations (see section 7).

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

3.6.4.2 *Side cast distance*

When dredged material is to be disposed of by side casting, it is important to ensure that the deposition is sufficiently remote from the dredged formation and on the downdrift side of the dredging area, to minimize the risk of re-entry of the side cast material into the dredged area.

For granular materials, deposition should be well outside the limits of the natural side slopes of the dredged area. Fine granular materials may disperse widely during settlement through the water column and, if water depths are more than a few metres, a significant proportion of the dredged material may re-enter the dredged area.

For silt and clay-sized particles, with much lower settling velocities and very low angles of repose, side casting is only effective if there is a natural current to transport the settling dredged material away from the dredging area. This effect is termed “dispersion” (see **3.6.5**).

3.6.5 Dispersion

3.6.5.1 *General*

In certain situations, it may be practical to dispose of the dredged material by dispersing it over wide areas.

If this is to be achieved, the dredged material has to be very fine with a low settling velocity and there have to be currents of adequate strength and duration to transport the sediment out of the dredging area into surrounding areas into which the dredged material will finally settle. It is essential that these areas are insensitive to the effects of the deposited material.

Generally, dispersion is most effective in high energy estuaries where large volumes of mobile fine sediment occur naturally.

Before dispersion methods are employed, careful study to determine the probable pattern of dispersion is essential. Dispersion methods should not be employed in areas that are sensitive to contamination by fine sediments. Such areas may include locations containing certain types of water extraction plant.

3.6.5.2 *Use of suction dredgers to disperse material into the tidal stream*

Suction dredgers (see **4.6**) or cutter suction dredgers (see **4.4**), which discharge via a pipeline, may be used to transport dredged material out of the immediate working area into the tidal stream or a deep body of water. Such methods are particularly applicable to the removal of sediments accumulated in impounded docks and basins that adjoin particularly dynamic estuarial or river systems. Tidal movement or river flow can then often be relied upon to disperse the discharged spoil over wide areas with little or no adverse effect. This method overcomes the problems of locking in and out of docks with barges or hopper dredgers and allows a continuous dredging process. It may be necessary to restrict the hours of discharge to a particular state of tide, usually the ebb.

3.6.6 Agitation

Dredging by agitation involves forcing material into suspension by mechanical or hydraulic means in order that it may be transported away by water flow.

The method is generally applicable only to maintenance dredging and works best in loose deposits of fine material in areas of significant tidal or fluvial flow.

The suspension of bottom sediments may be achieved by several types of dredging plant, including trailing suction hopper dredgers (see **4.2**), cutter suction dredgers (see **4.4**), dustpan dredgers (see **4.12**), boom dredgers (see **4.13**), and by bottom scraping or raking devices such as the bed-leveller (see **4.17**).

The success of agitation methods depends upon the distance through which suspended solids are transported and the area over which they are dispersed. This depends on the height to which the bottom sediments are raised in the water column, the fall velocity of the particles and the strength and direction of water flow during suspension. However, it is thought that agitation dredging may be environmentally unacceptable in many locations.

3.6.7 Pumping ashore

3.6.7.1 *General*

Material may be pumped ashore if site and environmental conditions allow for either disposal or land reclamation. The disposal of fine silt and clay-sized materials which normally arise from maintenance dredging is covered in **3.6.7.2** to **3.6.7.5**. For land reclamation and filling see section 8.

Material grain size has an important effect on pumping distance (see Figure 6).

Generally, it is not practical to locate an offshore mooring facility more than 1 500 m from the shore-line, unless booster pumps are incorporated. The mooring site should be chosen to provide the maximum shelter to the moored craft from the prevailing winds and sea condition. Pipeline connections for shore discharge are discussed in greater detail in section 8.

3.6.7.2 *Containment area*

The term “containment area” here refers to an onshore enclosed area specifically constructed to contain material arising from maintenance dredging operations (land reclamation containment is covered in section 8). Drainage of material consisting of fine particles of silt and clay can be a prolonged process, and it has to be recognized that any areas set aside for the disposal of dredged material are likely to be rendered sterile for a significant period. If the material arising is in the sand range, these drainage problems should not arise.

The containment area should be located as close as is practical to the point at which the discharging dredging vessel will be moored and should be adjacent to sheltered waters.

Consideration should be given to the routes along which pipes conveying the dredged slurry have to pass.

In some generally inland sites, it is possible that organic matter contained in the dredged material may give off an odour. It is unwise to locate disposal areas close to populated areas, particularly when populated areas are downwind of the disposal areas.

An important consideration in the design of the containment area for the disposal of fine materials is the release of moisture from the deposits. Moisture is most readily released when the surface area of the deposit is large relative to its depth.

3.6.7.3 *Depth of deposition*

For free-draining granular materials it may not be necessary to regulate the depth of deposition (see section 8). For fine materials, particularly those that contain an appreciable fraction of clay particles, some limit is necessary if drainage and consolidation within a reasonable time are to be achieved.

It is not possible to lay down rules concerning the optimum depth of deposition but, as a general guide, any area that is to be filled in a single process should not exceed a finished infilled depth of 1.5 m. For permanent sites, progressive infilling may be decided upon, in which case each intermediate lift of the fill area elevation should be confined to approximately 1 m. These depths refer to the thickness of deposit immediately following the effects of rapid dewatering and consolidation.

The total containment area capacity should be significantly greater than the final volume of dredged material that is to be accommodated. Fine sediments that are transported into the containment area by pumping will release their moisture very slowly and consequently high bulking, which results from the increased moisture content, may occur relative to the in situ bulk density of the material that is being dredged. Actual bulking depends upon the particular charactertistics of the dredged material.

There will be a fairly rapid initial settlement of the fine materials and an accompanying progressive appearance of clear water, followed by much slower consolidation of the settled solids. By observing the behaviour of the material in simple sedimentation tests, judgements may be made concerning the maximum capacity of the containment area and the depth of water that has to be maintained above the level of the settled solids in order to ensure that continued inflow of mixture is subject to an adequate settlement process before drainage of the clean supernatant water from the area.

Various methods are available for the determination of containment area capacity [25, 26].

3.6.7.4 *Containment area enclosure*

It is usual to contain dredged material onshore within purpose-built retaining embankments. Where practical, these can be most economically constructed using the material that naturally exists across the site. If the site is overlaid with a reasonable depth of topsoil, it is sensible to strip off this topsoil in advance of any deposition so that it may be used at the end of the disposal area’s life for top dressing. If convenient, the topsoil material can be used in the construction of the enclosing embankments.

The overall enclosed area may be subdivided to permit filling on a sequential basis. The degree of subdivision is governed by the minimum size of enclosed area that is necessary to achieve settlement of all fine materials, or of all materials above a certain specified size that have to be trapped within the area.

The height of the enclosing bunds has to be adequate to contain all the dredged material that is to be discharged into the area, together with an adequate depth of water to allow the deposition of the final material pumped into the area and an additional freeboard against over-topping or breaches resulting from weathering of the top section of the bund. In practice, a freeboard of between 300 mm and 500 mm is normally adequate.

Waste lagoons which are designed to hold, or are capable of holding, more than 25 000 m^3 of water above the natural level of any part of the adjoining land are subject to the control and provisions of the relevant legislation. Reference should be made to the Reservoirs Act 1975, the Mines and Quarries Act 1954 and the Mines and Quarries (Tips) Act 1969.

3.6.7.5 *Containment area drainage*

Drainage of containment areas consists of both the drainage of the supernatant water during the initial filling process and the long-term drainage that has to occur to allow adequate consolidation of the infilled material. The design of the containment areas should take account of these aspects.

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

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

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

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

3.7 Licences and consents

3.7.1 Disposal of dredged material at sea

A licence is required under Part II of the Food and Environment Protection Act 1985 for the deposit of substances or articles within UK waters, either in the sea or under the sea bed. The deposit of material at sea in the UK is subject to the Oslo and London Dumping Conventions. Such deposits include industrial wastes, sewage sludge and dredged material [23, 27].

Applications for the disposal of dredged material at sea are considered under the following three main categories:

a) source and characteristics of the material including quantity and composition, both physical and chemical;

b) characteristics of the disposal site, particularly the location in relation to living resources, amenity and hydrographic details;

c) interference with other users, e.g. fishing, shipping, recreation and mineral extraction.

The Food and Environment Protection Act is administered by the Ministry of Agriculture, Fisheries and Food in England and Wales, the Department of Agriculture and Fisheries in Scotland and the Department of the Environment in Northern Ireland. For the disposal of material within territorial waters, the consent of the Crown Estates' Commissioners (CEC) is also required. This is normally given concurrently with the issue of a licence under the Food and Environment Protection Act, subject to consent of those various Departments routinely consulted.

In England and Wales applications for a disposal licence have to include details of the vessels to be employed for disposal. Required details include the type of vessel and the maximum load in tonnes that can be carried. During disposal, records have to be kept of the type of vessel, method of discharge, time to discharge, speed, sailing time, load carried and position during disposal. The vessel's position has to be recorded by an approved device.

3.7.2 Licence to extract from the sea bed

In the UK, formal consent is necessary before material can be removed by dredging from the sea bed. In this section only those formal procedures that have to be complied with within the limits of the UK Continental Shelf are considered.

Usually the mineral rights in respect of the sea bed within the Continental Shelf limits are controlled by the CEC whose consent is required for any dredging work. In practice, specific consent is not normally applied for when maintenance dredging is undertaken.

A CEC production licence may not be required when material is to be dredged from within the boundaries of a port or harbour authority for the purposes of improving navigation, but consent to the work is required. However, if the dredged material is to be thereafter used for a beneficial purpose, such as land reclamation or beach replenishment, royalties upon that material may or may not be payable depending upon the statutory formation of the particular port. In the majority of such cases a royalty will be payable.

The CEC operate a two-stage licensing procedure. Any person or organization wishing to remove sea bed material has to first apply for a prospecting licence. Such a licence will only be issued if, in the opinion of the Crown Officers, its issue will not be detrimental to the best interests of the Crown and other interested parties.

Unless the area in which prospecting is to take place is sensitive, the issue of a prospecting licence is reasonably quick and uncomplicated. There is an established procedure of initial consultation with fishery interests [28]. Upon receipt of the licence, the licensee may carry out prospecting in the area either by trial dredging, subject to detailed licence controls and observance of an agreed code of practice, or by the use of conventional marine soil investigation methods. The basic procedure leading to the issue or refusal of a prospecting licence is shown in Figure 8.

The retained samples are normally subject to laboratory analysis to determine the physical properties of the deposits. All of the information gained from any prospecting work has to be supplied to the CEC.

Provided that the prospecting exercise has demonstrated that deposits of adequate quantity and quality exist, a production licence may be applied for at a later stage. The applicant has to state his proposed method of dredging, the annual quantity he proposes to remove from the sea bed, the manner in which he proposes to remove it and its end use.

When the application is for winning materials for use in the construction industry, the licence may have no fixed term, but may permit the removal of the maximum quantity of materials stated in the licence each year. If the licence is for a "one-off" exercise, such as beach replenishment or land reclamation, it may be issued specifically for the year of the proposed work.

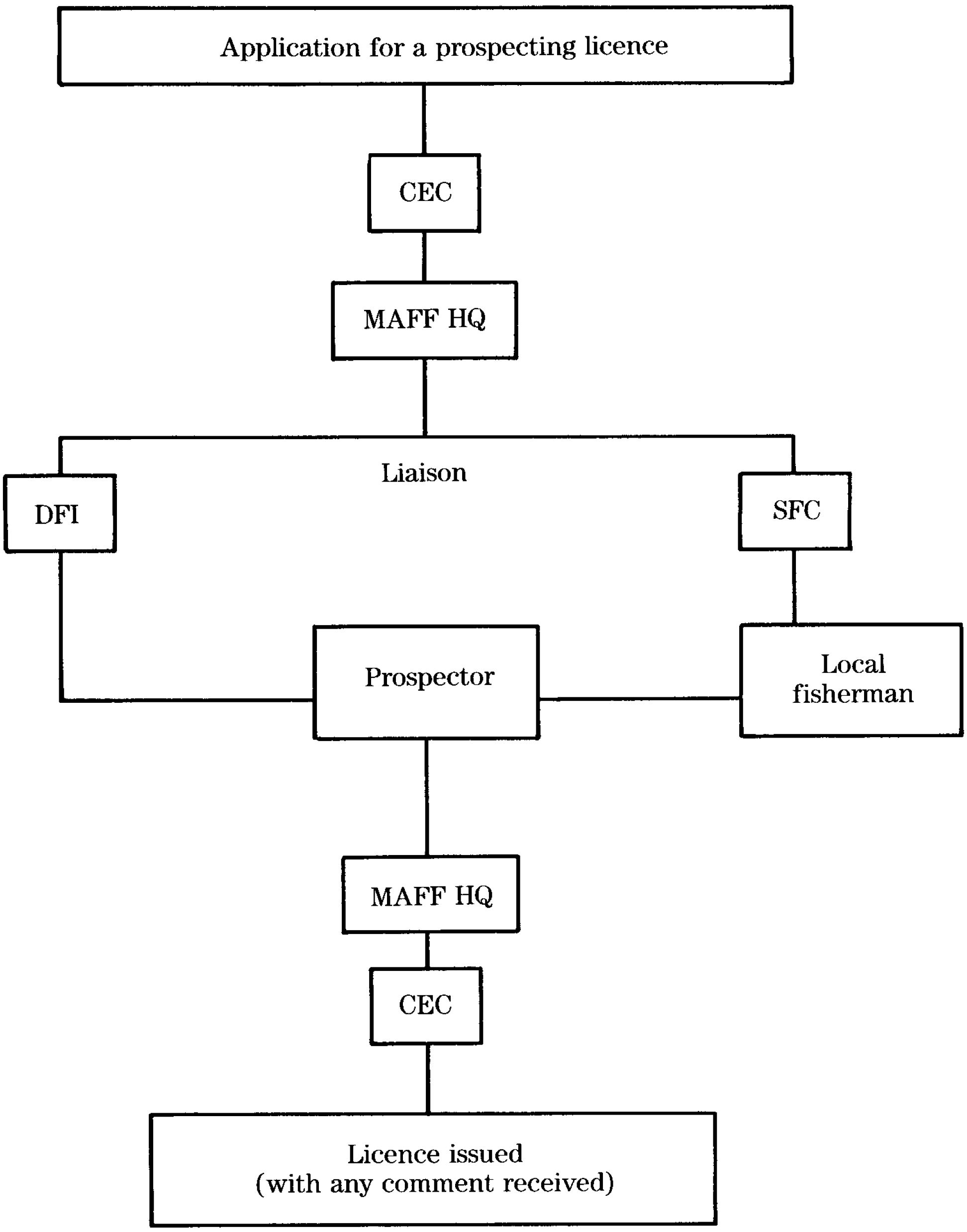
However, before the licence is issued consultation takes place to safeguard the interests of third parties. The CEC take advice on the question of local coastal stability from an independent coast protection scientific authority. If coastal stability is likely to be impaired the licence may be rejected. If the response is favourable, consultation coordinated by the Department of the Environment will extend to the fishing industry, local coast protection authorities, organizations who may have cables or services running through the area and navigation authorities.

If there are serious objections by the fishing industry a licence may not be issued. There is no appeal procedure in the event of a licence application being refused. However, the CEC are not bound to take account of any objections, although they are unlikely to override a serious and well-founded objection.

The period of consultation necessary prior to the issue of a production licence may be prolonged, particularly if the area is sensitive in terms of coastal stability or if there is an active fishing industry. The issue of a production licence within 6 months is unusual and, in sensitive areas, the time required may well extend to 2 years or more. The basic steps leading to the issue or refusal of a production licence are shown in Figure 9.

3.7.3 Permission to dredge

Dredging work that is proposed within navigable waters also requires the permission of the relevant port or harbour authority and, in the UK, of the Department of Transport, Marine Directorate, who administer Section 34 of the Coast Protection Act 1949.



Key to abbreviations
CEC = Crown Estates' Commissioners
DFI = District Fisheries Inspector
MAFF HQ = Headquarters of Ministry of Agriculture, Fisheries and Food
SFC = Standing Fisheries Committee

Figure 8 — Procedure in UK following an application for a prospecting licence

In addition to the permission of the bodies referred to in **3.7.1** and **3.7.2**, permission from other bodies may be needed. The permission of the CEC is normally required because in most areas around the UK, Crown ownership of the sea bed extends to the territorial waters, currently the 12-mile limit. However, occasionally another ownership may exist and the permission of that owner will be required. Within sea bed areas that extend beyond the territorial waters to the Continental Shelf, the CEC manage the rights owned by the Crown to the exploration and exploitation of the natural resources of the sea bed, excluding hydrocarbons.

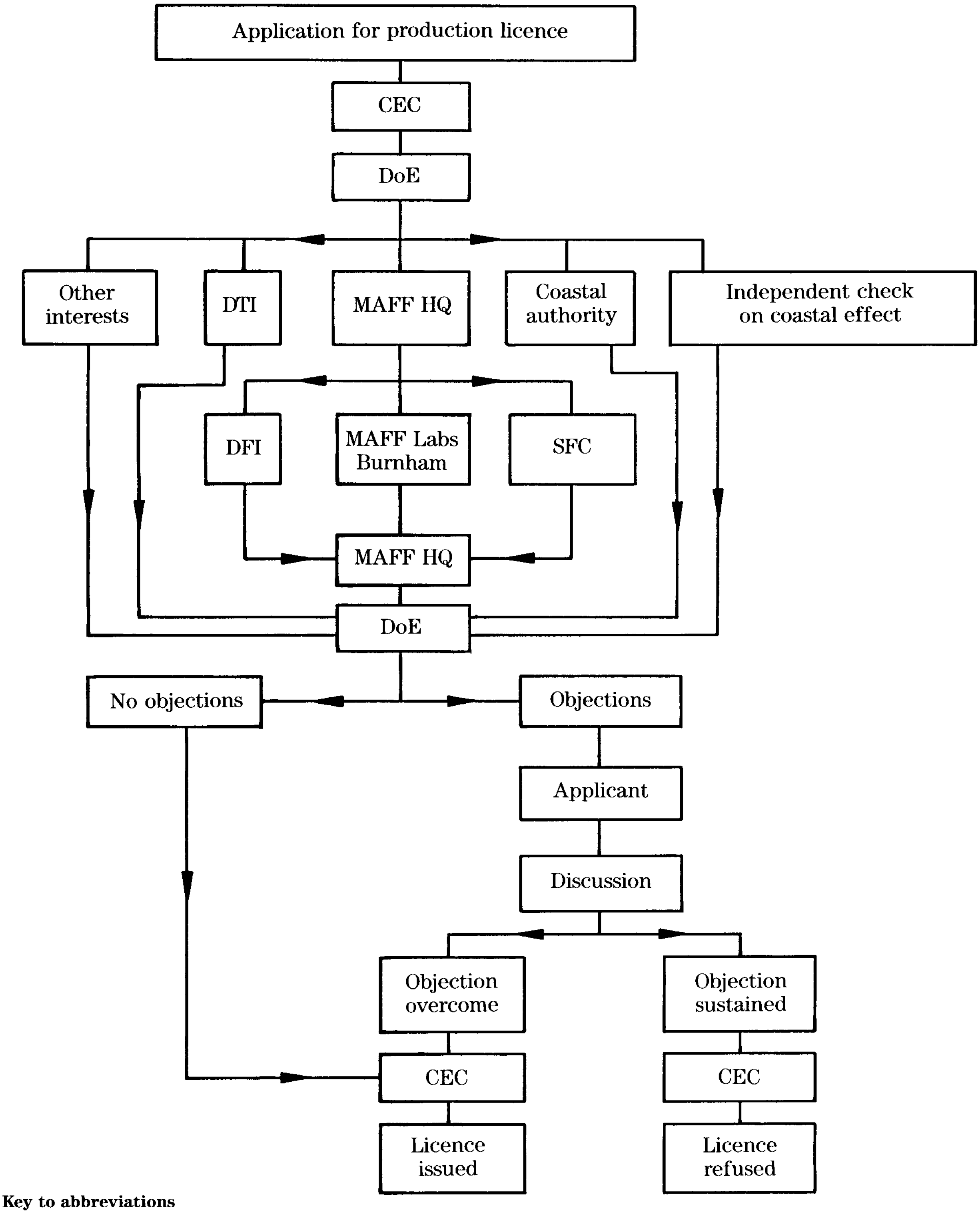
Under Section 18 of the Coast Protection Act 1949 it can be unlawful to excavate or remove materials from the seashore or under the sea bed. Some local coastal authorities have obtained enabling orders under the Act, by which their consent for dredging within 3 miles of the coast is required.

Approval from the responsible authority may be required under the Control of Pollution Act 1974 when dredging is proposed in close proximity to areas of habitation, or where noise is considered important and conditions are such that the suspension of significant amounts of fine materials, perhaps with toxic content (see **3.6.2**), may result (see BS 5228).

3.7.4 Permission to reclaim land

If it is proposed to reclaim land by the use of dredged material, various consents are required. Differing localities and situations may require differing consents. A thorough investigation of the necessary procedures is advised before any such work commences. Generally, the permission of the land owner in the proposed reclamation or borrow area is required, and in most cases in the UK the owner is the CEC.

Land reclamation also requires planning permission from the local authority within whose area the work is proposed, who are charged with the administration of the Town and Country Planning Act 1971, and a licence from the Ministry of Agriculture, Fisheries and Food under the Food and Environment Protection Act (FEPA) 1985 Part II (see **3.7.1**).



Key to abbreviations
CEC = Crown Estates' Commissioners
DFI = District Fisheries Inspector
DoE = Department of the Environment
DTI = Department of Trade and Industry
MAFF HQ = Headquarters of Ministry of Agriculture, Fisheries and Food
SFC = Standing Fisheries Committee

Figure 9 — Procedure in UK following an application for a production licence to extract from the sea bed

Section 4. Characteristics of dredging plant

4.1 Introduction

This section includes descriptions of the principal types of dredging plant in common use. Further details of plant and associated ancillary equipment are given in Appendix A.

Each of the many types of dredging plant has evolved to meet a particular requirement. As a result, some types of dredger are suited to only a narrow range of applications, while others are more versatile. Certain types of dredger may be unable to perform certain dredging tasks, or may only be able to perform that task at much reduced efficiency. It is therefore important that the methods of dredging that are likely to be employed are properly considered during the design and planning stages of the proposed works [29]. The cost of mobilizing dredging plant may represent a large proportion of the total cost of dredging, although this may not always be the case.

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

Dredging plant generally requires servicing by support craft except in exceptional circumstances such as when working close to quay walls or jetties. Examples of typical types of support craft are shown in Figure 10 and Figure 11.

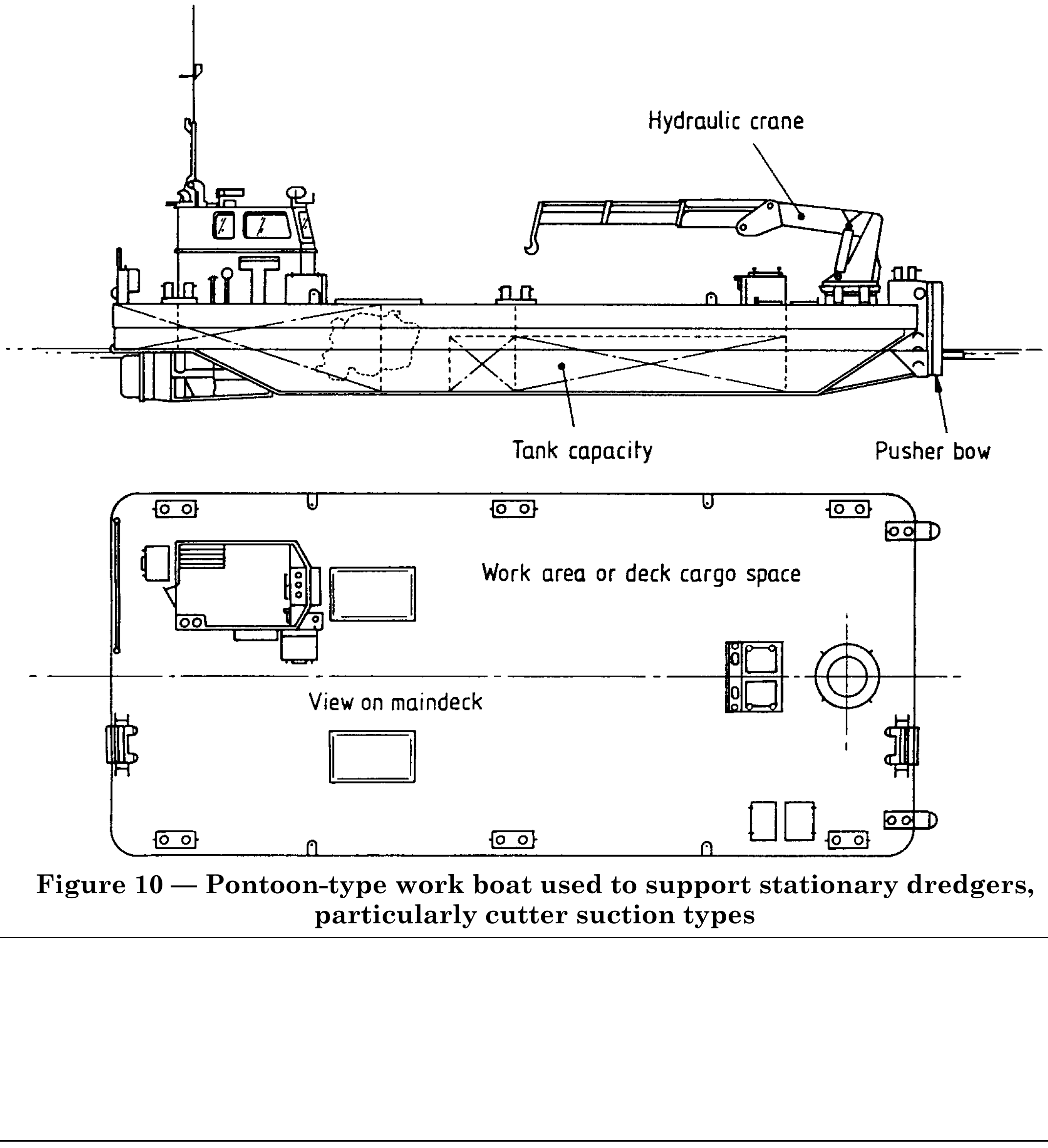


Figure 10 — Pontoon-type work boat used to support stationary dredgers, particularly cutter suction types

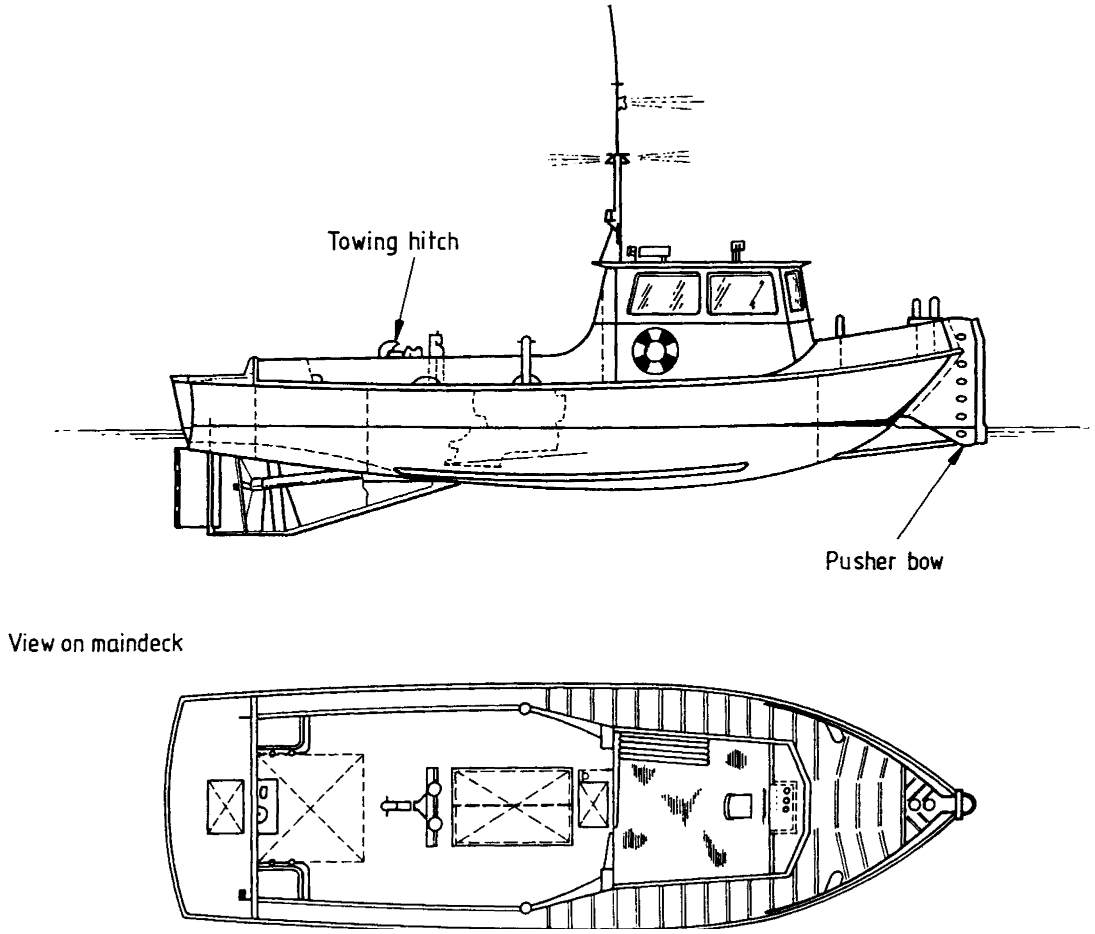


Figure 11 — Typical general-purpose launch-type work boat

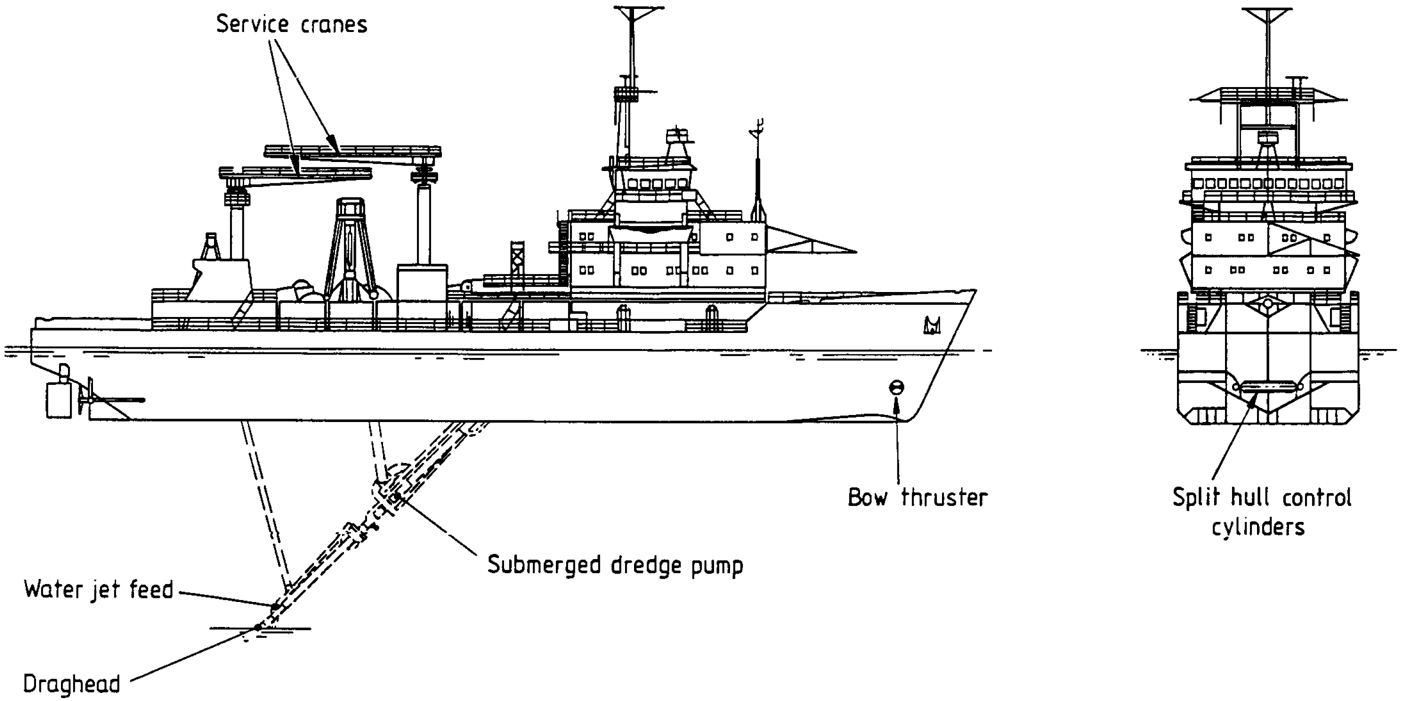


Figure 12 — Modern trailing suction hopper dredger with split hull and submerged dredge pump

4.2 Trailing suction hopper dredger

NOTE See **A.2**.

The trailing suction hopper dredger (see Figure 12) is a ship that is suited to river, coastal or deep sea navigation as the case may be, and that has the ability to load its own hold, normally called a hopper, by means of a centrifugal pump(s). Loading takes place with the ship under way. Discharge is normally by means of a bottom dumping arrangement or occasionally by pump discharge, which is usually to the shore.

The main advantages of the trailing suction hopper dredger are a relative immunity to adverse weather and sea conditions, an independence of operation, a minimal effect on other shipping when working in areas of shipping movement, an ability to transport spoil over long distances, a relatively high rate of production and usually a simple and hence inexpensive mobilization procedure.

The main disadvantages are an inability to dredge materials with significant inherent strength, an inability to work in areas of very restricted navigation, sensitivity to significant concentrations of foreign matter or debris and a tendency to dilute fine materials severely during the loading process.

The trailing suction hopper dredger is usually rated according to its maximum hopper capacity, which may normally range from 750 m^3 to 10 000 m^3.

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

To achieve optimum performance the draghead should be selected according to the type of material to be dredged and the dredger being used (see **A.2.5.2**).

If the spoil to be discharged is very cohesive or contains large solids, the restrictions presented by the bottom door or valve-surrounding structure may seriously prolong the time to discharge. The split hull trailing suction hopper dredger has been developed to alleviate these problems. An example of split hull construction is shown in Figure 13.

When the objective of the work is to reclaim land, it may be preferable to pump discharge the spoil directly from the hopper into the reclamation area. Some trailing suction hopper dredgers are specially constructed to permit this operation. Since the dredge pumps of the normal trailing suction hopper dredger are usually low head pumps, the trailing suction hopper dredger can not normally pump discharge through long pipelines unless intermediate booster pumps are employed.

4.3 Stationary suction hopper dredger

As with the trailing suction hopper dredger (see **4.2**), the stationary suction hopper dredger (see Figure 13) is a ship and it shares many of the characteristics of the trailing suction hopper dredger. The normal role of the stationary suction hopper dredger is the winning of sands and granular materials for use in reclamation or for concrete aggregates.

It has the advantage over pontoon-type suction dredgers (see **4.6**) that its ship-like construction allows independent operation in fairly exposed sea areas. Some stationary suction hopper dredgers can convert to trailing suction hopper dredger operation and vice versa.

The fluidization and entrainment of the soil to be dredged may be assisted by high pressure water jets arranged around the suction intake. This principle may be extended to permit the removal of granular materials from beneath an upper stratum of unwanted material, such as clay or peat.

4.4 Cutter suction dredger

NOTE See **A.4**.

4.4.1 General

The more common form of construction of a cutter suction dredger is that of a rectangular pontoon (see Figure 14), although the very large cutter suction dredgers may be ships. A cutter suction dredger may be self-propelled but is more commonly dumb (non-self-propelled). Dredging only takes place with the dredger moored in some way and it involves an initial powerful cutting action with suction and pumped discharge to barges or, more commonly, via a pipeline to a remote onshore area for disposal or land reclamation.

The main advantages of the cutter suction dredger are as follows:

a) an ability to dredge a very wide range of material, including weak rocks, and to convey by pumping the dredged material, with water, directly to the disposal or reclamation area;

b) an ability to operate in shallow water to produce a fairly uniform level bottom and a relatively high rate of production.

The cutter suction dredger is normally rated according to either the diameter of the discharge pipe, which may range from 150 mm to 1 100 mm, or by the cutterhead driving horsepower, which may range from 20 to 5 000, or in the case of very large dredgers by the total installed horsepower.

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

The main pontoon structure contains the dredge pump(s), the main engines and all ancillary engines, drives and equipment.

The positioning and control of the dredger is usually by means of a combination of spuds (see Figure 15) and winches. Occasionally only winches may be employed. Even more rarely, only spuds may be employed.

The discharge from the dredge pump(s) passes over the stern (or opposite end to the cutter) of the pontoon to a heavy hose or flexible coupling, to which is connected a floating pipeline (see **A.4.5.3**), which in turn is connected to an onshore pipeline. Sometimes an intermediate sea bed pipeline may be used.

4.4.2 Pipelines

Pipelines affect both the performance and operational efficiency of the cutter suction dredger. The diameter of the pipeline has a direct bearing on the efficiency of the hydrotransport process. Pipelines fall into the following two categories.

a) *Onshore pipelines.* Onshore pipelines are most commonly steel with bolted flange connection with a compressible gasket between flanges, which should provide a watertight seal.

When there are significant changes in elevation along the pipeline route, air valves ("snifters") should be fitted to allow the escape of trapped air, which may otherwise restrict performance, and to avoid the creation of an excessive vacuum, which may damage the pipe.

b) *Floating pipelines.* Strength is important if the pipe is to resist high internal pressures and bending. These requirements are generally met by the use of steel pipe with ball joint connections. Good resistance to abrasion or cutting is important but may have to be partly sacrificed in favour of flexibility. The most flexible pipeline construction is of reinforced rubber. It normally incorporates a jacket of buoyant material of such displacement as to provide a positive buoyancy when the pipeline is loaded with a pumped mixture of high relative density. The high cost of such pipelines can be reduced by using a composite construction, which mixes steel and rubber pipeline lengths.

4.4.3 Anchors

The choice of anchors to be used with a cutter suction dredger should be based on the ground conditions at the work site. Usually the cutter suction dredger works with one of the types of anchor that secure a hold by penetration into the sea bed. Large cutter suction dredgers working in rock may develop winch pulls in excess of 50 t, to which has to be added the dynamic loading arising from cutter reaction and wave action.

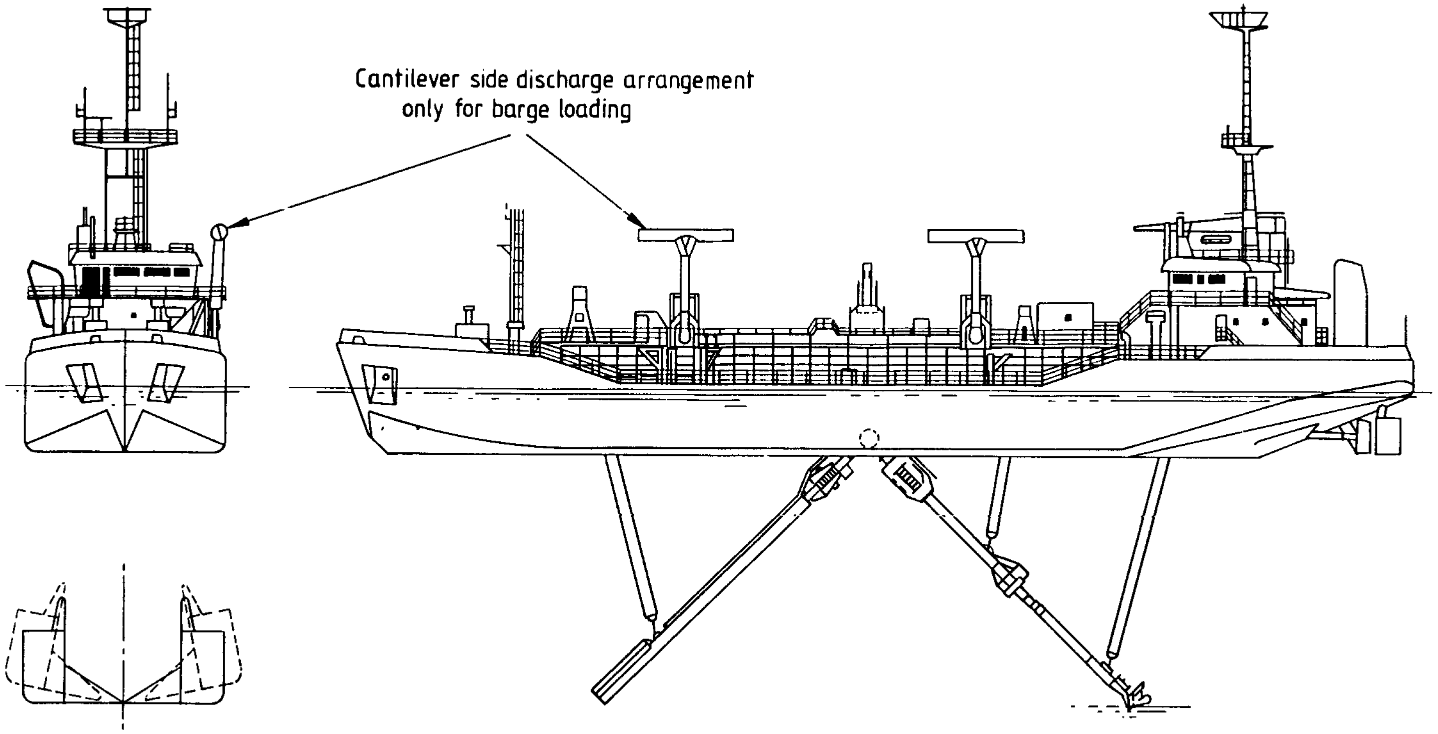
Occasionally, when the sea bed is hard, it may be necessary to use some type of gravity anchor, which relies on mass and friction to resist the winch pull. Various anchor types are covered in BS 6349-6.

4.4.4 Cutterheads

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

a) *Plain bladed cutters.* Plain bladed cutters are used only in weak materials, such as silts, sands and clays. Blade edges are normally replaceable. The number of blades is selected according to the intended application.

b) *Serrated blade cutters.* Serrated blade cutters are primarily for use in materials such as medium to stiff clays, medium dense sands or occasionally in very soft or heavily weathered rocks. Blade edges can be replaced when worn.



Example of split hull discharge systen

Forward facing suction pipe arrangement for use only in stationary dredging

Trailing suction pipe for use when dredging when moving slowly ahead

Figure 13 — Trailing suction hopper dredger fitted with barge loading side booms and alternative forward-facing suction pipe used for stationary dredging applications such as sand winning

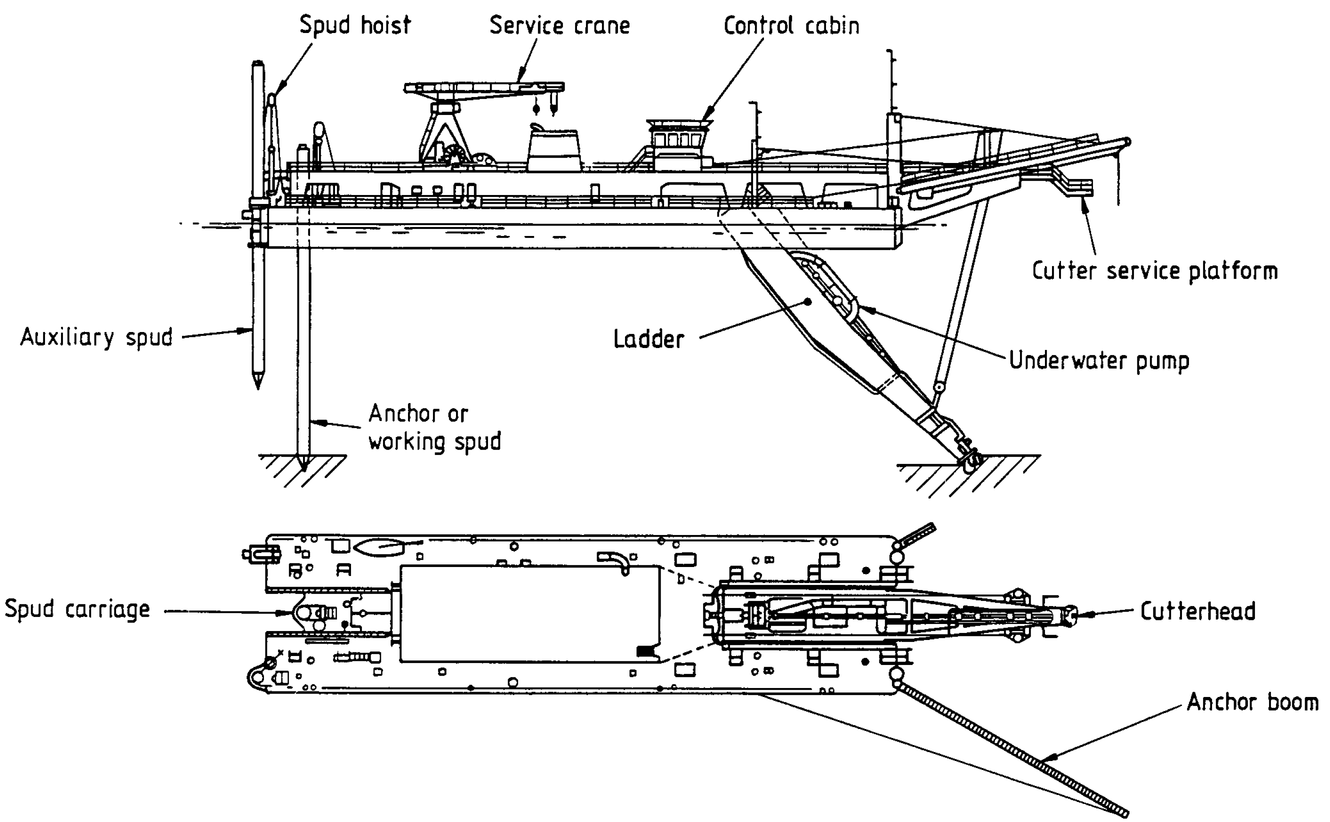
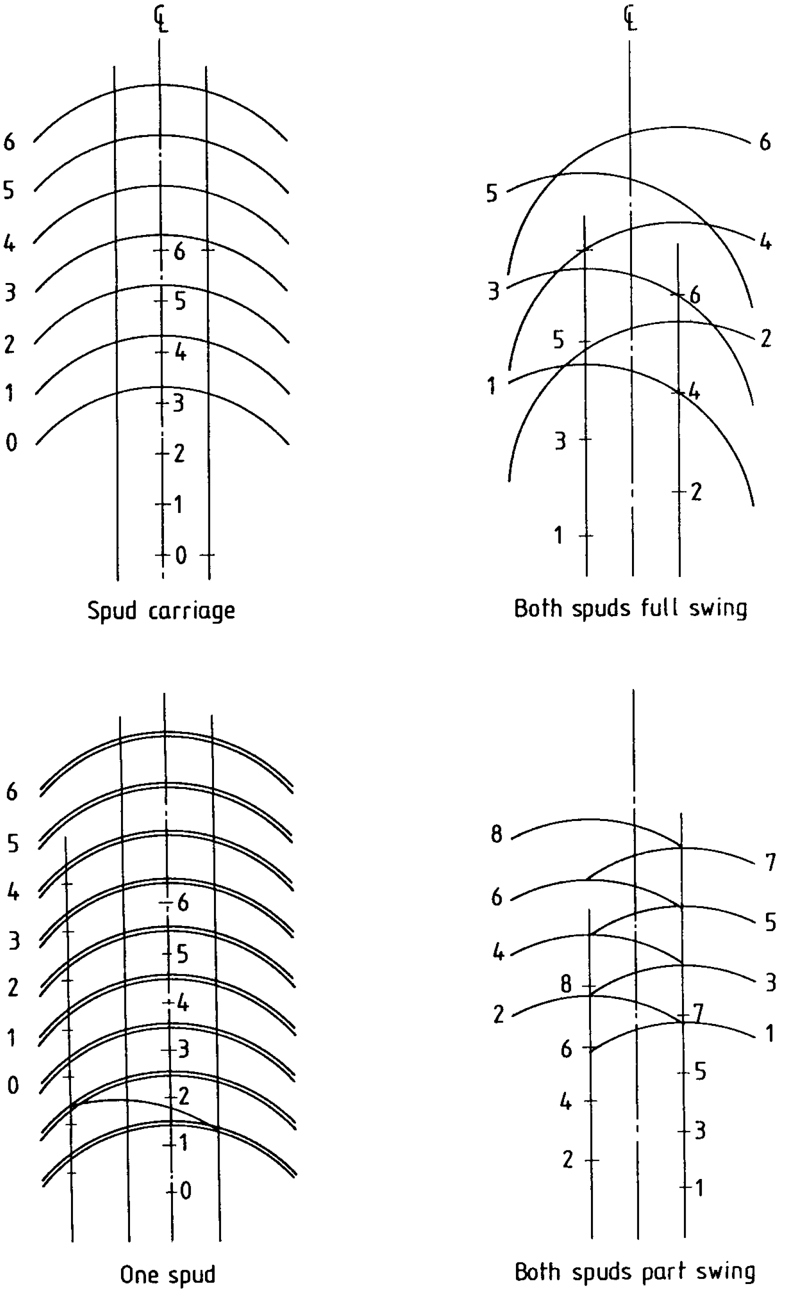


Figure 14 — Modern large cutter suction dredger fitted with submerged ladder pump and spud carriage



Spud carriage

Both spuds full swing

One spud

Both spuds part swing

Figure 15 — Alternative methods of advancement for spud-rigged cutter suction dredger

c) *Rock cutters*. Rock cutters are of heavy construction with a generous blade section. The blades incorporate integral sockets for the mounting of a variety of types of replaceable teeth. The shape of the blades is designed to maintain the maximum number of teeth in contact with the face regardless of dredging depth. The teeth may range from a chisel form for stiff clay and very weak rocks to a pick point form for the dredging of weak to moderately strong rocks. The teeth are made from a highly wear-resistant alloy steel and are usually attached by means of a single sprung pin, which reduces the time needed to change a tooth to a few minutes.

4.5 Bucket wheel dredger

The bucket wheel dredger is essentially a cutter suction dredger with a different cutter arrangment. Instead of a crown cutter, it employs a wheel cutter. The wheel cutter consists of closely spaced bottomless buckets or cutters, arranged around the circumference of a circular assembly, within which the suction intake to the dredging pump is located. When the wheel rotates while in contact with a face of material, material is cut and moved radially inwards, under the influence of gravity and water flow, to the suction intake chamber. Due to the finer control of movement into the face that is necessary with a wheel cutter, bucket wheel dredgers should be fitted with a spud carriage in preference to the alternative fixed spud arrangements.

There are currently two distinct types of bucket wheel available. One consists of a series of buckets, which are widely spaced around the driving wheel (see Figure 16), and the other consists of closely spaced cutters, which overlap to produce a "continuous tunnel" into which the spoil passes.

The advantages of the bucket wheel are reduced spillage and possible reduction in the overdredging necessary to produce a given final depth, equal cutting efficiency, regardless of the direction of traverse and dredging depth, and improved concentration of spoil when dredging cohesive materials. In some materials, the solids concentration achievable with a bucket wheel may be substantially greater than can be attained with a crown cutter with identical driving power, but in other materials the advantages cited may not be realized. Other potential benefits are a reduced tendency to become clogged when dredging in areas that contain large particles or debris, reduced swing winch loading and some of the benefits offered by the cutter suction dredger (see **4.4**) and the bucket chain dredger (see **4.9**).

The disadvantages of the bucket wheel dredger include substantially greater mass, the need for a supporting structure of greater strength and buoyancy, robust machinery and greater capital cost, the need for a more controlled feed into the face and hence for a spud carriage arrangement and susceptibility to blockage.

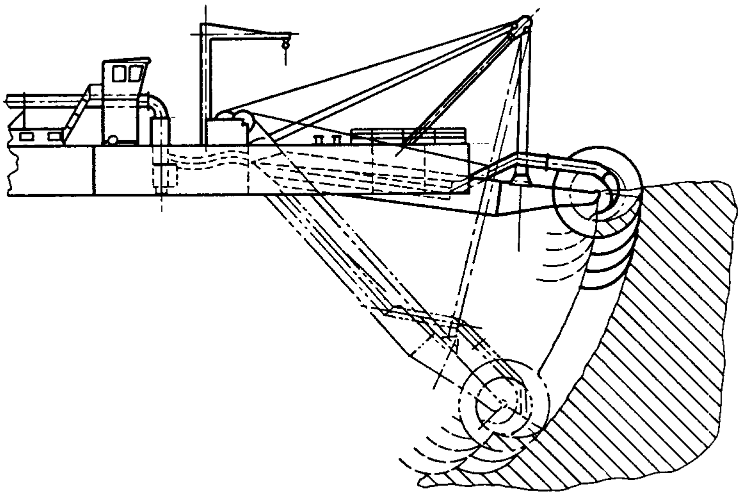


Figure 16 — Bucket wheel dredger advance into face of excavation using spud carriage

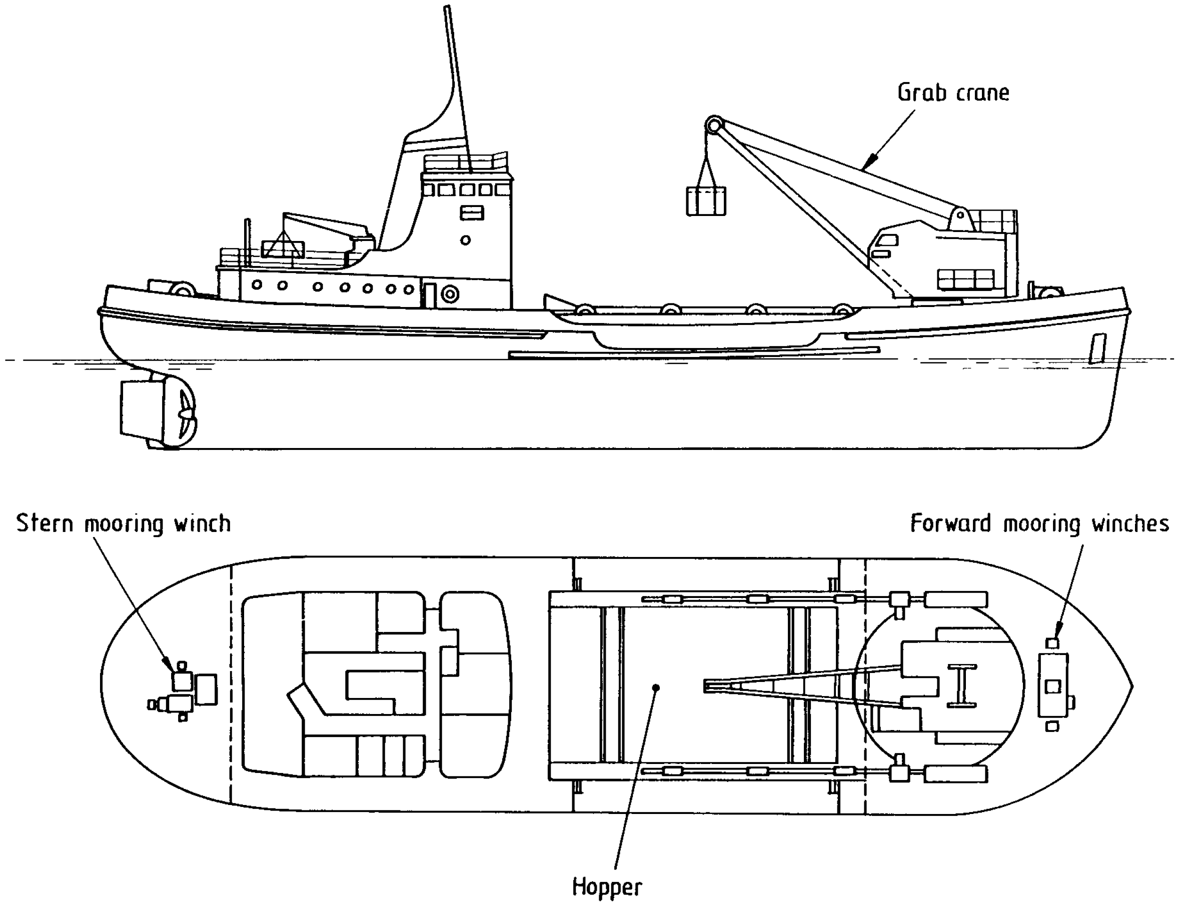


Figure 17 — Small self-propelled grab hopper dredger with single crane

4.6 Suction dredger

The general construction of the suction dredger is very similar to that of the cutter suction dredger (see **4.4**), but the suction dredger has no cutterhead. It is therefore only suitable for the dredging of loose materials or materials that can be easily broken down by water jets. It is not suited to the dredging of any materials with significant grain bonding. The suction dredger is employed primarily in the winning of sand for filling or for construction aggregates. Occasionally, it may be employed in the formation of channels, berths and basins.

The advantages of the suction dredger rest mainly in its relatively simple, lightweight construction, which may be reflected in lower capital and operating costs. Occasionally, suction dredgers may be designed for very deep dredging or for the dredging of granular materials from beneath an overburden of silt or cohesive material (see **4.3**).

The only disadvantage of the suction dredger is its lack of versatility, due to it being designed for a particular task.

In most situations, the anchoring of the dredger is by means of simple ground anchors (see **4.4.3** and **A.4.5.4**). Since this type of dredger is most commonly used for sand winning operations, where the ability to move quickly to a virgin area upon exhaustion of the current working area is more important than accurate positioning, anchoring with a pattern of anchors rather than with a combination of anchors and spuds is normally preferred.

4.7 Grab hopper dredger

NOTE See **A.7**.

As in the case of the trailing suction hopper dredger (see **4.2**), the grab hopper dredger is a ship (see Figure 17), but it is loaded by means of deck-mounted grab cranes rather than by suction pumps. Loading takes place with the dredger stationary at anchor and the number of loading cranes does not normally exceed four. The hopper capacity is normally modest and capacities in excess of 1 500 m^3 are uncommon. The method of discharge is invariably via bottom opening doors.

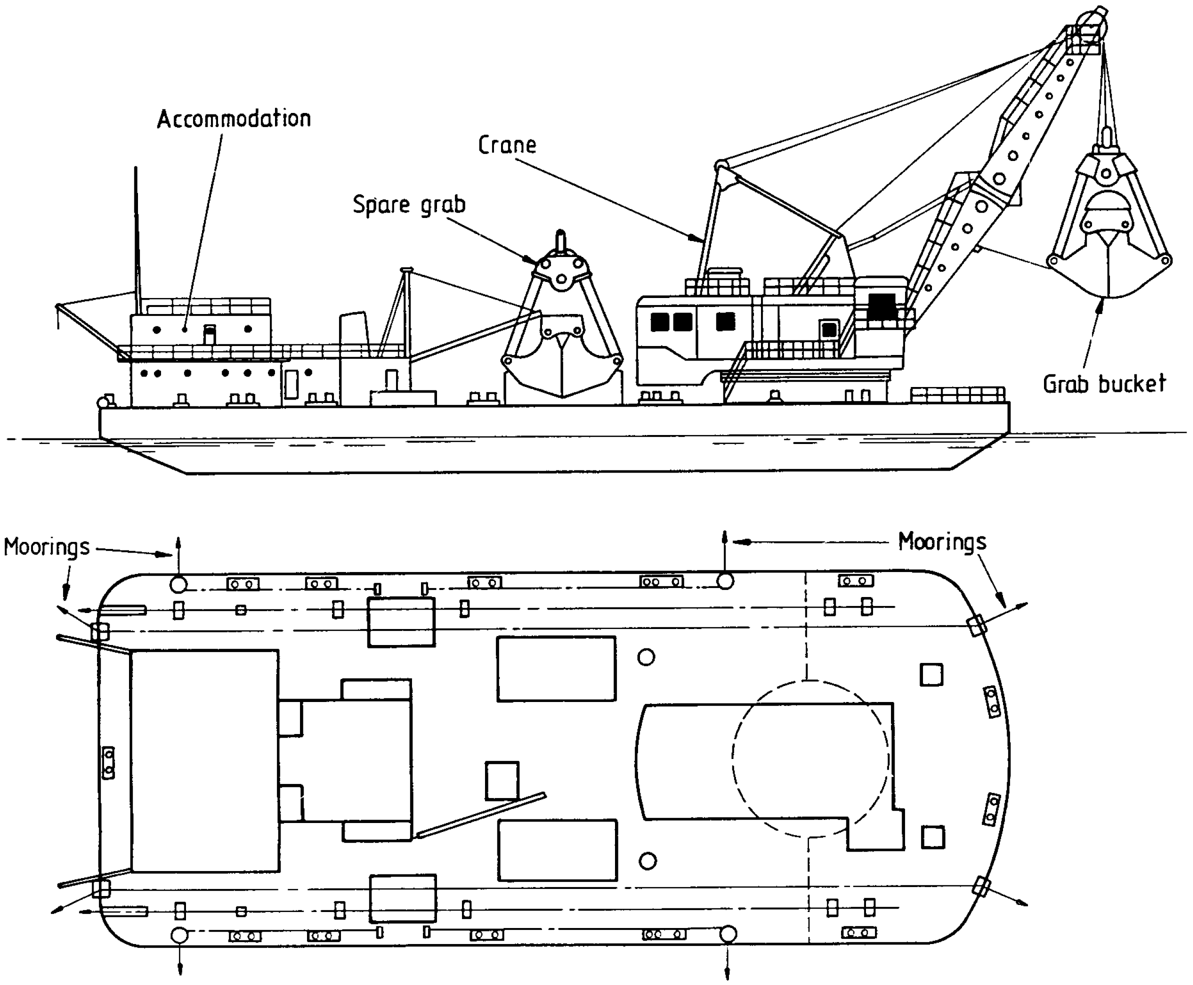


Figure 18 — Large grab pontoon dredger with all-winch mooring system

The grab hopper dredger has several advantages in particular circumstances. It loads spoil with minimal disturbance or dilution and the hopper can therefore be largely filled with solids. Also, loading by grab rather than by pump greatly reduces the effects of rubbish or debris. The rubbish or debris can therefore be handled with relative ease, although certain types of foreign matter, such as ropes, hawsers and chains, may cause problems during the discharge of spoil by becoming entangled with the bottom door structure, making it difficult to close the doors. These problems can be avoided by an experienced crew, who will separate potentially difficult materials and stow them on deck for subsequent disposal onshore. A system of large metal grids fitted over the hopper well can prevent debris from fouling the hopper doors but may have an adverse effect on production.

The grab is also well-suited to the dredging of confined areas, such as alongside quays, in dock entrances and around jetties. Dredging in these situations may be impossible with other types of dredger, unless aided by a bed-leveller (see **4.17** and **A.17**). The depth of operation of the grab is only limited by the rope capacity of the hoisting winch drum. It may therefore sometimes be possible to dredge to depths with a grab dredger, which would not be possible with other dredgers of comparable size.

The disadvantages of the grab hopper dredger are its relatively low rate of production compared with most other types of dredger and the difficulty of producing an accurate and level bottom finish.

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

4.8 Grab pontoon dredger

NOTE See **A.8**.

The dredging equipment of the grab pontoon dredger (see Figure 18) is essentially the same as that of the grab hopper dredger (see **4.7**), but the maximum capacity of the grab bucket and crane may be significantly greater. The dredger loads into independent hopper barges (see **A.19**). This permits an uninterrupted dredging operation with the result that higher overall rates of production are possible.

The grab pontoon dredger has the advantage of being able to dredge in difficult soils without being seriously affected by debris or occasional small boulders.

The disadvantages of the grab pontoon dredger are primarily relatively low production and poor bottom finish.

Bottom finish is very operator dependent due to the difficulty of achieving a complete and overlapping coverage of the bottom, particularly in deep water or where the strength of current is significant. The range of materials that can be dredged economically without pretreatment is very limited.

The grab pontoon dredger is normally rated according to the maximum capacity of grab that can be handled. This may range from 0.75 m^3 to 12 m^3.

4.9 Bucket chain dredger

NOTE See **A.9**.

The dredging function of the bucket chain dredger (see Figure 19) is achieved by a continuous chain of buckets, which scoop material from the sea bed and raise it above water. The buckets are inverted as they pass over the top tumbler and discharge under gravity onto chutes, which convey the spoil to barges alongside.

The heavy bucket chain is supported by a fabricated steel ladder and driven electrically or hydraulically via the top tumbler. The ladder is mounted on the centreline of a long rectangular pontoon. Positioning and movement of the pontoon are by means of a pattern of six winches and anchors (see Figure 20). The head winch, which is normally the most powerful, provides the reaction to the digging force and is used to advance the dredger into the face. The four side winches are used to traverse the dredger across the face. The stern winch maintains an overall equilibrium in balancing tidal forces or variations in the digging reaction.

The bucket chain dredger normally loads directly into barges, but in special applications may be used to feed a pump for hydrotransport, or in mining applications may feed directly to an attached process plant.

The breakout force applied via the bucket cutting edge or teeth may be substantial. When dredging in difficult materials, such as stiff clays or weak rocks, the dredger should be adequately robust and fitted with special buckets of reduced capacity and heavier construction and the chain speed (normally expressed in buckets per minute) should be reduced.

Occasionally, when dredging rock, a ripper tine may be substituted for every second or every third bucket.

Bucket capacity may range from 150 L to about 1 250 L and bucket speed from 0 buckets per minute to 30 buckets per minute, depending on the material being dredged.

The heavy construction of the bucket chain dredger, coupled with its flexible all-winch mooring system, allows operation in near-shore coastal waters in calm-to-moderate wave conditions.

The disadvantages of the bucket chain dredger include a wide spread of anchors, which may disrupt navigation, dependence on barge loading, which reduces its suitability for land reclamation or filling operations, low efficiency when required to remove only a small depth of material, noise levels that are higher than those usually generated by other dredgers and that may require special consideration, and in certain cohesive materials, which tend to be sticky, possible failure of the buckets to discharge properly.

4.10 Backhoe dredger

NOTE See **A.10**.

The backhoe dredger (see Figure 21) has evolved from the common land-based backhoe excavator, but whereas the land-based machine is normally mounted on a tracked or wheeled undercarriage, the dedicated dredging machine is mounted on a fabricated pedestal located at one extremity of a spud-rigged pontoon.

Occasionally, a conventional machine with tracked undercarriage may be employed in dredging work. The undercarriage becomes largely redundant for permanent dredging application. Secure, shock-absorbing pontoon mounting is important if the full digging potential of the machine is to be realized.

Spud location of the pontoon is necessary to provide a positive reaction to the hydraulic digging action, particularly when dredging in difficult ground.

The backhoe dredger is normally rated according to the maximum size of digging bucket that the machine can handle. This may currently be up to 23 m^3 for the largest dredgers. The size of bucket employed depends upon the nature of the material to be dredged and the maximum dredging depth. Maximum dredging depth may range from 4 m to 24 m.

The main advantage of the backhoe dredger is the ability to dredge a wide range of materials, including those that contain debris or (for large machines) boulders. Difficult materials, such as stiff clays and weak, weathered or fractured rocks, can be dredged by the larger dredgers provided that the maximum required dredging depth is not excessive.

The disadvantages of the backhoe dredger mainly relate to a low rate of production when compared with those dredgers in which the dredging process is relatively continuous (i.e. cutter suction and bucket dredgers) and its considerable dependence on the skill of the operator.

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

4.11 Dipper dredger

NOTE See **A.11**.

The traditional dipper dredger (see Figure 22) is a heavily constructed, rope-operated machine. To a limited extent, this traditional machine has been replaced by the hydraulic face shovel, which is itself a variation of the hydraulic backhoe dredger (see **4.10**).

Both the rope-operated and hydraulic dipper operate by digging forwards and upwards into the face. Both are mounted on spud-rigged pontoons to provide the necessary reaction to the digging force and both slew to discharge the bucket into a barge alongside.

The main advantage of the dipper dredger is its ability to handle a wide range of difficult materials, including weak, weathered or fractured rocks, stiff clays and boulder clays. The heavy construction and spudded pontoon of the rope-operated type permits operation in sea areas that are subject to modest wave action or swell. Since the dredger has to always advance into the face, it creates sufficient water depth in which to operate.

Disadvantages include a low rate of production compared with dredgers with a continuous dredging action, and a limited dredging depth.

The rope-operated machines can, size for size, dredge to greater depths than hydraulic machines. The construction of rope-operated machines is rugged and relatively unsophisticated. However, cycle times are slower and capital costs are greater than for the hydraulic machines. Designs and construction tend to be "one-off", whereas the hydraulic machines are all derived from basic production models, only the pontoon and digging arms being purpose built. The rope-operated machine can only bring into play the single leverage afforded by the dipper arm, but the hydraulic machine can also "crowd" the bucket, which may help to prise loose boulders or split cleavage planes in rocks.

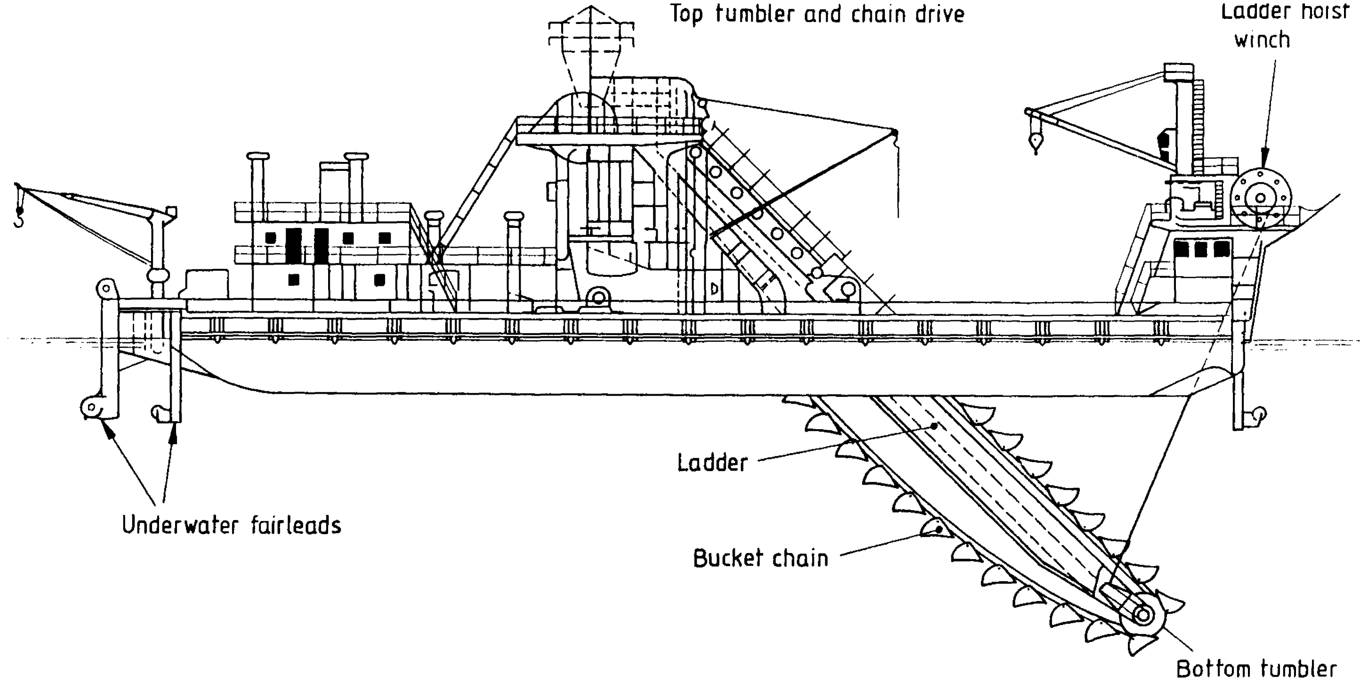


Figure 19 — Bucket chain dredger

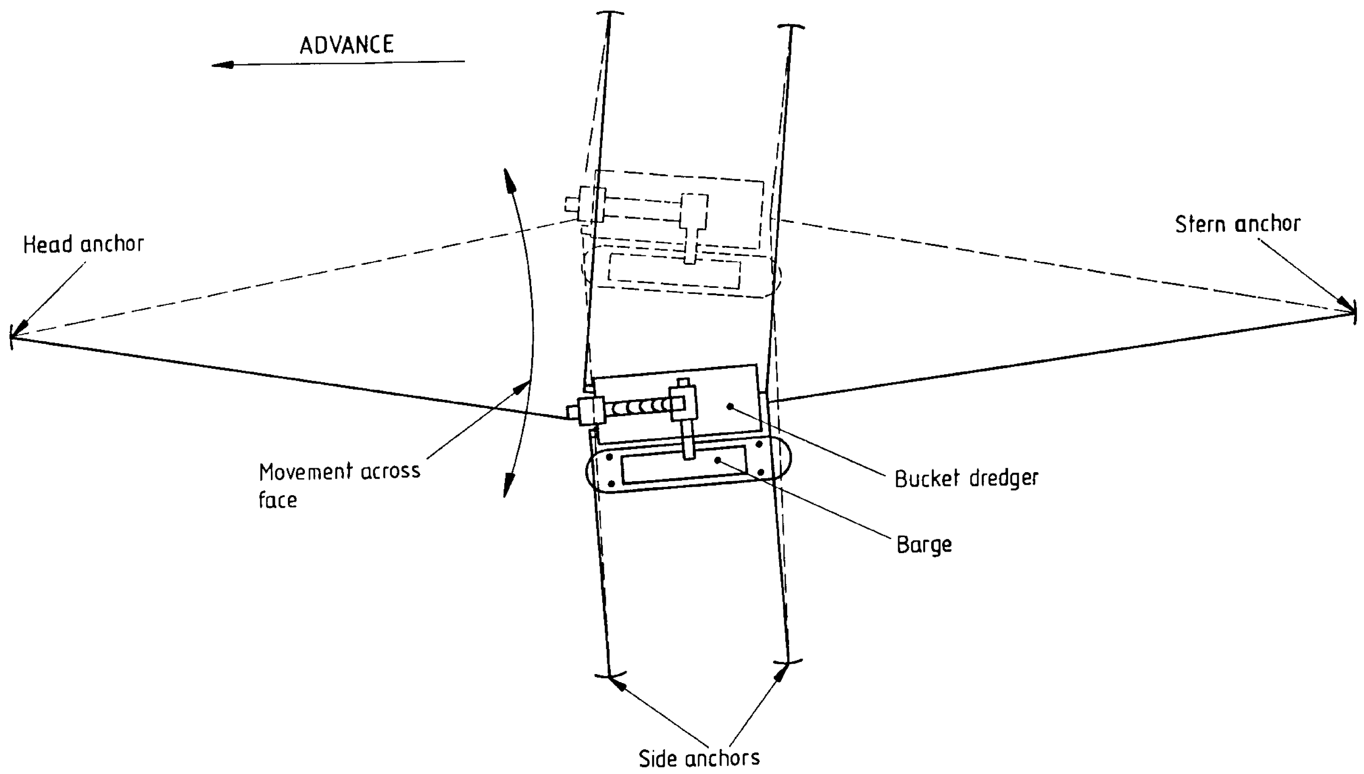
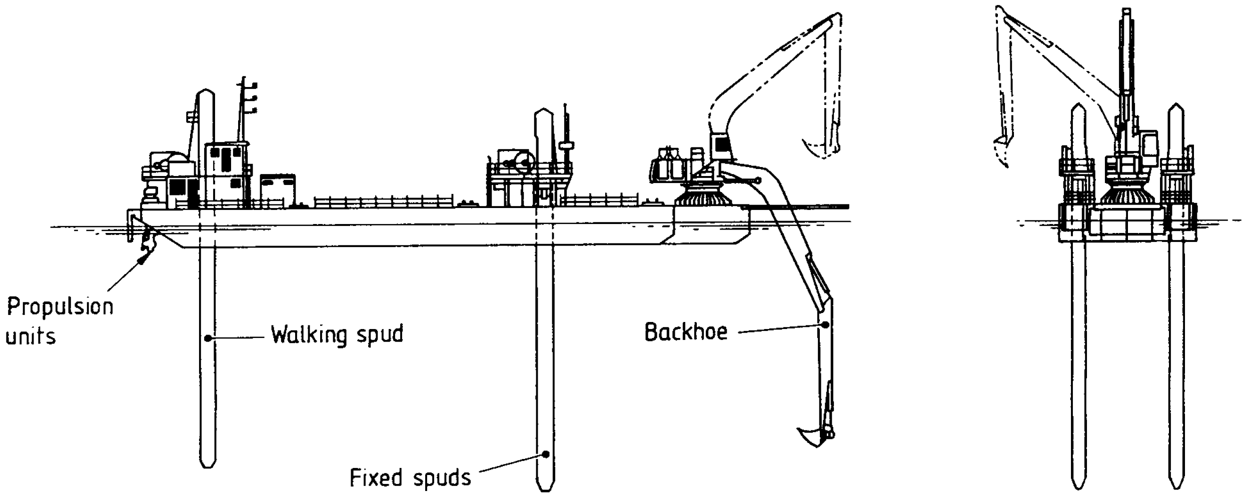
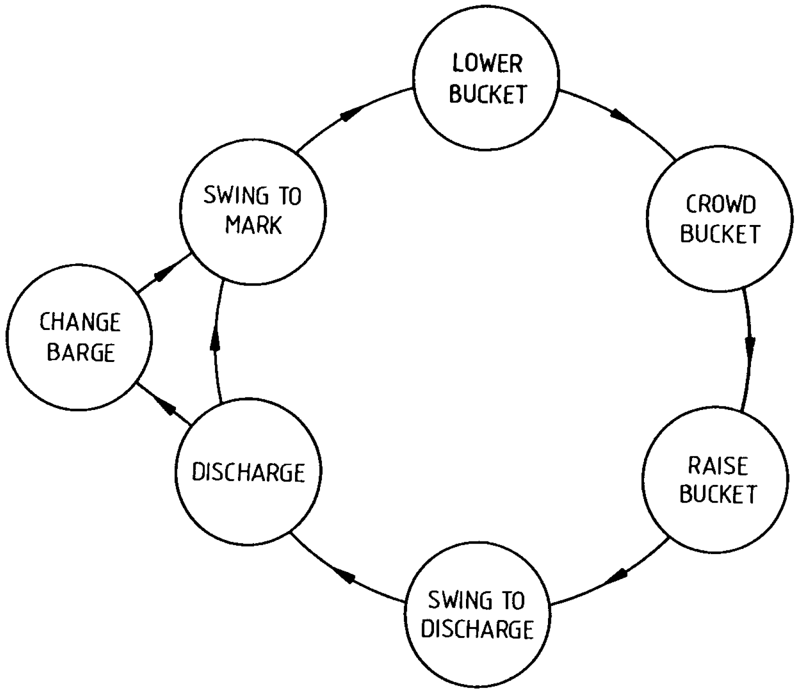


Figure 20 — Anchor pattern and working method of bucket chain dredger



(a) Method of operation



(b) Production cycle of hydraulic backhoe dredger

Figure 21 — Hydraulic backhoe dredger

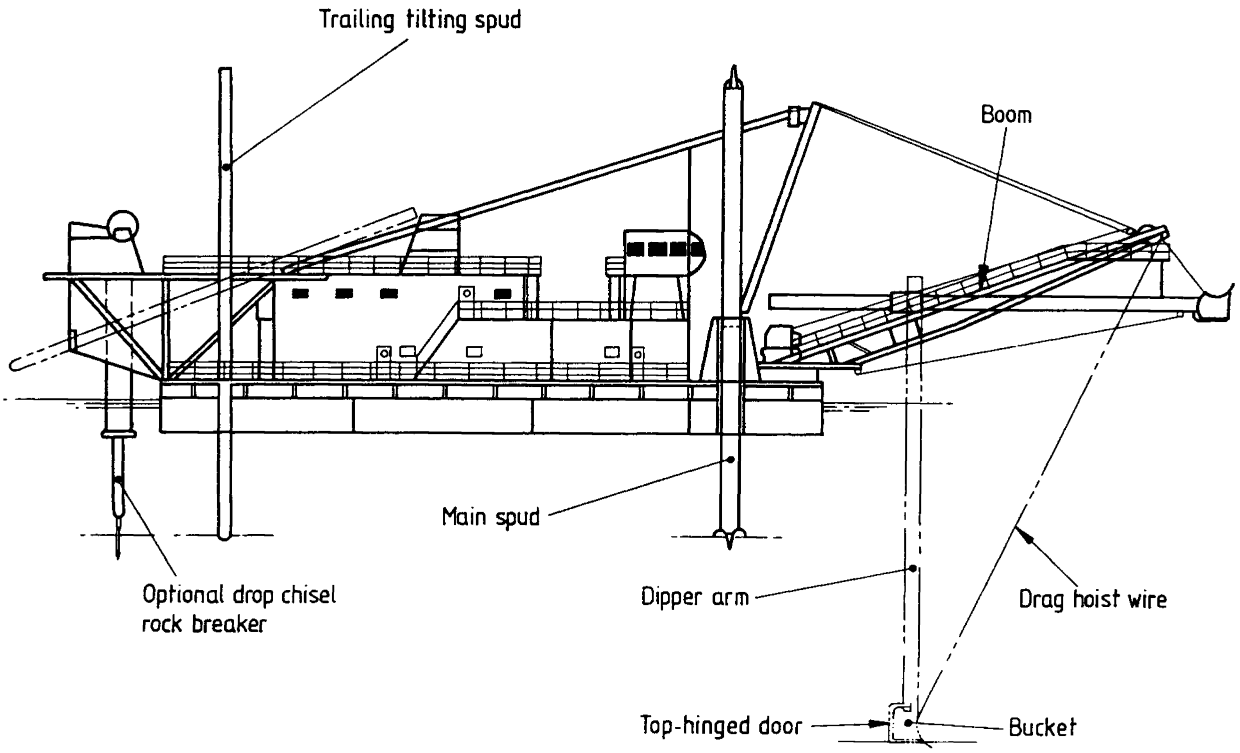


Figure 22 — Rope-operated dipper dredger

4.12 Dustpan dredger

NOTE See **A.12**.

The dustpan dredger is a suction dredger that usually discharges through a short floating pipeline but occasionally discharges into barges. In many respects it is similar to the suction dredger (see **4.6**).

The most significant difference between the dustpan dredger and the suction dredger is the design of the suction head (see Figure 23). The head has no mechanical cutting action but relies instead on an array of water jets to loosen and fluidize the bed deposits.

In most situations it is an advantage if the dustpan dredger is self-propelled. The dustpan dredger does not work on spuds, but is located and moved by winches (see Figure 24). In normal operation the dredged material is discharged into deeper or rapidly flowing water a few hundred metres from the dredging area.

The dustpan dredger is particularly useful where there is a need to remove thin deposits of granular and detritus material from relatively large areas.

The disadvantage of the dustpan dredger is the absence of any positive mechanical cutting mechanism, which limits efficient operation to the dredging of recent unconsolidated deposits. The flexibility of the all winch method of location means that accurate dredging in plan is not usually practical.

Specially designed dustpan dredgers may be used to produce accurately a plane level surface to the sea bed for the founding of precast structures.

4.13 Side casting or boom dredgers

NOTE See **A.13**.

Dedicated side casting dredgers are not common. It is essentially a trailing suction hopper dredger (see **4.2**), but without the hopper. Instead of the dredged material passing into the ship's hopper, it is discharged to one side of the ship via an elevated pipe that is supported by a boom structure. For large dredgers discharge may be up to 90 m from the hull centreline.

Instead of the one or two trailing suction pipes conventionally fitted to a trailing suction hopper dredger, up to four pipes may be fitted. One to port, one to starboard and two through a well amidships or over the stern.

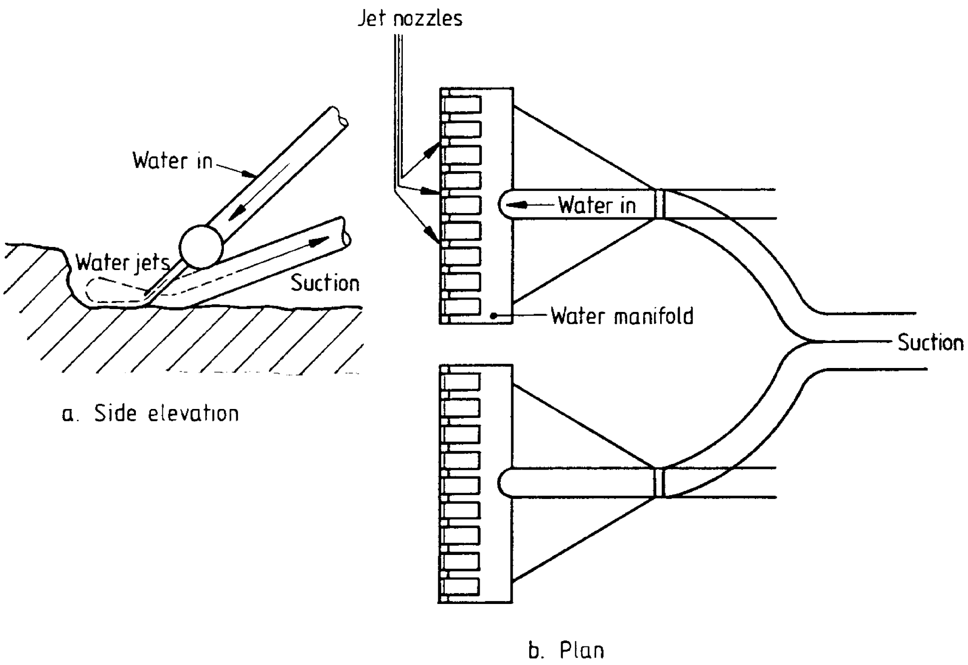


Figure 23 — Dustpan dredger with suction head arrangement

Dredgers of this type are mostly used in the maintenance of long navigation channels that are subject to rapid siltation and where conventional disposal off site would be uneconomic. The method relies upon material being removed from the channel at a substantially faster rate than it is returned naturally.

Since there is no need to sail to a disposal site, production is continuous, the only limits on production being the capacity of the dredge pumps and the solids concentration that can be achieved in the pumped mixture.

The main advantage of the side casting dredger is the very high rate of continuous production that can be achieved. The main disadvantage is that the dredged material is only removed a short distance from the dredging area and hence may return to the area quickly. There may also be unfavourable environmental effects arising from the high level of induced water turbidity where fine particles are present.

4.14 Jet pump dredgers

NOTE See **A.14**.

Jet pumps (see Figure 25) may be incorporated into any dredger that works on the suction principle but are normally confined to plain suction types, such as the stationary suction hopper dredger (see **4.3**) and the suction dredger (see **4.6**). They may also be used to assist in the ejection of gas from dredged mixtures with important improvements in production of materials that contain significant amounts of gas. The jet pump is positioned in the suction pipe, normally at the extremity.

The advantages of the jet pump include an ability to dredge to greater depth and to continue dredging with a buried suction intake without undue risk of cavitation (assuming a system designed to operate buried) a much reduced risk of pipeline blockage when discharging through long pipelines and reduced costs due to wear if handling abrasive materials.

The disadvantages of the jet pump include a significant reduction in the overall system efficiency when compared with a solids-handling centrifugal pump, and a rather limited residual head available for the discharge of the dredged materials through pipelines. The maximum discharge distance is therefore significantly less than with a centrifugal solids-handling pump.

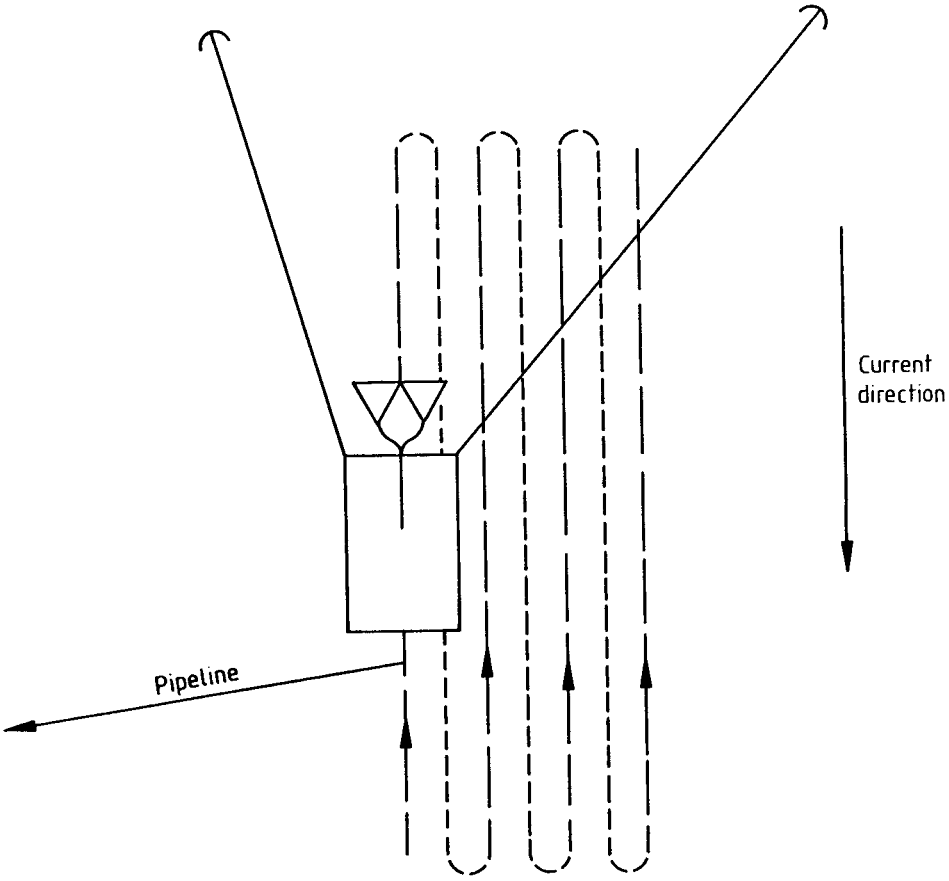


Figure 24 — Typical working pattern for dustpan dredger

For longer discharge distances or high heads, it becomes necessary to employ a conventional solids-handling centrifugal pump in the discharge line to provide additional head (see **A.18**).

4.15 Air-lift dredgers

NOTE See **A.15**.

The air-lift dredger (see Figure 26 for method of loading) achieves flow in a pipe by the injection of compressed air at the submerged extremity of the pipe. The entrained air results in a reduction in the density of the air/water mixture within the pipe and an upward flow is induced. Fine loose soils, including silts and fine sands, may be eroded and carried in suspension by the inflowing water. The system works best when removing fine materials in deep water.

The advantage of the system is its great simplicity, including absence of submerged moving parts. A small dredging assembly may be very light in mass, which makes it particularly suited to use by divers.

In general, the air-lift dredger serves as a simple underwater cleaner for the clearance of sediment from around wrecks or structures and for the cleaning of submerged foundations, etc.

4.16 Amphibious dredgers

NOTE See **A.16**.

The amphibious dredger is generally small and may be capable of working in water that is too shallow for conventional craft.

Generally, the amphibious capability is confined to small grab pontoon dredgers (see **4.8**) and small cutter suction dredgers (see **4.4**) and enables them to bypass structures which restrict a waterway as when the dredger is employed in the maintenance of canals and channels.

4.17 Bed-levellers and ploughs

NOTE See **A.17**.

Bed-levellers (see Figure 27), sometimes called ploughs, are not dredgers, but a means of moving material over the sea bed, or causing it to rise into suspension to be transported away by natural water flow.

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

The bed-leveller is most commonly used in association with a trailing suction hopper dredger (see **4.2**). It may be used to draw material from areas inaccessible to the trailing suction hopper dredger into its reach, or to level off the high spots left by the trailing suction hopper dredger due to “tracking” or some other problem.

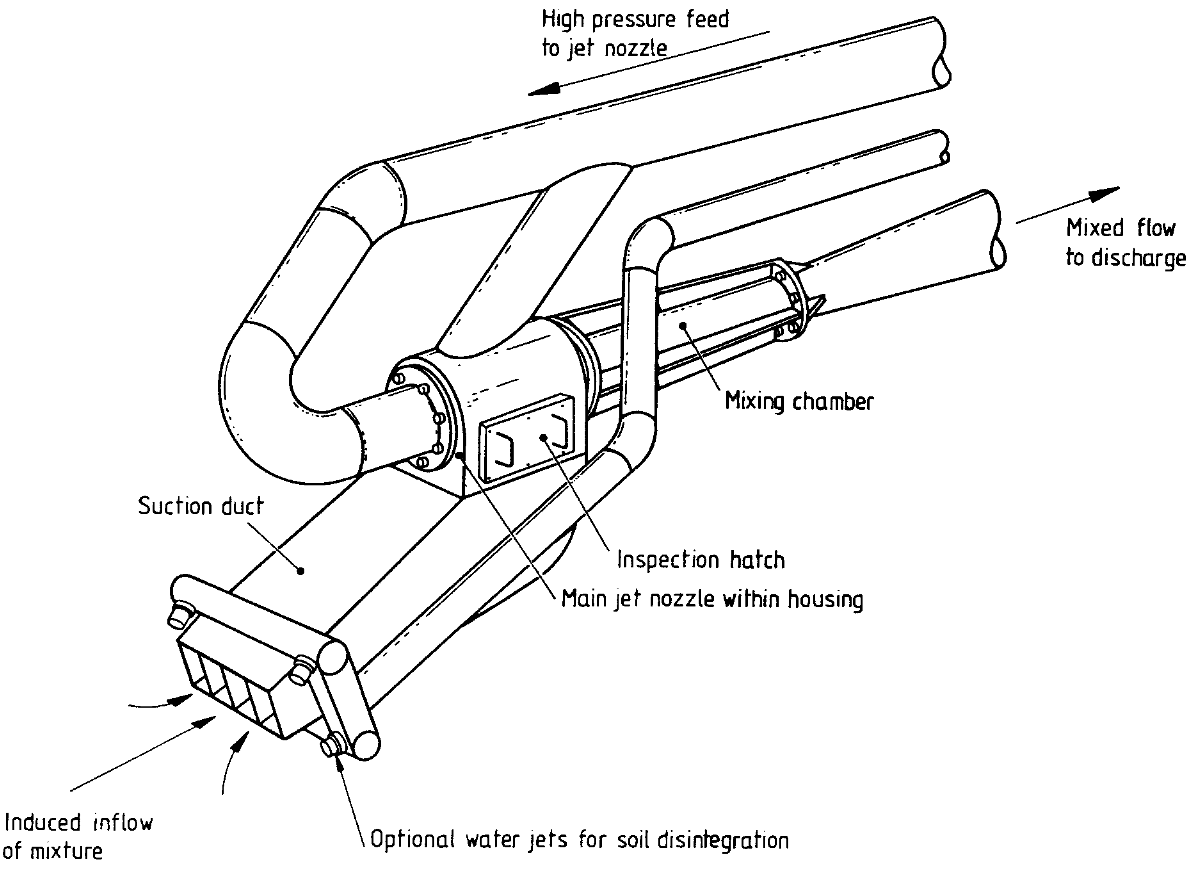


Figure 25 — Illustration of jet pump with suction intake incorporating water jetting arrangement

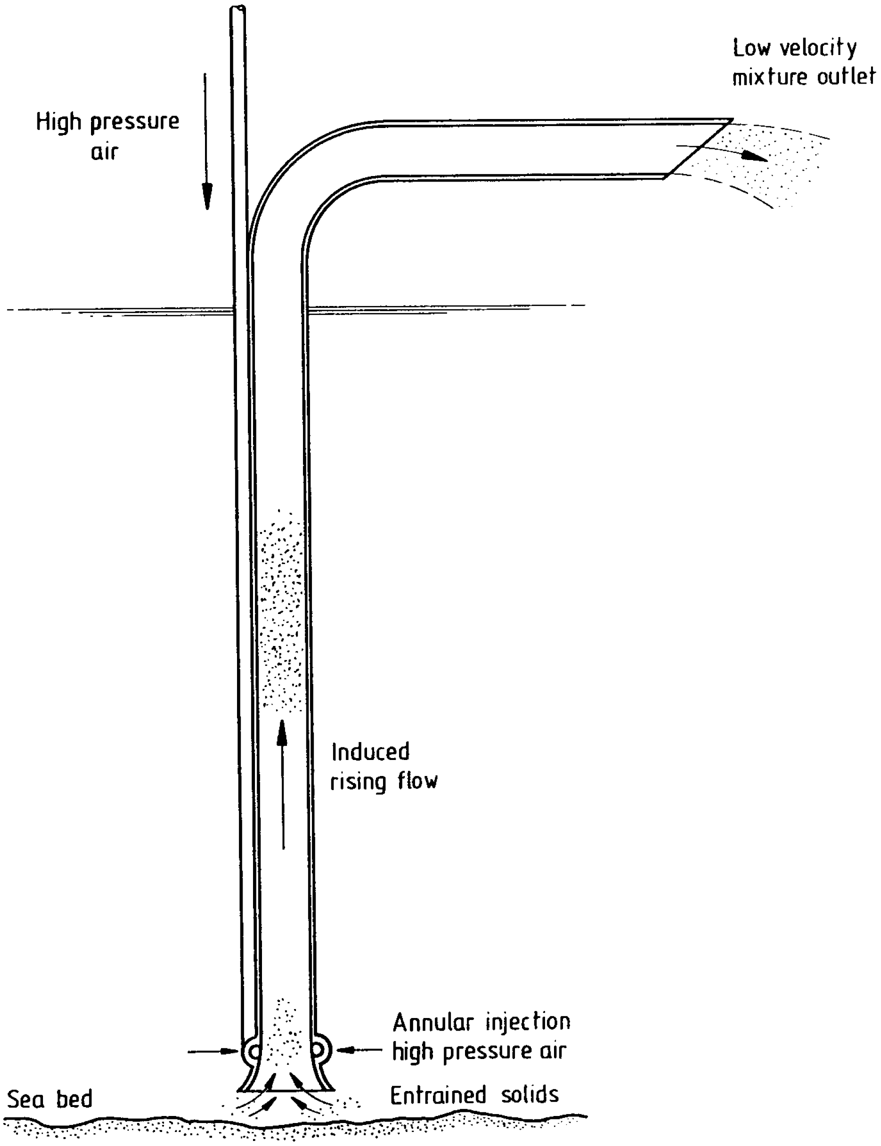


Figure 26 — Illustration of air-lift principle

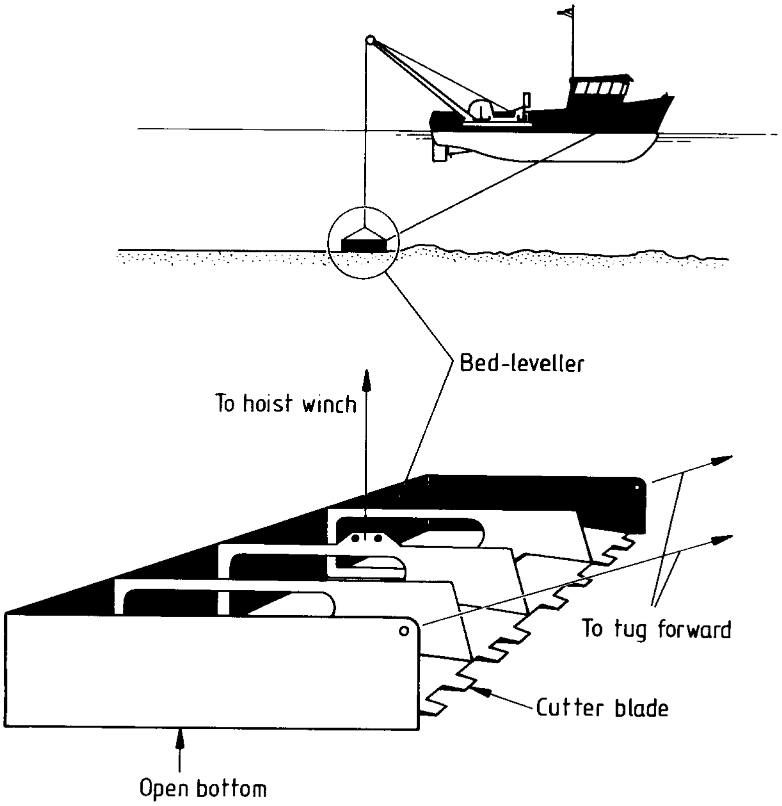


Figure 27 — Deployment method for bed-leveller and typical bed-leveller assembly

Section 5. Guidance on selection of dredging plant

5.1 Introduction

An appreciation of the dredging plant and methods most likely to be employed may result in a more efficient or more economic design.

The selection of plant is influenced by, among other things, physical factors including work type, soil type, site conditions and the volume of material to be dredged.

More than one type of plant may be capable of carrying out the required task. In some cases, particularly for small-scale works, the selection may be influenced strongly by plant availability or economic considerations.

Important decisions concerning plant selection should where possible take account of the full range of site conditions and requirements.

A preliminary guide to the selection of dredging plant for particular tasks is given in Table 14 to Table 17.

5.2 Use of Table 14 to Table 17

The tables assume a knowledge of various site conditions. This knowledge is used to determine the general suitability of each type of plant in relation to the site characteristics. Suitability is indicated in the tables by a number 1 to 3, or an “N” denoting that the plant is not usually suitable.

Low number ratings indicate the dredger types that are usually most suited to the required task. Special factors may dictate the consideration of other types, even those indicated to be “not usually suitable”.

It is intended that these tables provide only a general guide to plant suitability. They should not be considered to be definitive. The simplistic approach does not take account of all factors, but normally provides a reasonable indication of the optimum plant type(s) for a particular task.

Some aspects of particular dredging tasks or dredger types require special consideration that is not provided by the tables. These matters are described in **5.3** to **5.9**.

5.3 Mobilization of plant

The ease of mobilization of dredging plant or movement between different work areas is often an important consideration in plant selection, particularly for small works. Generally, only self-propelled seagoing dredgers enjoy case of movement without tugs and support craft. These advantages are mainly confined to the suction and grab hopper types and to very large cutter suction dredgers (see **4.2**, **4.3**, **4.4** and **4.7**).

5.4 Debris

Areas that are likely to contain appreciable quantities of debris, such as fitting-out or scrap berths and river berths, may be difficult to dredge with suction-type dredgers. For these areas, grab dredgers are most appropriate unless the area is first cleared by means of a bottom rake (see **4.17**).

NOTE Attention is drawn to the legal requirements in connection with the disposal of debris (see **6.4**).

5.5 Restricted working space

Trailing suction hopper dredgers (see **4.2**) are generally best employed in relatively unrestricted areas. On occasions, it may nevertheless be sensible to employ the trailing suction hopper dredger if the bulk of the dredging requirement is well-suited to its use, even though relatively small amounts of dredging are required to be carried out at reduced efficiency in less accessible areas.

5.6 Plant for maintenance dredging

Maintenance dredging (see Table 14) normally involves the removal of recently deposited fine sediments. Consequently, the plant may not necessarily need to be exceptionally powerful or heavily built. If the distance to the disposal area is long, the maximum sailing speed of the hopper or dredger will be significant and for hopper dredgers it is advantageous if the hopper is designed specifically for the loading and transport of fine materials.

For regular maintenance dredging, the ranges of quantity to be dredged that are listed in Table 14 are for each separate campaign. Where these quantities represent an annual requirement of maintenance dredging, the use of a small, lightweight trailer may be most appropriate.

5.7 Plant for capital dredging

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

Generally, plant to be employed upon capital works is of more rugged construction and greater power than plant of the same type designed specifically for maintenance work.

A guide to plant commonly employed is given in Table 15.

Table 14 — Guidance on the selection of plant for maintenance dredging

Site conditions	Standard trailer	Light trailer	Cutter suction	Bucket wheel	Grab hopper	Grab pontoon	Bucket	Backhoe	Dipper	Barge unloader
Bed material										
Loose silt	1	1	1	1	2	2	2	2	N	1
Cohesive silt	1	2	1	1	1	1	1	2	N	1
Fine sand	1	1	1	1	2	2	2	2	N	1
Medium sand	1	1	1	1	2	2	2	2	N	1
Coarse sand	1	2	1	1	2	2	2	1	N	1
Sea conditions										
Enclosed water	3	2	1	1	1	2	2	2	N	1
Sheltered water	1	1	1	1	1	1	1	1	N	2
Exposed water	1	2	3	3	3	N	3	3	N	N
Disposal to:										
Shore	2	2	1	1	N	2	2	2	N	1
Tide	1	1	1	1	N	N	N	N	N	N
Sea	1	1	N	N	1	1	1	1	N	N
Quantities										
< 100 000 m^3	2	1	1	1	1	1	2	1	N	1
< 250 000 m^3	1	2	1	1	1	2	1	2	N	1
< 500 000 m^3	1	2	1	1	2	3	1	3	N	1
> 500 000 m^3	1	2	1	1	3	3	1	3	N	1
Heavy traffic	1	1	3	3	2	2	3	1	N	2
Confined working	N	3	3	3	2	1	3	2	N	2

Key

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

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

Table 15 — Guidance on the selection of plant for capital dredging

Site conditions	Standard trailer	Light trailer	Cutter suction	Bucket wheel	Grab hopper	Grab pontoon	Bucket	Backhoe	Dipper	Barge unloader
Bed material										
Loose silt	1	1	1	1	2	2	2	2	3	1
Cohesive silt	1	1	1	1	1	1	1	2	3	1
Fine sand	1	1	1	1	2	2	1	2	3	1
Medium sand	1	1	1	1	2	2	1	2	2	1
Coarse sand	1	1	1	12	1	1	2	2	1	1
Gravel	1	2	1	1	1	1	1	1	1	1
Soft clay	1	2	3	1	1	2	1	2	2	2
Medium clay	2	3	3	2	2	2	1	1	2	3
Stiff clay	3	N	3	2	3	3	1	1	1	N
Boulders	N	N	3	3	3	2	2	1	1	3
Very weak rock	3	N	1	2	3	3	2	1	1	N
Weak rock	N	N	1	3	N	N	3	1	1	N
Moderately weak rock	N	N	1	N	N	N	N	1	2	N
Pretreated rock	2	N	3	N	3	2	2	1	1	
Sea conditions										
Enclosed water	N	3	1	1	1	1	1	1	1	1
Sheltered water	1	1	1	2	2	1	2	1	2	3
Exposed water	1	2	3	3	3	3	3	2	3	N
Disposal to:										
Shore	1	2	1	1	N	N	N	N	N	1
Tide	1	1	2	1	N	N	N	N	N	N
Sea	1	1	3	3	1	1	1	1	1	N
Quantities										
< 100 000 m^3	2	1	1	1	1	1	2	1	1	1
< 250 000 m^3	1	2	1	1	2	2	1	1	2	1
< 500 000 m^3	1	3	1	1	3	3	1	2	3	1
> 500 000 m^3	1	3	1	1	3	3	1	3	3	1
Heavy traffic	1	1	2	2	2	3	3	2	2	2
Confined working	3	3	3	3	1	1	3	1	2	2

Key

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

NOTE Other factors not referred to may influence the choice of dredger. The table provides only a preliminary engineering guide.

Table 16 — Guidance on the selection of plant for land reclamation and beach replenishment

Site conditions	Standard trailer	Light trailer	Cutter suction	Bucket wheel	Grab hopper	Grab pontoon	Bucket	Backhoe	Dipper	Barge unloader
Bed material										
Fine sand	1	1	1	1	N	2	2	2	3	1
Medium sand	1	1	1	1	N	2	1	1	3	1
Coarse sand	1	2	1	1	N	2	1	1	3	1
Gravel	1	3	1	1	N	2	1	1	3	1
Cobbles	2	N	2	2	N	2	2	1	2	3
Very weak rock	3	N	1	2	N	3	2	1	1	3
Weak rock	N	N	2	3	N	N	N	1	3	N
Sea conditions										
Enclosed water	N	3	1	1	N	1	2	2	2	2
Sheltered water	1	1	1	1	N	1	1	1	1	1
Exposed water	1	3	3	3	N	N	3	3	3	N
Placing by:										
Direct dumping	3	2	N	N	N	1	1	1	1	N
Direct pumping	N	N	1	1	N	N	N	N	N	1
Transport and pump	1	2	N	N	N	2	2	2	3	N
Dump and pump	1	1	N	N	N	1	1	1	1	N
Quantities										
< 100 000 m^3	2	1	1	1	N	1	2	1	2	2
< 250 000 m^3	1	2	1	1	N	2	1	1	2	1
< 500 000 m^3	1	2	1	1	N	2	1	1	3	1
> 500 000 m^3	1	3	1	1	N	3	2	2	3	2
Heavy traffic	1	1	3	3	N	2	3	2	2	2
Confined working	N	3	3	3	N	1	3	2	2	2

Key

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

NOTE Other factors not referred to may influence the choice of dredger. The table provides only a preliminary engineering guide.

Table 17 — Guidance on the selection of plant for rock pretreatment and dredging

Site conditions	Diver driller	Floating pontoon	Jack-up pontoon	Standard trailer	Cutter suction	Bucket wheel	Grab pontoon	Bucket	Backhoe	Dipper
Bed material										
Very weak rock	N	N	N	N	1	2	2	1	1	1
Weak rock	2	N	N	N	1	3	3	2	1	1
Moderately weak rock	2	N	N	N	1	N	N	3	3	2
Pretreated rock	N	1	1	2	2	3	2	2	1	1
Sea conditions										
Enclosed water	1	1	3	N	2	2	1	2	1	1
Sheltered water	2	1	2	1	1	1	1	1	1	1
Exposed water	3	3	1	1	2	3	3	2	3	2
Disposal to:										
Shore	N	N	N	N	1	1	N	N	N	N
Tide	N	N	N	N	N	N	N	N	N	N
Sea	N	N	N	1	2	2	1	1	1	1
Quantities										
$< 10\,000\ m^3$	1	1	2	3	2	2	1	2	1	2
$< 50\,000\ m^3$	3	1	1	2	1	1	2	1	2	1
$< 100\,000\ m^3$	N	1	1	1	1	1	3	1	2	2
$< 300\,000\ m^3$	N	1	1	1	1	1	3	1	3	2
Heavy traffic	N	2	1	1	2	2	2	3	2	2
Confined working	1	1	3	3	3	3	1	3	2	2

Key

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

NOTE Other factors not referred to may influence the choice of dredger. The table provides only a preliminary engineering guide.

5.8 Plant for land reclamation

Dredging plant employed in land reclamation work has to be capable, at some stage, of placing dredged material on to land or of forming land. This is normally most efficiently achieved by pumping through pipelines (see section 8).

Only certain types of dredger are capable of direct pump discharge, the principal types being the self-discharging trailing suction dredger (see **4.2**), the cutter suction dredger (see **4.4**), the bucket wheel dredger (see **4.5**) and the suction dredger (see **4.6**). Other types of dredger that load barges may be used, but are likely to require the use of a separate barge unloader (see **A.19.6**).

For beach renourishment work, direct bottom dumping at high tide may occasionally be an alternative to direct pumped discharge.

A guide to plant commonly employed is given in Table 16.

5.9 Plant for rock dredging

Direct rock dredging is possible only with very rugged and powerful dredgers. Some rocks may be dredged directly, others may require pretreatment (see section 9).

Rock that can be dredged without pretreatment may best be dredged by large cutter suction dredgers (see **4.4**), dipper dredgers (see **4.11**), backhoe dredgers (see **4.10**) or bucket chain dredgers (see **4.9**). Very large grab pontoon dredgers (see **4.8**) may occasionally be used. A guide to the ease with which rocks may be dredged is given in Figure 28.

If the area of dredging is continuously exposed to moderate or heavy wave attack, the use of stationary dredgers other than grab dredgers may be impractical. A large trailing suction hopper dredger (see **4.2**) fitted with rippers in the draghead may be used in some circumstances if the rock is very weak and highly weathered.

A guide to plant commonly employed is given in Table 17.

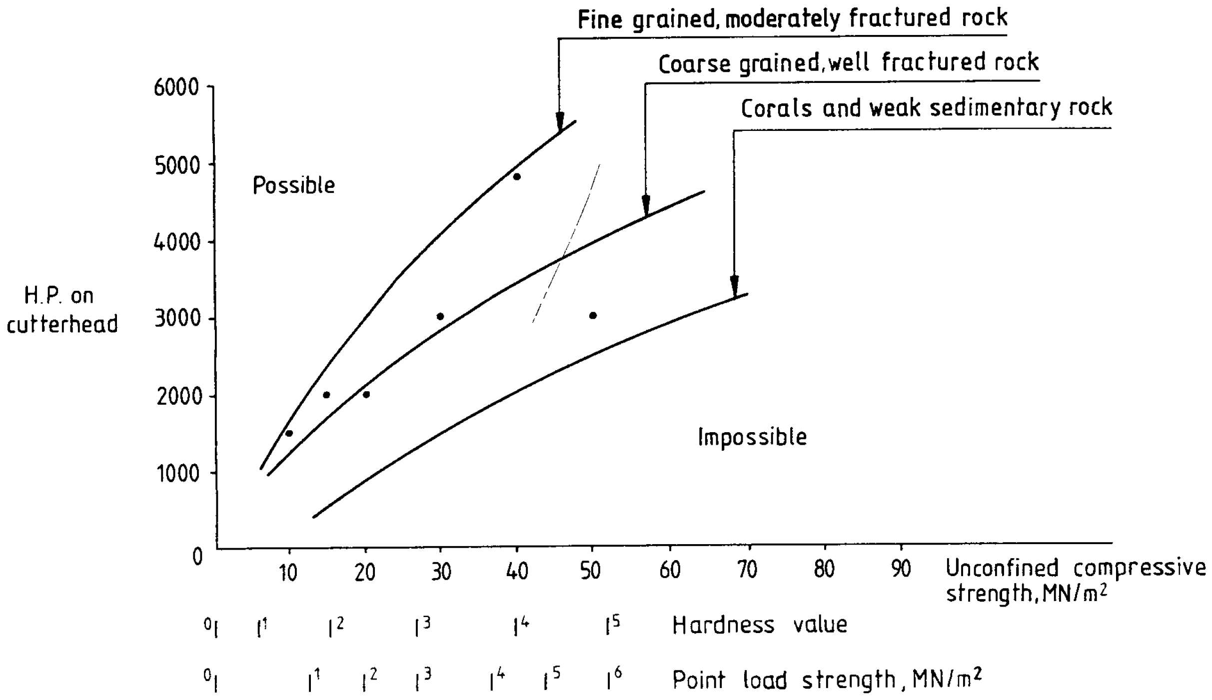


Figure 28 — Guide to ease of dredging of rocks when using suitable cutter suction type dredgers

Section 6. Capital dredging

6.1 Introduction

There are a number of special factors, in addition to those of soil conditions, etc. covered elsewhere, that may affect capital dredging works and that should be considered during design, plant selection and actual operations. These special conditions are covered in **6.2** to **6.10**.

6.2 Munitions

For many years it has been common practice to dispose of unwanted explosive devices by dumping in selected offshore areas. Similar, less controlled pollution of this kind has occurred during war time and also as a result of practice firing.

Generally, the approximate position of specific dump sites is recorded and can be determined by searching through the local marine survey charts or local or military records, or by enquiry to the appropriate body. The position of explosives resulting from less controlled activities may not be known.

If the presence of explosives is suspected, a magnetometer sweep (see **2.10.2.4**) may aid detection, provided that the munitions have a substantial ferrous metal content. However, if the composition is predominantly of non-ferrous metal or plastics, the only course of action may be to instigate a diver inspection to identify the presence of any surface munitions.

In areas where the presence of munitions is known, trawling methods may be attempted to recover surface and near-surface munitions prior to dredging.

The following considerations should be borne in mind before dredging.

a) The appropriate specialized division of the armed forces should be contacted to provide advice and, if possible, to clear or render harmless any explosive devices on the site. Normally, submarine explosives are dealt with by the Royal Navy and explosives on land, or that finish up on land as a result of dredging are dealt with by the Army.

b) Guards should be fitted over the intakes of suction dredgers to prevent items over a defined size from entering.

c) A clearly defined procedure for reporting and for taking action should be devised and adhered to.

d) Where the risk is high, sensitive areas of the dredger may need to be armour-plated to protect personnel, and dredgers with particular safety features may need to be employed.

6.3 Wrecks

The locations of wrecks of significant size are normally marked on admiralty charts, or are known to the local port or harbour authority. Fuller information on known wrecks around the coast of the UK can be obtained from the Hydrographer of the Navy.

All wrecks within, or in the vicinity of, the area to be dredged, or within navigation routes between work areas, including disposal areas, should be clearly marked on the drawings of the works and if necessary physically by means of buoys on the work site.

Where the presence of wrecks is suspected but not known, detection may be possible by means of side-scan sonar (see **2.2.6**), if the wreck is upstanding above the sea bed, or magnetometer sweeps (see **2.10.2.4**).

6.4 Debris

The presence of debris or foreign matter, e.g. wires, chains, tyres and scrap, may have a serious adverse effect on dredging, particularly where suction-type dredgers are employed.

Debris can be expected in dockyards, some areas of harbours, canals, rivers and in made ground.

The presence of surface debris can be checked by side-scan sonar (see **2.2.6**), underwater television, diver inspection or raking (see **4.17**).

Areas with significant concentrations of debris will usually be dredged most efficiently by grab or backhoe dredgers. Alternatively, an attempt to clear the area by raking in advance of dredging can be made, but this may have only limited success.

In the UK, areas at sea that are licensed for the disposal of dredged material may not normally be used for the disposal of debris.

6.5 Clays

Certain clays of high plasticity may adhere to the buckets of any bucket-type dredger. As a result, the material may be difficult to discharge from the bucket and subsequently may be difficult to discharge from the hopper into which it is loaded. When this problem is suspected, it is advisable to employ hoppers of a clean internal construction with the wide opening for spoil disposal (see **A.19.5**).

6.6 Peat

Peat may be difficult to dredge due to its low density, possible gas content and tendency to swell rapidly upon the removal of any overburden.

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

If pumped into onshore containment areas, the high bulking will necessitate substantial excess capacity within the containment area.

Suction methods should be avoided if possible.

6.7 Flints

High concentrations of flint cobbles or nodules, which may occur on the surface of weathered chalk deposits, are highly abrasive and may cause exceptional wear rates in pumps and pipelines. Dredging may be most economic using a bucket-type dredger.

6.8 Vegetation

Heavy vegetation, in the form of seaweed, reeds, rushes, mangrove, etc., can cause serious problems for suction-type dredgers.

Heavy weed concentration may cause pump blockage or may create cooling problems through the blockage of the cooling system of the dredgers or other craft on the site.

Where high concentrations of weed are known to occur, it may be preferable to employ bucket-type dredgers or to employ separate plant to clear the weed in advance of dredging. Discharge from hoppers may cause problems.

6.9 Dredging of cobbles and boulders

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

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

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

When suction, cutter suction or trailing dredgers are used to dredge material believed to contain boulders, they are usually modified for this purpose.

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

a) blasting, followed by grab dredging;

b) dredging alongside the boulder to make a pit into which the boulder falls, below the dredge level (this may create problems for any future dredging work);

c) trawling the boulders with wire nets from a specially adapted fishing boat (unlikely to be successful except in ideal conditions).

6.10 Dredging of naturally well-graded sands

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

Dredgers that do not exert a positive thrust in their digging action, such as wire line grab dredgers, may not achieve satisfactory outputs in naturally well-graded sands of this nature.

Such materials can also prove difficult to discharge from hoppers. In hoppers with chain-operated bottom doors, the sand may consolidate around the chains to such an extent that upon release of the chain tension the doors remain closed. Alternatively, “arching” within the sand mass may resist discharge, even though the bottom doors are open or, in the case of split hoppers, the hull is partially split.

Section 7. Maintenance dredging

7.1 Introduction

Many aspects of maintenance dredging are covered in other sections and consequently only particular aspects are considered here.

Maintenance dredging is a special activity in that it generally involves only the removal of soils recently deposited, comprising relatively fine sediments. Normally, the material to be removed is of small thickness and low strength. Exceptionally, when dredging close alongside quays or jetties, particularly in shipbuilding areas, the sediments may be polluted by foreign matter, such as scrap metal, ropes and rubbish.

The interval between maintenance dredging programmes may be as little as a few weeks or as long as a few years.

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

If necessary, almost any kind of dredging equipment can be used for maintenance dredging, but in the main only certain types are used, such as the trailing suction hopper dredger, bed-leveller, grab dredger, occasionally the bucket dredger and the stationary suction dredger (see section 4 and Table 14).

7.2 Soil density limitations

In many areas where maintenance dredging is a regular activity, the material to be dredged may be of a semifluid nature consisting of very fine particles in a dense solution, which is sometimes mobile. The density of these deposits is at a minimum at the upper surface and increases with depth. In some instances, the transition from clear sea water to sea water containing sediment may be almost imperceptible. In these situations, the determination of navigable depth may be difficult using conventional echo sounding equipment. If navigable depth is determined purely on the basis of the analogue record produced by the echo sounder, particularly where the echo sounder is of high frequency and low energy, dredging may be carried out at intervals that are shorter than is strictly necessary in order to preserve safe and proper navigation.

The need to avoid excessive dredging is stated elsewhere in this standard. Navigable depths may be determined on the basis of predefined density rather than an echo sounder record. In this case, the maximum density of fluid mud that is acceptable from a navigational viewpoint should be determined on the basis of the types of vessel that will be navigating through the area and the manoeuvres that have to be performed by those vessels. When the limiting density has been decided, measurement of the depth at which that density occurs may be made either by means of a lead line (see **2.2.3.3**), in which the lead is of such dimensions and overall density as to limit its penetration to approximately coincide with the predetermined density requirement (not a satisfactory method), or a density meter may be employed (see **2.2.4**).

Recent work has indicated that the viscosity of fluid muds is also an important property that may affect navigation.

7.3 Methods

The method of dredging and the particular type of plant to be employed should be determined on the basis of the specific dredging requirement and the particular characteristics of the site. A guide to the selection of plant for particular types of maintenance dredging activity is provided in section 5 and Table 14.

7.4 Frequency

The frequency with which a dredging programme is required is normally dictated by the rate of sediment accumulation in the areas to be dredged. However, certain measures can be taken to extend the interval between dredging campaigns. These may include overdredging or making some judgement concerning the limiting density of the sea bed material as described in **7.2**.

In most cases, the greatest economy results from the longest acceptable interval between dredging programmes. Where the rate of siltation is not adversely affected, the interval may be extended by overdredging. However, care has to be taken as overdredging may result in more rapid accretion.

The application of a maximum acceptable density can have a similar end result to that of overdredging in that bed levels may, in some instances, be allowed to rise significantly above the apparent safe level, as indicated by echo sounding.

The main economy resulting from an increase of the interval between dredging campaigns arises from an overall reduction in the costs of mobilizing the dredging plant. Savings in the cost of administration and supervision can also be expected (assuming contract dredging). These costs are normally independent of the quantity to be dredged. Further important savings may result from the enhanced production made possible by the greater depth and density of material to be removed.

Section 8. Land reclamation and beach replenishment

8.1 Introduction

This section is devoted primarily to reclamation using granular materials. The use of fine materials, such as those arising from maintenance dredging in ports, is dealt with in section 3.

Land reclamation or beach replenishment may be carried out using fill material derived from dredging or from land sources. Only those methods that use dredged fill material are considered here. Preferably, these only involve granular materials.

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

Beach replenishment may be required to increase beach levels to reduce wave attack or for amenity purposes, or may require the creation of a barrier for sea defence purposes. It may have certain advantages relative to “hard defence” methods, including environmental, recreational, financial (distributed costs), minimal local disruption and the absence of any detrimental effect on adjoining beaches.

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

8.2 Site preparation

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

Where the site is overlaid by weak superficial deposits it may be necessary to remove these deposits before filling commences. The decision as to whether or not it is necessary to do so is influenced by engineering and economic judgements.

In order to determine the rate and amount of settlement that will result if strata are surcharged by the placing of fill, the characteristics of the soils to be surcharged and of the fill material have to be determined. This is normally done through a site investigation and subsequent laboratory testing. Fill materials may undergo a change of density resulting in the final placed fill density being greater or more commonly less than the in situ density of the source material. Calculations to determine the rate and extent of foundation settlement subsequent to the placing of fill should therefore be based upon the maximum density of the fill material, as determined by laboratory testing (see clause **4** of BS 1377-4:1990).

8.3 Materials

8.3.1 General

It is usual to use only granular materials for land reclamation. Occasionally, long-term land reclamation may be carried out using cohesive materials that arise from maintenance dredging (see **3.6.7**). In such cases, the consolidation period is usually measured in years and the resulting land is only capable of supporting light loads. Only granular materials are used in beach replenishment.

8.3.2 Materials for land reclamation

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

An economic material is a well-graded, free-draining sand with particle sizes in the range of 0.10 mm to 0.60 mm. Sand and gravel mixtures are normally also suitable, but materials with a significant content coarser than 0.60 mm may cause problems if there is a need to pump over long distances due to the greater slurry velocity that is necessary to maintain the particles in suspension, and hence the higher energy requirement during the pumping transport process (see Figure 6).

Materials that are finer than 0.10 mm may be subject to excessive losses during dredging, handling and placing.

The maximum percentage of fines that is acceptable in materials for land reclamation depends to some extent on the overall grading of the material. A well-graded material containing a high percentage of coarse particles may be better able to absorb higher percentages of fines without any adverse effect due to the greater voids ratio. A difficulty that arises whenever significant percentages of fines are present, however, is the natural tendency for the fines to segregate during hydraulic placing (see **8.10**).

Materials that are not well graded may consolidate less well.

If the fill material is to be placed by pumping, fines may also be released with the draining water when flow velocities within the area of reclamation are sufficiently high to maintain fine particles in suspension. When fill is placed hydraulically without containment bunds, the free escape of draining water normally removes most of the fine particles.

8.3.3 Materials for beach replenishment

Material for beach replenishment should be of such a size that the losses that occur naturally under the influence of waves, tides and currents are not excessive. This normally requires that the material grading is similar to, or coarser than, that occurring naturally on the beach to be replenished or on stable beaches that are subject to similar conditions. In the UK it is usual to use rather coarse material for beach replenishment, although in the Low Countries the use of relatively fine sands is common.

A compromise between the ideal beach replenishment material and material that is readily available locally may be necessary for economic reasons. The mobility of the beach material is normally inversely proportional to the particle size, but the costs of dredging and placing the material are normally proportional to its coarseness.

The optimum grading of material for a stable beach is totally site dependent. The use of coarser material than the natural beach results in a steeper beach slope and the use of a finer material results in a less steep beach slope. Empirical relations have been established that provide an estimate of the effect on beach slope of materials of different grain size from the natural beach material [30].

8.4 Volumetric change

Changes in bulk density will arise at various stages of the dredging, handling and placing processes. There may be a reduction in volume of the material due to the loss of fines. In some instances there may be an increase in volume due to a change in density of the placed fill relative to the in situ deposits in the borrow area. Volumetric change may be influenced by several factors and is very dependent on both the characteristics of the dredged material and the nature of the dredging and handling processes.

It should be noted that experienced judgement is required to provide reliable estimates of volumetric changes. For general guidance see Figure 29.

NOTE See [31].

It is common in beach replenishment that the volume dredged is significantly greater than the final retained beach volume. The excess volume that has to be dredged to provide a given beach volume is sometimes termed the “overfill factor”. Various models exist for the estimation of this “overfill factor” [30].

8.5 Borrow areas

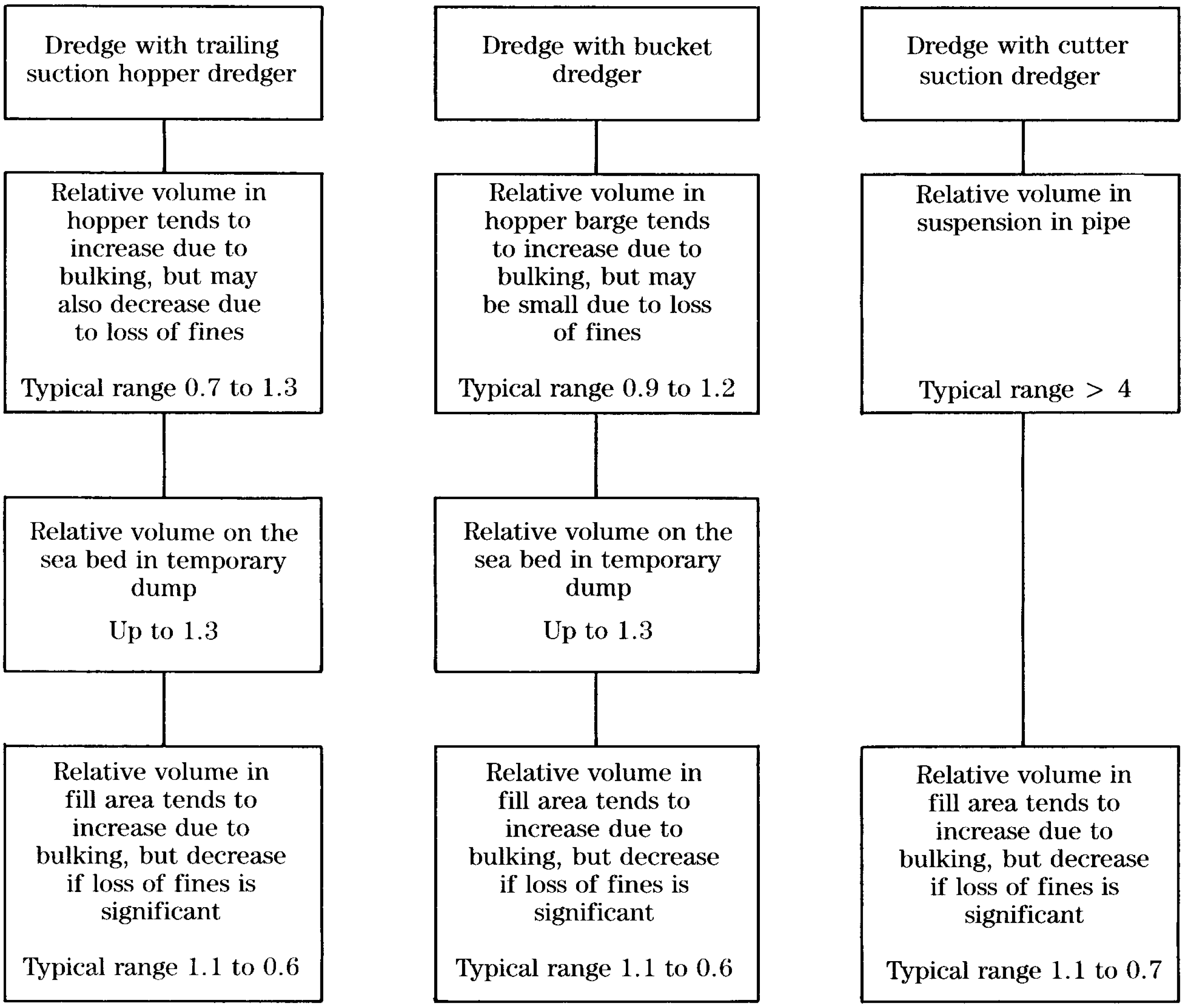
The borrow area should be located as close to the area of filling as is practicable without jeopardizing the stability of the fill or other works or structures in the vicinity.

For land reclamation, it is often possible to use material arising from deepening work adjacent to or close to the area of reclamation. This is the ideal situation, particularly when a balanced cut and fill can be arranged.

It is preferable that usable material in the borrow area extends from sea bed level continuously to the full depth to which dredging is to take place. This ideal situation may not always exist. Where good quality fill is overlaid or interspersed with thin strata of fine materials, it may be practical to “lose” the fines during the dredging and placing processes. Where the proportions of material unsuitable for filling are substantial or the release of fines is not acceptable, selective dredging may be necessary with unsuitable materials being stripped independently and removed from the area. In some instances it may be possible to remove the good material from beneath the overburden by deep suction methods (see **4.3**).

The borrow area should be free of any rock formations within, or close to, the proposed depth of extraction, and the approaches to the area should be free of any rocks or obstructions that may be unduly hazardous to the plant to be employed.

If the proposed borrow area sustains a significant marine population or is important to the reproductive cycle of marine species, careful weighing of the benefits of extraction against the potential for temporary or permanent damage to fisheries should be carried out. Normally, effects will be minimized by the removal of only a thin surface layer and by dredging during winter. Unfortunately, winter working may be more expensive or even impracticable.



NOTE The final volume in fill is very dependent on the content of fine particles in the material dredged and the consequent loss of these fines during dredging and handling.

Figure 29 — Typical changes in fill volume that may occur during dredging and handling

8.6 Rehandling

8.6.1 General

When the borrow area is remote from the area of filling it may be necessary to rehandle the dredged material.

8.6.2 Rehandling pit

A common combination of plant employed in rehandling is that of the trailing suction hopper dredger and the cutter suction dredger. The trailing suction hopper dredger is used to dredge material from a remote borrow area and to deposit it on the sea bed close to the boundary of the area to be filled. The material deposited on the sea bed is then redredged using a cutter suction or stationary suction dredger and pumped via a floating pipeline to the area of reclamation. When this system is employed, the point of temporary deposition should preferably be accessible to the primary dredger (trailing suction hopper dredger) at all states of the tide.

Losses from the rehandling site may be reduced if it takes the form of a predredged pit, referred to as a "rehandling pit". The pit capacity should be sufficient to avoid interference between the various items of plant and to provide adequate temporary storage, so that in the event of one of the items of dredging plant being stopped, the operative plant can continue working for a reasonable period without interruption of the process.

The maximum elevation of material stockpiled in the rehandling pit should not interfere with the operation of the primary dredger (trailing suction hopper dredger).

The dispersion of dumped material, particularly fine sands, increases with water depth. Serious losses may occur if water depths at the rehandling site are excessive.

The plan area and orientation of the temporary rehandling pit should take account of the dimensions and characteristics of primary and secondary dredging plant, the interaction of the plant and the prevailing or most important wind and wave directions. Although temporary, the formation of a rehandling pit may require formal consent (see **3.7**).

8.6.3 Hopper pump discharge

Dredged fill material delivered to the site by a trailing suction hopper dredger or by hopper barges may be pumped directly into the fill area without intermediate deposition. This may be done by the trailing suction hopper dredger using its own pumps (see **4.2**).

During discharge the dredger is usually moored securely and connected to a discharge pipeline. Sometimes this may be achieved for land reclamation work by mooring at an existing pier or quay. However, for beach replenishment such facilities are rarely conveniently available. The link between the discharging dredger and pipeline is normally the weakest and most vulnerable part of the system.

It is generally considered that for exposed sites the most suitable type of mooring and pipe connection consists of a heavy sea bed anchor block or pile, on which is mounted a swivel connection for both the discharge pipe and mooring line. From the anchor point a fixed sea bed pipeline runs to the shore and a short flexible floating pipeline leads to the sea surface. On arrival the loaded dredger picks up and connects to the mooring line and then picks up and connects to the floating pipeline. The swivel connection allows the dredger to "stream", bows into the prevailing wind or current, during the connection and discharge period. By this arrangement work may continue during sea conditions that otherwise may stop work.

When material is delivered to the site by hopper barge, the hopper may be discharged by a barge unloader, sometimes called a reclaimer (see Figure 30). Such methods require relatively sheltered conditions.

The barge unloader is a fixed pump-set, normally floating, alongside which the loader hopper barge is moored. The cargo is fluidized by water jets and discharged via a pipeline by a solids-handling centrifugal pump.

8.7 Containment

It is usual, although not always essential, to contain fill placed into reclamation by means of a boundary structure. This may take the form of temporary or permanent embankments, sheet steel piling or concrete structures.

If fill is not contained during and subsequent to placing, considerable loss of fines may occur. In the longer term, erosion of the fill under the action of waves and currents may occur.

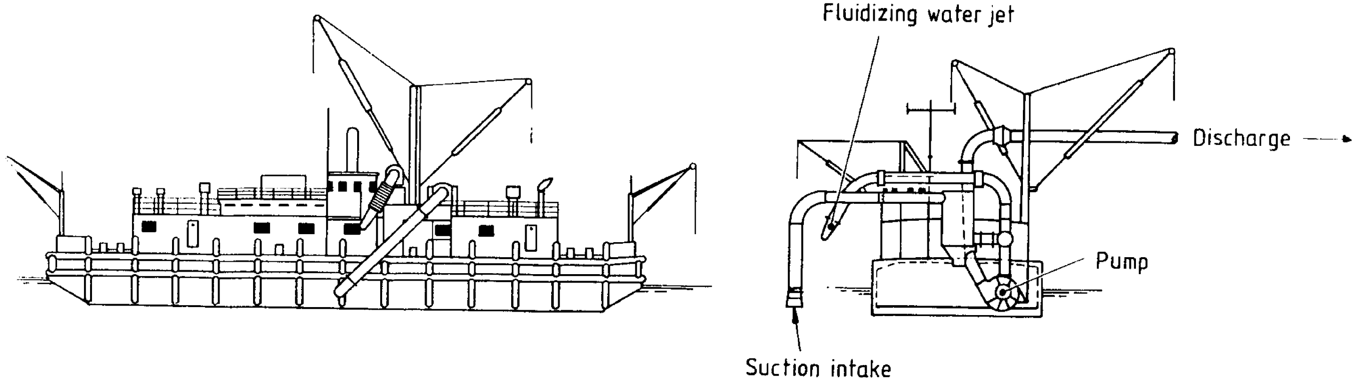


Figure 30 — Typical barge unloader (reclaimer)

8.8 Segregation of fines

When dredged material is transported hydraulically into the fill area, there is a natural tendency for separation of the various component particle sizes to occur. Coarse material is deposited close to the point of discharge and particles of smaller size or lower specific gravity are transported further. This may result in pockets of fine materials forming, which may not achieve the required strength within an acceptable period of time.

Fines may also accumulate in front of the advancing face of denser fill with the consequent formation of weak deposits immediately in advance of the main filling. This concentration of this material may eventually be overtopped by coarser material and hidden from view. The finished fill surface may then appear uniform and sound but may conceal pockets, perhaps quite extensive, within which bearing capacities may be very low. This situation should be avoided where reclamation is for development purposes.

8.9 Chemical contamination

Certain toxins and heavy metals may attach themselves to fine sediments. In some industrial areas these contaminants may occur in significant concentrations. When fine sediments are to be used for landfill in reclamation, particularly when arising from industrial areas, a thorough procedure of sampling and laboratory analysis should be carried out to determine the concentration of any toxins or heavy metals. An assessment can then be made of the implications for the proposed application of the reclaimed land.

8.10 Consolidation

The consolidation of granular materials that are properly placed by hydraulic methods when particle size is in excess of 0.10 mm is normally rapid and improvement in density is normally good without further treatment. However, when the fill permeability is low, or when filling has been carried out in fully or partly submerged conditions, consolidation may be poor. In [35] common relative densities for hydraulically placed fine to medium sands are given as 35 % to 45 % if placed in submerged conditions and 50 % to 65 % if placed above water.

8.11 Compaction

Where compaction is necessary (see **50.2.7** of BS 6349-1:1984), the surface layer of 300 mm to 400 mm can be most effectively compacted by using a vibrating plate, or roller, compactor. For maximum effect, the frequency of vibration should be selected to suit the characteristics of the fill material.

The effectiveness of surface vibration compaction decreases with depth. Increasing the vibrator mass will extend the depth of influence, but if the depth of fill to be compacted exceeds approximately 2 m, alternative methods, such as vibroflotation or dynamic compaction, may be necessary (see clause **9** of BS 6031:1981).

8.12 Settlement

Well-placed hydraulic fill on firm ground is not normally subject to significant settlement. If the completed filling is compacted (see **8.11**) the subsequent settlement is normally negligible.

When fill is placed upon weak ground, such as unconsolidated silts, clays or peats, surcharge by the fill results in consolidation of the foundation materials with consequent settlement of the fill mass. The settlement can be estimated using conventional soil mechanics theory, provided that the properties of the foundation material and the load of the overlying fill are known. This estimate should be made in advance of filling as it may significantly influence the final fill quantity required. In areas of complex geology, which are common in estuarial areas, widely varying differential settlement may occur.

8.13 Protection

In sheltered situations, it may be acceptable to allow the fill to form its own defence by a natural adjustment of profile in response to local wave activity. However, land reclamation that adjoins the sea normally requires protection against erosion by waves and currents.

Protection may take many forms depending upon the proposed land use and the sea conditions that prevail in the area. Protection is most commonly achieved by some form of armouring, which may include sand asphalt, pressure-grouted concrete mattresses, concrete block revetment or riprap rock (see BS 6349-1).

8.14 Wind erosion

Large areas of land reclaimed by filling with fine or medium sands that are exposed to strong winds will suffer erosion when the sandfill is dry. If sensitive areas exist in the near vicinity downwind, problems of sand pollution may arise.

Estimates of the rate of sand transport by wind may be made using Bagnold's formula [32]. Bagnold's formula assumes sand to have zero moisture content, which will rarely be true. Work by Terwindt provides a relation between moisture content on the beach and the minimum sheer velocity needed to initiate sand transport by wind. From this the rate of sand transport under various moisture conditions anticipated can be estimated [33].

The movement of wind-blown sand can be restricted with limited success by the erection of sand fences to trap the mobile material. In order to achieve a permanent solution, it may be necessary, if practicable, to seal the sand surface with an erosion-resistant layer. This may consist of top-soiling and the establishment of vegetation or, in areas of commercial development, the formation of a bituminous or concrete wearing surface. In areas that are not subject to significant traffic, a temporary seal can be achieved by the sprayed application of a bituminous emulsion.

8.15 Monitoring of replenished beaches

Knowledge concerning the behaviour of renourished beaches is sparse, and this lack of knowledge can only be rectified by the proper monitoring of completed works. A complete detailed survey should be made before the work and this normally requires a combined land and hydrographic survey.

Regular monitoring surveys are necessary to provide information because of natural seasonal variations in beach profiles. The most rapid modification of a renourished beach normally occurs shortly after completion. Consequently, surveys should initially be at short intervals of about 3 months. After the first year, survey periods can be extended to 6 months.

Surveys should monitor beach profile and beach material grading. Profiles have to extend seawards beyond the area of beach mobility to an area where sea bed levels are stable. A sufficient number of beach samples should be taken to provide a representative picture.

Since profiles are seasonably variable, comparison of levels may be of only limited value. A more reliable indication of change is given by measuring the change in beach sectional area above an arbitrary reference elevation, which should be below the level of possible beach or foreshore mobility. From these beach sections changes in beach volume can be calculated. Cross sections should be at centres close enough to be representative of local variations and should extend well beyond the end limits of renourishment.

Section 9. Rock dredging

9.1 Introduction

The dredging of rock is the most expensive type of dredging carried out in normal maritime and fluvial engineering. In this context, rock is considered not only in its normal definition of igneous and metamorphic rocks and mudstones, but also as an extensive volume of grains cemented together by a matrix.

Since rock dredging and pretreatment equipment are so specialized, it is vital that investigations are carried out to determine whether rock is present in any quantity, however small, within the areas to be dredged. Hence agglomerated and cemented sands are treated as rocks, while boulders are not. The dredging of cobbles and boulders is covered in **6.9**.

Once it has been demonstrated that there is a requirement for rock to be dredged, it is necessary to determine whether the rock can be dredged directly without pretreatment, or whether pretreatment is necessary, or whether a combination of methods will be most effective.

There appears to be no single measurement that can be taken that provides a proper assessment of the ease with which a particular type of rock can be excavated [11, 34, 35]. This is because there is no single property of the rock that, in itself, renders the rock easy or difficult to excavate, but rather a series of properties, all of which affect the ease of rock excavation to varying degrees. The position is further complicated by the fact that different methods of excavation take advantage of different characteristics of the rock, and so the properties that make the rock easier to excavate by one method may make it more difficult to excavate by another [36, 37].

9.2 Direct dredging

Dredgers that operate successfully in rock that has not been pretreated do so by their ability to loosen and break up the rock during the excavation process. Table 18 shows those dredgers that are capable of dredging rock in certain conditions without pretreatment and their methods of operation. Table 20 provides more general guidance on the selection of plant for rock dredging.

Table 18 — Characteristics of dredgers able to dredge some rocks without pretreatement

Dredger type	Fragmentation/excavation	Type of rock dredged
Cutter suction	Rock is chipped away by cutter teeth. Production is relatively high. Material is normally discharged via a pipeline, but may be loaded into barges with some loss of fines	Moderately strong sedimentary rocks, such as sandstone, siltstone, mudstone, chalk and marl. Also corals and weak limestone
Bucket wheel	Rock is chipped away by bucket teeth. Production good only in very weak rocks. Material normally discharged through pipeline but barge loading is possible	Very weak sandstones, weak marls, weak corals, weak conglomerates, certain mineral deposits
Bucket chain	High point loads on bucket teeth, continuous process. Tendency to break out slabs of rock in certain conditions of bedding. Normally only used for large loading	Most sedimentary rocks up to moderately strong
Dipper	Very high point loads on teeth. Rock is levered out, which may tend to result in large slab formation in certain types of bedding. Only used to load barges	Thin lenses of sedimentary rocks and weakly cemented conglomerates. Massive chalks, marls, weak sandstone, corals and volcanic tuffs
Hydraulic backhoe	Positive bucket action with strong leverage through bucket "crowding". Tear out falls off sharply with increasing depth. Method tends to product large slabs in certain bedding conditions	Moderately weak sandstones and shales at shallow depths. Weak sandstones, corals and conglomerates at greater depth
Grab pontoon	Very heavy bucket of reduced capacity necessary to achieve initial tooth penetration. Very variable and often unpredictable results. Only used for barge loading. Low production	Very weak sedimentary rocks and corals
NOTE For fragmentation and bulking requirements see Table 21.		

Table 19 — Scale of weathering grades of rock mass

Term	Description	Grade
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces	I
Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering	II
Moderately weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh discoloured rock is present either as a continuous framework or as corestones	III
Highly weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones	IV
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported	VI

Any dredgers employed on this work are required to be suitable with respect to weight, strength, power, etc.

Most rocks that can be dredged directly are sedimentary rocks and corals. It is unusual for igneous or metamorphic rocks to be suitable for dredging without pretreatment. However, the in situ state of the rock has a profound influence on the ease with which it may be dredged. The following characteristics are relevant.

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

b) *Weathering*. The degree of weathering affects rock strength. Highly weathered rock often becomes quite friable and relatively easy to excavate. Weathered layers may be dredgeable, but other layers may not (see **2.12** and Table 19).

c) *Jointing and fracture planes*. The natural jointing and discontinuity of a rock are highly significant when determining the ease with which the rock may be dredged. The spacing, orientation, continuity, tightness and surface texture of fracture planes all affect the ease with which the rock may be dredged.

d) *Rock strength*. Rock strength is usually expressed by reference to the uniaxial compressive strength of the rock. However, the point load strength index (see Table 9) and Protodiakonov number are also used as parameters for assessing rock strength with regard to the ease with which the rock may be dredged.

9.3 Limiting factors

9.3.1 General

The limiting factors described below are those directly related to dredging rock. More general limiting factors for dredgers are set out in **3.2**.

9.3.2 Rock characteristics

Of all operating parameters, those related to the rock characteristics have the greatest effect on a dredger's ability to dredge and the output achieved. Due to the very wide variability of rock (see **9.2**) it is not possible to determine how a rock affects the ease with which dredging may take place by simply identifying rock type. Strength, weathering, bedding, jointing, dip and strike all affect dredging performance.

Table 20 lists other data relating to the ease of dredging of rock by mechanical dredgers.

9.3.3 Sea state

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

Table 20 — Ease of dredging of rocks by mechanical dredgers

Dredger type	Remarks
Cutter suction	Capable of handling a wide range of weak rocks. Sandstones, mud and silt stones, corals and weak limestones are generally no problem for large dredgers. Can not handle large boulders or rocks, which fracture into large pieces
Bucket wheel	Only suited to very weak rocks, which fracture readily into small (less than 200 mm) pieces. Very little "spill" and hence well suited to foundation and preparation, etc.
Grab pontoon	Only suited to the weakest of rocks and then only when fitted with a heavy toothed bucket. Poor depth control and irregular bottom finish. Capable of greater dredging depth than all other types. Well suited to the removal of pretreated rock providing that fragmentation and bulking are good
Bucket	Rather sensitive to bedding and angle of dip. Better able to handle large pieces than suction types and hence well suited to removal of pretreated rock
Hydraulic backhoe	Sensitive to bedding and angle of dip. Similar capabilities to dipper but with faster cycle times. Performance deteriorates sharply with increasing dredging depth
Dipper	Sensitive to bedding and angle of dip. Suited to a wide range of weak rocks including those liable to poor fragmentation and materials that contain boulders. Relatively low rate of production. Tendency to create ridges at edges of cut

NOTE For fragmentation and bulking requirements see Table 21.

9.3.4 Water depth

Apart from the standard water depth limitations, it should be noted that the backhoe is more susceptible to limitation in deep water due to the twisting forces imposed on the boom during the digging part of the dredging cycle.

9.3.5 Depth of excavation

Most dredgers benefit from having a moderate depth of material to excavate. However, the thicker cuts may be more difficult to excavate by backhoe and dipper because these machines operate best by breaking off slabs of rock and thinner slabs are easier to break. Bucket and cutter suction dredgers chip away smaller fragments of rock and benefit from a good depth of cut. Bucket dredgers can work in up to 2 m of material but the optimum depth of cut is very dependent on the nature of material. It should be noted that pretreatment costs per unit volume reduce as the excavation becomes deeper (see **9.5.6**).

9.4 Dredging pretreated rock

Rock may be pretreated to enable dredgers to excavate it (see **9.5**). The degree of pretreatment required depends on the type, power and size of the dredger and the form and strength of the rock. The two most important factors in determining the ease of dredging pretreated rock are the fragmentation and the bulking.

Fragmentation varies considerably in broken rock and the average size of fragment is of little importance. Since the maximum size dredgeable is usually controlled by the dimensions of the machine, it is important that most of the rock is below a specified size. The D_{95} and D_{99} of the rock are more important than the D_{50}. It is prudent to have plant available to dredge the oversize fragments or to comminute them to within the acceptable size range. Whether or not it is necessary to provide additional plant depends on the size of the project.

Table 21 provides guidance on the relative importance of fragmentation required for the various dredgers.

9.5 Pretreatment

9.5.1 General

Pretreatment of rock prior to dredging is necessary for most igneous and metamorphic rocks and also for strong sedimentary rocks. The necessity for pretreatment depends on the rock state and the type of dredger to be used. The decision to pretreat may also be affected by the quantity to be dredged. For small quantities, it may be more economic to pretreat and dredge with a smaller, more easily mobilized dredger than to bring in a larger dredger that could dredge without pretreatment.

Table 21 — Fragmentation and bulking of rock normally required to allow satisfactory dredging

Dredger type	Fragmentation required (diameter refers to D_{95})	Bulking required
		%
Cutter suction 800 mm suction	Up to 300 mm. The smaller the better for pumping. Large pieces are unacceptable	10 to 15
Bucket wheel 700 mm suction	Up to 150 mm. The smaller the better for pumping. Large pieces are unacceptable	15 to 20
Bucket 650 L rock buckets	Up to 600 mm. Some larger pieces are acceptable if not too large to pass through the well	10 to 20
Dipper 5 m^3 bucket	Up to 800 mm. Larger pieces can be raised depending upon bucket size and power available	10 to 20
Backhoe 3 m^3 rock bucket	Up to 500 mm. Larger pieces in isolation are acceptable depending on bucket size and power available	10 to 20
Grab pontoon 5 m^3 rock bucket	Up to 500 mm with occasional larger pieces	20 to 30
Trailer suction 800 mm suction	Less than 100 mm. Any significant occurrence of larger pieces is liable to block draghead.	25 to 40

NOTE 1 The table refers to pretreatment by drilling and blasting.
NOTE 2 Bulking means increase in rock volume (or heave) from voids resulting from the explosion.
NOTE 3 Suction and bucket sizes under “Dredger type” are not absolute limits, but operation with smaller sizes may be difficult.

Pretreatment may be applied in various forms including the following:

a) percussion or rock breaking;
b) rock ripping;
c) rock splitting;
d) surface blasting;
e) drilling and blasting.

The pretreatment method selected depends on the volume and thickness of rock and the fragmentation and bulking required to enable the dredger to excavate the material.

Pretreatment methods in items a) to c) may be applied in cases where the use of explosives is not permitted. The methods in items d) and e) are more common.

9.5.2 Percussion or rock breaking

Rock breaking by percussive methods is one of the oldest forms of pretreatment. In its simplest form, it consists of dropping a heavy needle or chisel, weighing from 5 t to 30 t, vertically on the rock. This method is slow (see **A.21**). More sophisticated power-driven rock breakers are fitted with pneumatic or hydraulic rock hammers, which drive a chisel into the formation.

9.5.3 Rock ripping

Ripping may be carried out by modifying the equipment on a dredger to take one or more ripper teeth in place of, or attached to, the standard excavating unit. Examples of this are the single teeth that may be fitted in place of the bucket(s) on hydraulic backhoe or bucket dredgers and the rows of teeth that may be attached to the draghead of trailing suction hopper dredgers.

Pretreatment by rock ripping is usually slow. For backhoe dredgers production deteriorates sharply with increasing water depth.

9.5.4 Rock splitting

As an alternative to using high explosives, it is possible to split rock by mechanical, hydraulic or chemical means in a drilled borehole. These are relatively laborious methods and are not commonly used. Special situations in which the use of such methods may be advantageous include those where the use of explosives is not allowed and those where particular precision is required.

9.5.5 Surface blasting

NOTE Before explosives are used, reference should be made to BS 5607. See also **10.5**.

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

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

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

Charges are laid to a regular pattern and would be 10 kg to 25 kg in mass in a typical case. The spacing of the pattern would be varied to suit the rock type and formation but would usually give a blasting ratio (mass of explosive to area of rock blasted) of 3.5 kg/m^2 to 7 kg/m^2.

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

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

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

9.5.6 Drilling and blasting

9.5.6.1 *General*

Drilling and blasting is the most widely used method of pretreatment for bulk rock excavation. It consists essentially of drilling holes in the rock to a regular, predetermined pattern and depth, charging them with explosives and detonating a group of charges, either instantaneously or separated by millisecond delay intervals. The drill holes are usually vertical, but horizontal drilling can be successfully employed in special circumstances.

Drilling is usually carried out from a floating or elevated pontoon (see **A.21**), but for very small or otherwise inaccessible areas it can be performed by divers. The drilling pattern is primarily controlled by the amount of explosive required to give the desired fragmentation of the rock and the diameter of the holes drilled.

A typical drilling pontoon and a typical drilling platform are shown in Figure 31 and Figure 32 respectively.

9.5.6.2 *Blast ratio*

The amount of explosive required may be expressed by reference to the blast ratio B (in kg/m^3), which is calculated from the equation:

$$B = \frac{w}{LvS}$$

where

w = charge per hole (in kg);

L = drilled length of hole (in m);

v = burden (distance between rows of holes) (in m);

S = spacing (distance between holes) (in m).

Blast ratios normally range from 0.45 kg/m^3 to 2 kg/m^3 depending on the rock type and formation and the fragmentation required.

9.5.6.3 *Drilling patterns*

Drilling patterns should be such that the burden and spacing are similar, and holes should be drilled beneath the design level by an amount equal to the greater of the burden or the spacing. This overdrilling is necessary to ensure that fragmentation occurs to the design level.

The pattern itself can be rectangular or triangular, depending on how the pontoon and drills are moved (see Figure 33). A triangular pattern is likely to give more consistent fragmentation since the maximum distance that the rock can be from any blasthole is reduced for any pattern area. However, rectangular patterns are often used because they are easier to execute and may be more appropriate for specific purposes, such as pretreatment for trenches. Common drilling patterns and illustration of the terminology used are shown in Figure 33.

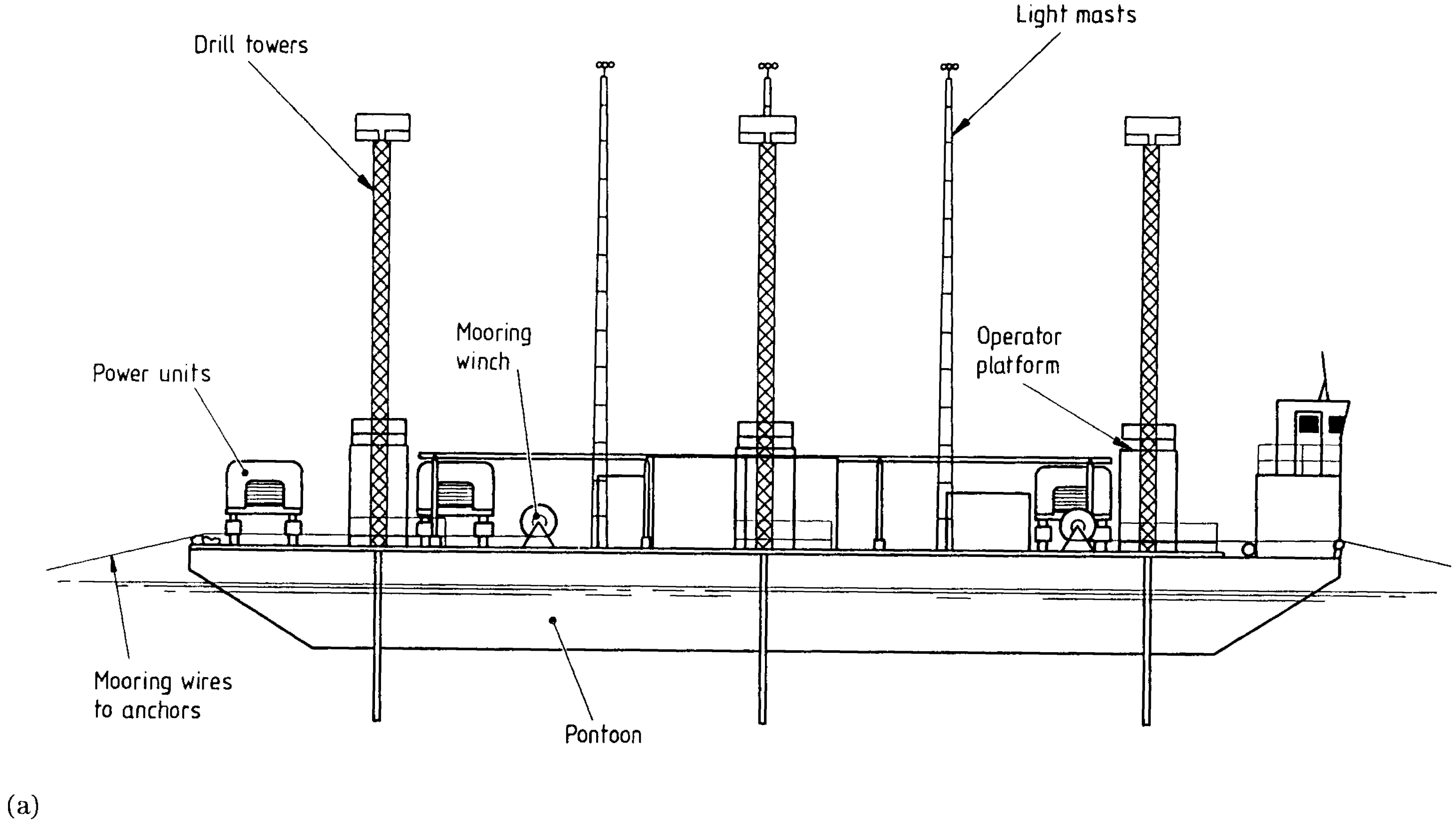
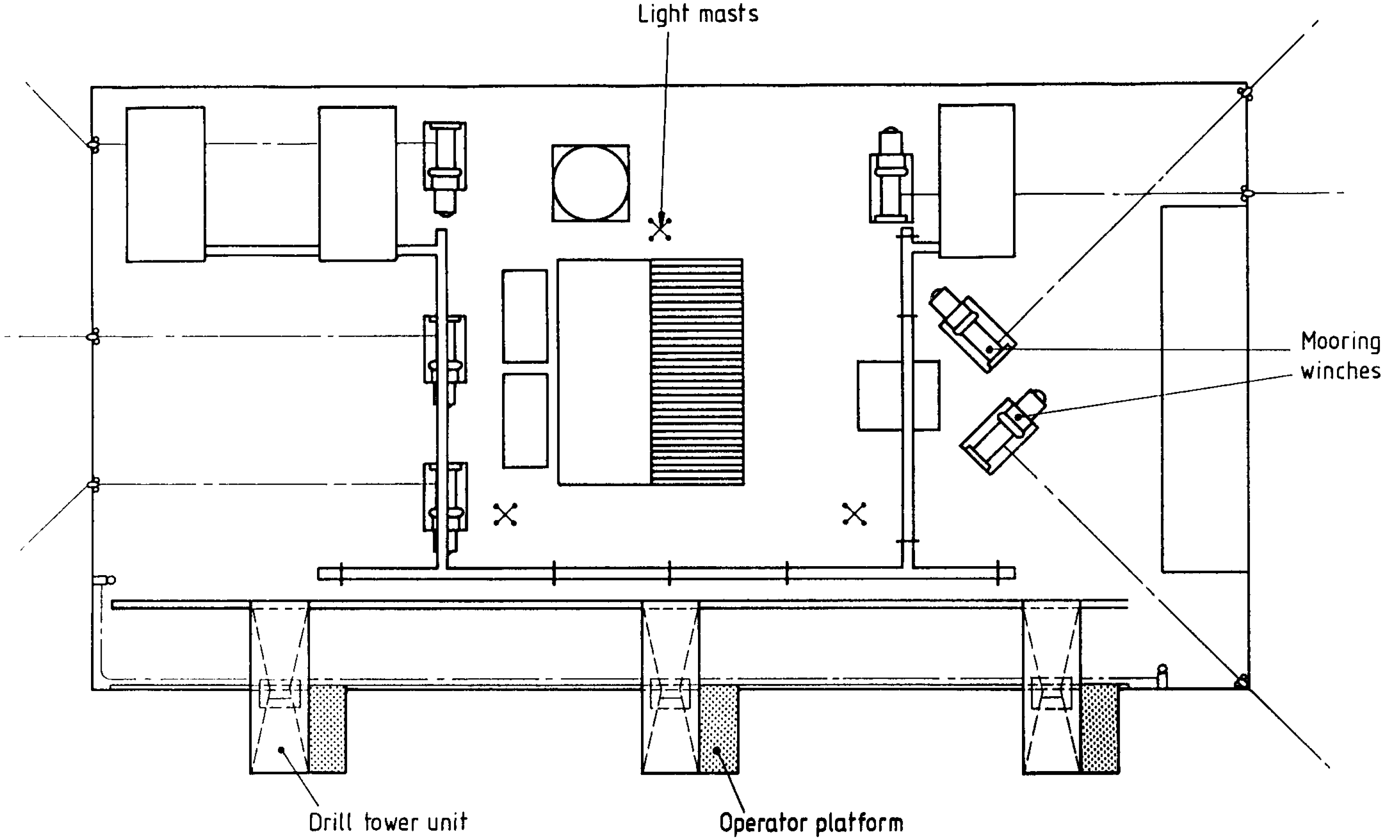


Figure 31 — Typical over-side three-tower floating drilling pontoon with winch location



(b)

Figure 31 — Typical over-side three-tower floating drilling pontoon with winch location *(concluded)*

9.5.6.4 ***Extent of drilling and blasting***

Drilling and blasting should extend to a point outside the rock dredging area (see Figure 34). The necessity to blast outside the periphery of the delineated rock dredging area depends on the behaviour of the rock during blasting. It is possible for rock adjoining the blasted area to be cracked and to heave by bulking so that the rock surface moves upwards.

9.5.6.5 ***Depth of rock***

The depth of rock which may be blasted in one cut will depend on the site conditions. As rock thickness increases it is important to take increased care with respect to deviation from vertical drilling. Excessive deviation will affect the burden and spacing of the charges and thus the fragmentation. It may also cause sympathetic detonation between holes (see **9.6.1**).

It should be noted that very small thicknesses of rock still require the same overdrilling and charging as large thicknesses, thus the cost of drilling and blasting a thin layer can be extremely high.

The sequence of overburden drilling is shown in Figure 35.

9.5.6.6 ***Drilling systems***

Drilling for underwater blasting is carried out using either of the following methods, although that described in item a) is the more common.

a) *Sea surface operations.* Drilling operations from the sea surface are carried out from floating or elevated pontoons. Pretreatment pontoons are described in **A.21**. In shallow water areas, land-based equipment may be used from a temporary working surface formed by filling the area with material to a level just above high water. The drilling system used from pontoons or on land is described in **A.21**.

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

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

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

9.6 Explosives and accessories

9.6.1 Explosives

For underwater use, explosives have to be of the high strength gelatinous or slurry type. For efficiency and safety, the explosive has to be sufficiently waterproof to remain underwater for up to 24 h without being unduly affected by the water, yet, after immersion for a long period, the explosive should have been rendered inert. The chosen explosive has to be compatible with the method of initiation selected.

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

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

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

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

9.6.2 Accessories

Careful consideration has to be given to initiating systems. The two main types of initiating systems are detonating cords and long lead electrical detonators.

When using detonating cord it is essential that it passes through all of the cartidges being used in a particular borehole. The cords from each borehole should be connected together at the surface. Care has to be taken that cords do not cross as a cord may be severed before it has propagated the detonation.

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

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

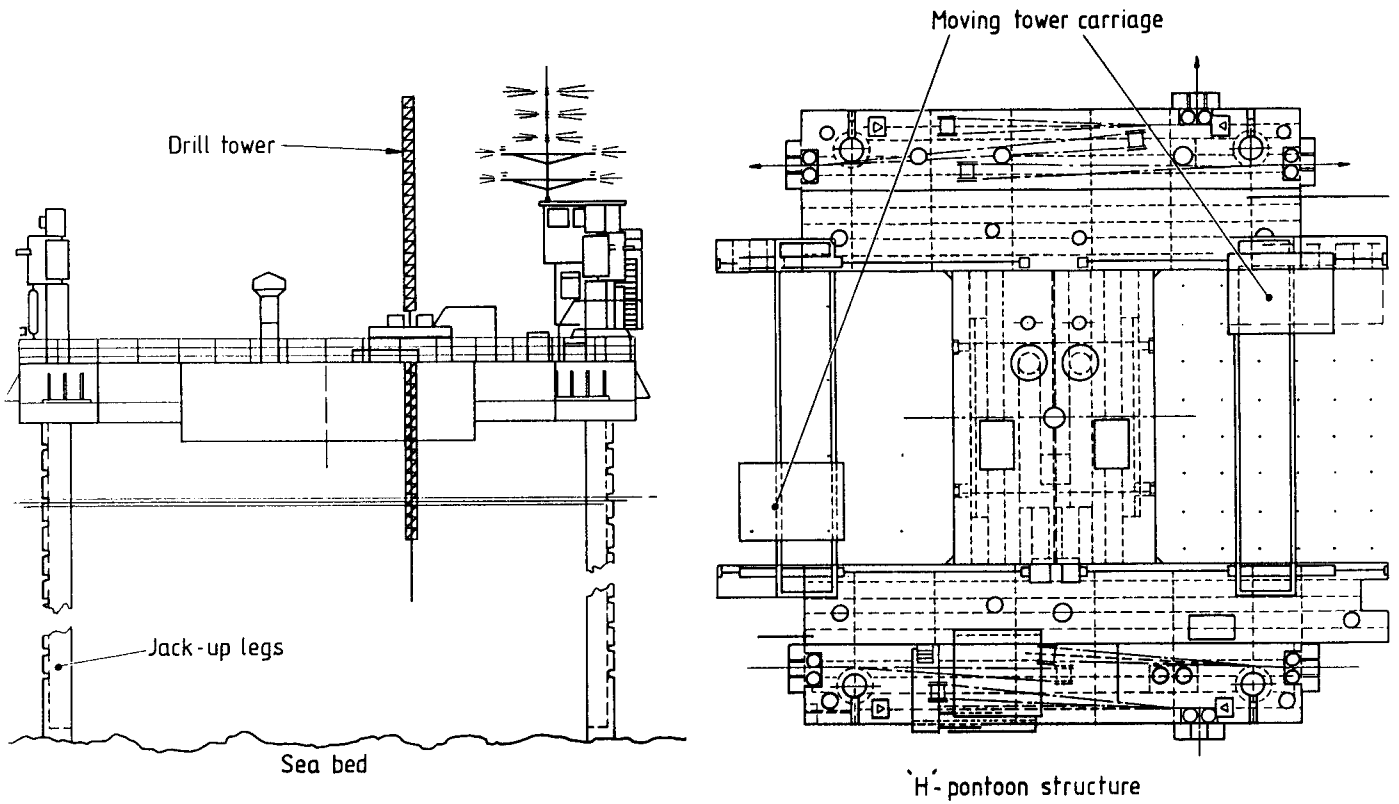


Figure 32 — Self-elevating H-configuration drilling platform

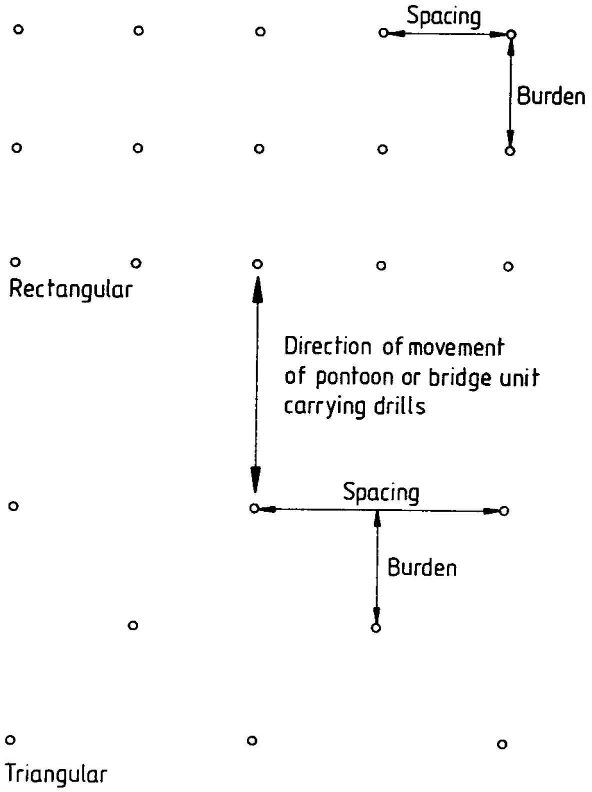


Figure 33 — Common pretreatment drilling patterns and terminology

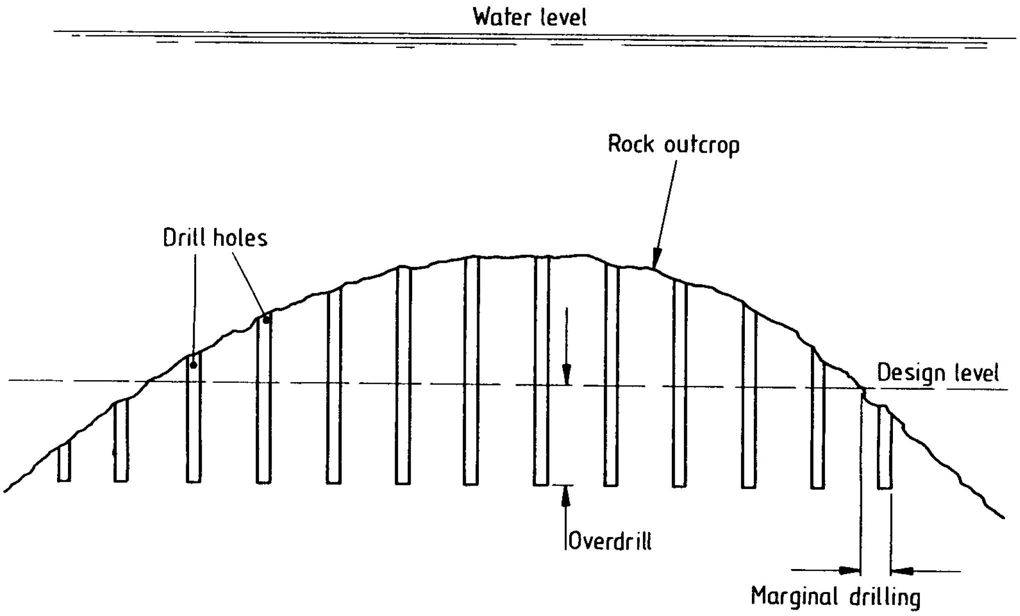


Figure 34 — Example of the need to extend drilling and pretreatment beyond the depth and extent of required dredging

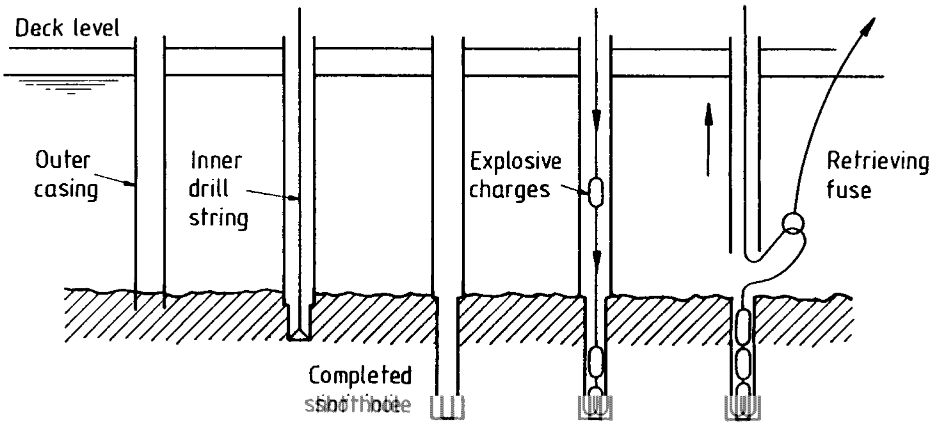


Figure 35 — Illustration of sequence of the overburden drilling method

Section 10. Environmental considerations

10.1 Introduction

Careful consideration should be given to the potential effects of dredging on the immediate environment to minimize adverse effects. An assessment of the environmental impact should be made before commencing any dredging works. If there is an unacceptable degree of uncertainty expert advice should be sought.

The importance of the effects of dredging on the local environment depends largely upon the nature of that environment.

The potential effects of dredging may include water turbidity, the movement and deposition of fine sediments (which may occasionally be contaminated by harmful matter), noise, shock or vibration. These matters are dealt with in **10.2** to **10.6**.

10.2 Release of fines

Fines are likely to become raised and suspended in the water column as the result of any kind of dredging activity.

There are processes, such as agitation dredging (see **3.6.6**), which deliberately cause the suspension of fine materials. The subsequent dispersion of suspended material depends upon the local pattern of water movement (see **3.6.5**).

In areas in which fine materials are normally contained within a coarser or cemented material, such as with silty sands or chalk, dredging may release fines into an environment in which they are not usually present in significant quantities. This may have no adverse effects. However, if the quantities released and deposited are large, short-term or even permanent damage to marine life may result.

Large concentrations of fines may also have an adverse effect on local installations that rely upon the abstraction of water for their operation, e.g. power station cooling systems and fish farms.

Provided that appropriate precautions are taken, it is possible to avoid the release of excessive quantities of fine material in most cases.

If appropriate, model studies should be made to estimate the pattern of distribution of fines and the potential consequences on the local environment, and a monitoring programme should be initiated during the works.

10.3 Release of toxins

Significant concentrations of harmful substances are generally most likely to occur within, or downstream of, industrialized areas that are subject to industrial pollution.

Harmful substances are most likely to become trapped within deposits of fine sediment. Some substances become locked onto the sediment particles and remain attached despite disturbance by dredging. Other substances, such as some heavy metals, may be released as a result of dredging.

The important requirement for dredging polluted material is to minimize the volume of material released into suspension, and therefore any form of agitation dredging is unacceptable. The overflowing of hoppers should be minimized or prevented. Closed systems in which the dredged material is disposed of by pumping into a carefully controlled containment area may present the fewest problems, but dumping at sea under expert advice may be another option that causes minimum environmental damage.

10.4 Noise

Noise that arises from dredging operations is not normally excessive. However, the frequency of noise emission from certain types of plant, such as the bucket chain dredger (see **4.9**), may be objectionable in the close proximity of residential areas.

It is common practice for dredging plant to be operated for 24 h a day. Noise levels that are acceptable during normal working hours may be unacceptable at night.

It is not possible to give reliable guidelines as to what is an acceptable level of noise emission but the Control of Pollution Act 1974 gives guidance of levels acceptable to local authorities in the UK (see also BS 5228-1).

10.5 Shock and vibration

10.5.1 General

Shock and vibration are of consequence only when explosives are used for the pretreatment of rock (see **9.5**) or the removal of wrecks.

Explosive charges detonated under water cause a waterborne shock wave and ground vibrations, both of which should be studied prior to explosives being used on site. It may be necessary to restrict their intensity to certain levels for environmental or safety reasons, and marine life may also be affected. In such cases, the method of dredging should be adapted to minimize the effects. This might be done, for example, by reducing the size of cut made during each cycle.

Since the intensity and effect of an underwater explosion is site specific it is recommended that specialist advice be sought.

Direct dredging of rock in the close proximity of structures may cause some vibration within the structure or its foundations but this is normally only of consequence if the structure or foundation is particularly sensitive.

10.5.2 Waterborne shock waves

Waterborne shock waves from explosions freely suspended in water are characterized by a rapid rise to a peak overpressure, followed by a slower return to normal pressure. Further shock waves of reduced intensity may follow due to the expansion and collapse of the bubble of explosive gases released to the water during the explosion. The peak overpressure and the rate at which it occurs (the impulse) are important values to be determined.

The effect that peak overpressure and impulse have on vessels, marine life and humans has been the subject of considerable research and, as yet, no generally accepted guide lines have been formalized relating to safe distances between subjects and explosives detonated underwater.

10.5.3 Groundborne vibrations

Groundborne vibrations are transmitted from the site of an explosion through soil and rock to nearby structures. The amplitude, frequency and propagation velocity of the vibrations depend on the mass of explosives detonated instantaneously and the characteristics of the site.

Groundbourne vibrations may cause distress to persons residing or working near the site where blasting is being carried out and this might cause the activity to be classed as a nuisance. If the groundborne vibrations are sufficiently severe they may cause superficial or even structural damage to buildings. The estimation of vibration levels which might cause these problems is a complex matter and it is recommended that specialist advice be sought.

Vibration levels on site may be reduced by reducing charge weights for instantaneous shots or by using high detonator delay numbers giving appropriate delay intervals.

10.6 Fisheries

Mobile fish populations are not normally harmed by dredging unless, as a consequence of dredging or its effects, feeding grounds are extensively damaged or destroyed.

Immobile populations, such as shellfish or fish spawn, can be harmed both directly by dredging within the area or residence and indirectly by a reduction of light or oxygen as the result of increased water turbidity or the blanket deposition of fines (see **10.2**).

All forms of marine life may be affected by the release of toxins in significant quantities, but harmful pollutants are generally less likely to be present in important fishing areas.

The following departments can provide guidance on the location and extent of important fisheries of all kinds.

a) In England and Wales, the Ministry of Agriculture, Fisheries and Food.

b) In Scotland, the Department of Agriculture and Fisheries for Scotland.

c) In Northern Ireland, the Ministry of Agriculture.

Before dredging works are commenced, the location of local fisheries should be identified and the potential effects of dredging on those fishcries should be assessed. Care should be taken that dredging which may destroy the food source or habitat of the fisheries is not carried out. It may be possible to adopt methods of dredging that are not unreasonably harmful to fisheries. In some instances, this results in higher dredging costs.

So far as the dredging of aggregates is concerned, attention is drawn to the current code of practice for the winning of aggregates [28], agreed between the fishing industry and the aggregate dredging industry.

Section 11. Site control of dredging operations

11.1 Introduction

Dredging is a civil engineering activity that is normally carried out afloat. The need for setting out and dimensional control exists as it does on land, but the same methods can not normally be employed. Communications require special consideration because access to dredging plant is only possible by boat under favourable sea conditions. Radio communications are therefore important.

The working hours on dredging works, particularly on contract dredging, are normally far longer than those on most land-based activities. The control and management of dredging works has to provide for these special conditions.

11.2 Vertical control

It is usual for vertical measurements to be made relative to the water surface, which is in turn related to a datum. The datum may be the national land survey datum, such as Ordnance Datum Newlyn in the UK, or in ports and harbours may be the admiralty chart datum, which is normally the level of the lowest astronomical tide. The difficulty of using chart datum for engineering works is that it is not a uniform datum. Chart datum serves well for shipping in that it provides a relation between sea bed level and tide level that is approximately constant throughout coastal regions and allows for the wide tidal variations that can occur. Great care should be exercised in the choice of datum to be used, particularly when dredging works extend over long distances or traverse areas of significant tidal variation. Some ports and harbours use a purely local datum.

The measurement of sea level or water level may be made by a variety of methods (see BS 6349-1).

11.3 Horizontal control

The position of stationary or slow moving dredgers may be simply controlled by reference to fixed shore marks, which form transit lines.

Position may also be checked from the shore by theodolites or a theodolite-mounted electronic distance measurer (EDM). Independent shore-based methods do not provide immediate information concerning position to the Master of the dredger. They may also be inadequate at night or during poor visibility.

For trenches or straight channels that are reasonably close inshore, position along a line can be determined by reference to a shore-based laser marking the centreline of dredging, with additional lasers of different colours marking the cut extremeties. Alternatively, shore-based transit marks can be used.

The more common methods of horizontal positioning for dredging plant are the range-range and range-bearing systems described in relation to a hydrographic survey in **2.2.5** and BS 6349-1:1984.

11.4 Communications

For effective management of dredging operations, good, reliable communications are necessary. These can normally only be achieved by means of radio.

Most large dredging plant and ancillary plant capable of independent navigation are equipped with radio that operates in the marine band frequencies. To achieve satisfactory overall communications, it is necessary to incorporate small craft and interdependent shore-based operations, such as reclamation area supervision, into the network. This normally requires an independent, licensed VHF wavelength. Licensing in the UK is administered by Licensing Section, Radio Regulatory Division, of the Department of Trade and Industry, Waterloo Bridge House, Waterloo Road, London SE1. In addition to providing overall management control, such systems perform an important safety function.

11.5 Project management and supervision

The major differences between dredging works and normal onshore civil engineering construction are the marine environment and the practice of continuous working, which is common in the dredging industry. Work commonly continues on a 24 h basis for 7 days per week.

Management and supervision should therefore be structured not only to provide appropriate supervision and survey control but also, in the case of operations management, to provide for the maintenance, repair and supply of the dredging and ancillary plant.

For exposed sites, management should also maintain a close watch on changing weather conditions in order that appropriate precautionary action may then be initiated before deteriorating weather conditions place floating plant in jeopardy.

11.6 Safety

It is essential to give proper consideration to all matters of safety, recognizing that there are special and particular risks associated with operations over water.

Section 12. Methods of measurement of work

12.1 Introduction

The specification of hydrographic survey work for dredging is covered in detail in section 2 and in [2]. The objective of this section is to highlight those methods specific to the measurement of dredging work.

12.2 Bathymetric survey of dredging area

Bathymetry (see **2.2.2**) is the determination of sea bed levels, normally by echo sounding (see **2.2.3.2**). For measurement it is necessary to have sea bed levels taken both before and after dredging. Survey lines should not normally be at more than 25 m centres.

Overall correctness depends on the accuracy of measurement and on how representative of the sea bed are the levels taken.

The frequency of echo sounder used should be suited to the particular conditions and thereafter should be the same for all related surveys on the same site.

If it is important to determine the surface of even very soft sediments, a high frequency echo sounder should be used; otherwise a lower frequency may be applicable. Penetration of the echo sounder signal into the sea bed is strongly influenced by sea bed density and so may be variable. An approximate guide to penetration is given in Table 2.

During echo sounding, tide levels should be recorded close to the survey area, either continuously or at intervals not normally exceeding 15 min.

Survey lines on consecutive surveys should preferably be sailed in the same direction. Normally, speed of the survey vessel over the ground should be the minimum that is compatible with maintaining reasonable and safe steerage. The speed should be as nearly constant as is practicable when sounding is in progress, although this may not always be possible, particularly when lines terminate at structures or in shallow water. When variation in speed is unavoidable the interval between position fixes should be reduced as appropriate.

Position, whether determined by electronic or optical methods, should be regularly checked by reference to onshore transit marks at some point along the survey line.

As far as possible, steep slopes should be crossed at approximately right angles and at constant speed.

Sounding lines should extend beyond limits of the required survey area by a reasonable margin.

If automated survey systems, which include digitized echo sounder records, are used, simultaneous analogue records should also be made.

During plotting, a random manual interpretation of the analogue record should be made and plotted for comparison with the automatic plot or plot made from digitized data.

12.3 Land survey of reclamation or filling area

For areas of proposed filling for land reclamation that are above mean sea level, or where the water is too shallow for hydrographic survey work, normal land survey methods should be used.

Prior to filling, surveys should be made on lines at centres of between 10 m and 25 m, depending upon the variability of local ground levels.

If the ground upon which filling is to take place is soft or is underlaid by weak, compressible deposits, settlement beacons or plates should be installed on a suitable grid before filling commences. Settlement beacons are very vulnerable to disturbance during filling and should be of substantial construction.

An alternative to the use of beacons for recording settlement is the installation of flat concrete slabs or steel plates prior to filling. These have to be accurately placed and secured on a regular grid over the area to be filled. On completion of filling, the level of the plate can be determined by probing through the fill.

The computation of quantities of filling is simplified if the post filling survey is made on the same lines or grid as the initial survey.

12.4 Navigation channels

For measurement purposes, navigation channels should be surveyed using a narrow beam echo sounder with a transducer beam angle of less than 10°. Cross section lines should be made at close centres with additional longitudinal lines to prove minimal navigable depth. A narrow beam echo sounder produces more accurate cross sections for measurement purposes but is less suitable for the identification of high spots.

Survey lines should extend well beyond the anticipated top of the finished side slopes on both predredged and post-dredged surveys. If range-range electronic position fixing systems are employed, it is preferable that one station should be located not less than 500 m outside the survey area on, or approximately on, the channel centreline. If possible, a second station should be located not less than 1 000 m outside the channel survey area in a position such that the angle of intersection of range arcs is close to 90° and never less than 60° (see **2.2.5.3**). Long or meandering channels require a number of different shore station positions. The same station positions should be used for predredged and post-dredged surveys.

If possible, a position along each line should be checked against the crossing of a shore transit line. Alternatively, a range-finder device can be used to provide the necessary check. Some range-finder instruments can be used to measure off any vertical hard surface, such as a quay wall, while others require a special reflector (preferred). Both types can provide significantly greater accuracy than range-range or range-bearing methods (see **2.2.5.4**) over short distances.

For the accurate survey of very narrow or steep-sided channels see **12.5**.

12.5 Trenches

The accurate measurement of trenches requires exceptional care. The echo sounder transducer beam angle should be not greater than 5°.

The position along the trench may be measured by means of a range system with a single shore station positioned on the trench centreline. Alternatively, a shore-based range-bearing system may be used and, for short trenches close inshore, may provide a reasonably accurate position across the trench.

If a range-range system is used, difficulty may arise in locating the shore stations to provide good range arc intersection geometry. Unless station positions that provide good geometry can be established the range-range system should not be employed.

To determine accurate position across the trench, shore-based lasers (see **2.2.5.5**) or transit marks (relatively short, trenches only) may provide a more positive and accurate method.

When electronic position systems are used, it is advantageous if they are used in conjunction with automatic data logging equipment in order that ranges or range and bearing can be read and logged at very short intervals. It may not be possible to read ranges manually at sufficiently short intervals to produce a true cross section of the trench. The importance of this depends on the particular site conditions. If the speed and line of the survey vessel are approximately constant throughout the line, manual fixing may provide satisfactory results.

All cross section lines should be sailed in two directions, approximately at right angles to the trench, and any difference in cross section due to echo sounder beam angle or unavoidable positional errors should be averaged out.

Where natural sediment movement may result in rapid trench infilling, repeat surveys should be made at regular intervals, the position of all survey lines remaining consistent.

12.6 Tolerances

It is common practice, but is not essential, to specify tolerances that will be included in measurement for payment purposes. Some realistic working tolerance is essential (see **3.3** to **3.4**).

The method of payment for quantities dredged from within these tolerances depends on local and commercial considerations.

12.7 Pretreatment areas

Pretreatment normally extends outside the area from which rock has to be removed (see **9.5.6.4**).

Payment is normally made on a square-metre basis for a given depth of fragmentation.

The measurement areas covered by pretreatment should be determined by regularly fixing the position of the pretreatment pontoon during each drilling pattern, or at the beginning and end of each sequence of pontoon movement.

The pontoon position may be fixed by shore-based triangulation using optical instruments or shore-based range and bearing systems (see **2.2.5.4**).

Alternatively, position can be determined from the pontoon by means of a sextant (see **2.2.5.2**) and suitable shore marks. In this case, accuracy is improved if shore transits are erected on the centreline of each area of pretreatment. Electronic range-range systems may also be used (see **2.2.5.3**).

12.8 Boulders

Boulders present special measurement problems.

Relatively small numbers of boulders within a matrix of otherwise easily dredged material may seriously reduce production (see **6.9**).

It is normal to measure boulders individually with payment being made by number in a particular size range, but it is not recommended that boulders with a maximum dimension less than 350 mm are measured individually.

The recommended system of measurement is on the basis of a count of boulders recovered within specified size ranges. In each case, the maximum dimension describes the size. Boulders that are not recovered but are swept aside or buried can not be measured. In this case, payment on the basis of time lost may be more appropriate.

12.9 Quantity computations

The limited accuracy that is possible with normal methods of hydrographic survey is reflected in the accuracy with which quantities can be computed. Over large, relatively flat areas of cut or fill, which are common in dredging works, consistent errors of a few centimetres in depth may result in serious errors in quantity, particularly when the overall depth to be removed by dredging is small. Depth measurement to within 0.10 m accuracy is not normally possible.

12.10 Hopper measurement

Hopper measurement involves the estimation of the solids contained in the loaded hopper of a barge or trailing suction hopper dredger (see **4.2**).

Although widely used, the method rarely provides an accurate reflection of quantities removed from the sea bed [38] and should only be used when measurement on the sea bed by survey is not practical.

For granular materials, which quickly settle out of suspension, the hopper contents may be determined by taking account of a number of soundings from a fixed reference level to the surface of the solids load. Soundings should be taken at not less than five points on each side of the hopper.

The average surface level, obtained by adding all measurements and dividing by the number of measurements, relates to a particular filled volume, as determined from the official hopper calibration (ullage tables) for the vessel.

If the dredged material contains significant quantities of fines, there will be a vertical density gradient within the hopper load. If water is retained within the hopper, the surface density will be close to 1 t/m^3 and, in mixed materials, may exceed 2 t/m^3 at the bottom of the hopper. This makes the accurate determination of hopper contents very difficult.

An approximate quantity can be determined by sounding to the surface of the solids, as described for granular materials, and computing that volume. The remaining volume of suspended or very loose solids can be estimated in a variety of ways. The most suitable is to use a density meter (see **2.2.4**) to determine the vertical density profile. Alternatively, samples can be recovered from various depths within the hopper and analysed in the laboratory to determine the solids content or density (see Appendix B).

Hopper measurement takes no account of material removed by agitation and so may seriously underestimate the true production achieved. The displacement of the dredger is not easily measured and may vary with speed and may be altered in time by changes in fuel and water load, etc.

12.11 Measurement by instrumentation

The solids production of hydraulic dredgers, such as the trailing suction hopper dredger (see **4.2**), cutter suction dredger (see **4.4**) and suction dredger (see **4.6**), is given by the integration with time of mixture flow and solids concentration.

Most modern hydraulic dredgers are fitted with velocity meters or flowmeters and density meters in the discharge pipeline. Unfortunately, the accuracy of the individual instruments is currently no better than ± 10 % and hence the overall accuracy is less. Errors are greatest in mixed materials when flow is not uniform. Measurement of density and velocity may then be subject to serious error.

When operations on a particular site are prolonged and the dredged material is fairly consistent, a correlation between the production recorded by instruments and by survey may be possible. Thereafter, instrument readings can be used to estimate production between progress surveys.

12.12 Bar sweeps

The use of echo sounders to prove post-dredging depth, even in conjunction with side-scan sonar, may not be sufficient when depth is critical, such as in areas containing rock or boulders.

The usual method employed when the proving of minimum depth is important is that known as "bar sweeping".

Appendix A Operational aspects of dredging plant

A.1 Introduction

By the careful and informed design and specification of dredging work the variety of plant required may be reduced, or plant used may be operated at greater efficiency. The following information, which is supplementary to that contained in section 4 includes a brief guide to the factors affecting production.

Overall production is given by the product of the average hourly production and the number of productive hours. Productive hours, more commonly referred to as "effective hours", are the theoretical hours that the dredging plant is available to work less any lost time. Time may be lost for many reasons and the main cause of lost time may be different for different types of plant or for different working conditions. The most common causes of lost time are as follows:

a) weather;

b) sea conditions;

c) mechanical breakdown;

d) maintenance;

e) suction intake blockages;

f) tide levels;

g) adverse currents;

h) shipping priority;

i) bunkering, victualling and crew changes.

In special circumstances land-based plant may be used for dredging but these are not described here.

A.2 Trailing suction hopper dredger

NOTE See **4.2**.

A.2.1 *General*

The trailing suction hopper dredger is a dredger that dredges while moving freely. It is therefore very well suited to the dredging of shipping channels and is widely used for a range of maintenance dredging applications and capital works.

A.2.2 *Method of operation*

The important features of the trailing suction hopper dredger are illustrated in Figure 12.

A large proportion of the internal space of the ship is given over to the provision of hopper space in which the dredged spoil is loaded by one or two (very occasionally four) large centrifugal pumps. The pumps may be fitted inboard or may be fitted in the trailing suction pipe(s). The suction pipe is stowed inboard when the ship is in transit between the dredging site and the dump site.

Within the hopper, solids in the pumped mixture settle out of suspension and the supernatant water is discharged via an overflow arrangement. Adjustment of the overflow level allows some degree of control over the particle size of material retained in the hopper. Very fine materials may be slow to settle out of suspension and in such materials no increase in hopper load is achieved by continued pumping beyond the time of overflow, with the overflow at the highest level. In coarse, heavy materials it may not be possible to carry a full hopper load and the overflow weir level has to then be maintained at a level lower than maximum level.

The production cycle begins when the draghead is lowered into contact with the sea bed and dredging commences, normally at speeds ranging from 1 kn to 4 kn.

The entrainment of solids from the sea bed into the suction flow is achieved mainly by the erosive action of the inflowing mixture. The pressure differential also aids the loosening of granular materials. In difficult materials, such as consolidated sands, stiff clays and very soft rocks, disintegration of the sea bed material may be achieved with, for example, high pressure water jets, scrapers or knives. Dragheads and their attachments are described in **A.2.5.2**.

The suction pipes are normally articulated part way along their length by means of a gimbal construction, which supports a rubber hose connection between the adjoining lengths of rigid suction pipe. This articulation permits both vertical and horizontal movement.

When the hopper is loaded the solids are discharged, usually by bottom dumping at a disposal area (see **3.7.1**). Alternatively, if the solids are to be disposed of onshore or used in land reclamation, connection is made to a pumping main and pump discharge commences. Bottom dumping normally requires only a few minutes, whereas pump discharge may require more than 1 h.

A.2.3 *Production cycle*

The importance of the component parts of the production cycle varies according to the site conditions and requirements. Each component of the production cycle has to be individually assessed for each new work. The main components of the cycle are as follows.

a) *Loading time.* Heavily dependent on the characteristics of the material to be dredged. Difficult to calculate with certainty, experienced judgement very important in assessment. When loading very fine sands, silts and soft clays, it is unlikely that there will be any significant increase in the hopper load achieved by continued pumping beyond the time that hopper overflow commences. In this case, time to load is a function of total pumped flow rate and the hopper capacity. Production depends on the solids concentration in the pumped mixture.

b) *Turning time.* Conditions on some sites may require that one or more turns are made during or on completion of loading. Depends upon site conditions, size of dredger, etc.

c) *Sailing time.* This is given by length of navigation route to disposal site divided by average speed when loaded under prevailing conditions of weather, waves, current, traffic and navigational restrictions.

d) *Time to discharge.* When dumping loose material by bottom dumping, this is only a few minutes. For cohesive material, it depends on design of hopper, method of discharge, character of material, etc. Difficult to calculate with certainty and experienced judgement is very important in assessment.

e) *Time to discharge/pump ashore.* When this is by pumping to shore or filling area, it has to include time to moor, make connection to the discharge pipeline, disconnect when empty and cast off. Actual time to pump discharge hopper depends on length of pipeline, terminal elevation of pipeline, particle size distribution of dredged material and the particular characteristics of the dredger. Can be calculated within reasonable limits given adequate data. Particularly sensitive to size of dredged material.

f) *Sailing time to work site.* Given by length of navigation route divided by average speed when light, under prevailing conditions of weather, waves, current, traffic and navigational restrictions.

Daily production is the sum of the hopper contents for each complete cycle achieved. The number of cycles is given by the total effective hours divided by the average cycle time in hours. For a well-managed dredger with average site conditions and job duration, the lost production time may amount to between 5 % and 25 % of the theoretically available working time. Special site conditions may however result in much higher losses.

A.2.4 *Limiting factors*

There are limits on where the trailing suction hopper dredger can operate and what it can achieve. These vary according to the size and characteristics of the individual dredger but an indication of the extreme limits that apply to economic operation is given in Table 10.

A.2.5 *Ancillary equipment*

A.2.5.1 *General*

The independent operation of the trailing suction hopper dredger does not require a wide range of ancillary equipment. The main variations that may occur concern the draghead and the method of discharge. These are not discussed in detail here, but the main options are covered in **A.2.5.2** and **A.2.5.3**.

A.2.5.2 *Dragheads*

The most common types are the "vizor" and the "Californian". Vizor types are most commonly used for the dredging of soft or loose materials and Californian types are most commonly used in more compact materials, such as sand. Where the bed material is well compacted, water jets may be used to break up the material. The use of a particular type of draghead is not however exclusive to particular materials. Experiment and experienced judgement may be necessary to discover the optimum draghead for particular site conditions. Many shipbuilders, contractors and other users have developed their own dragheads.

NOTE See Table 22.

Table 22 — Dragheads

Type	General application
Fruhling	Silts, soft clays and loose sands
Silt	Silts
Californian	Sands, especially compact sands
Venturi	Sands
Waterjet	Firm sands and medium clays
Active	Medium, firm and stiff clays

A.2.5.3 *Discharge mechanisms*

The trailing suction hopper dredger is normally required to discharge the hopper contents by bottom dumping. This may be achieved via a number of doors in the bottom of the hopper. The doors may be hinged on one edge and restrained by chains or by links attached to hydraulic actuating cylinders. Sealing is achieved by the compression of a rubber or synthetic surround to the door. Hinged doors are susceptible to damage when dumping in shallow water or rough seas and may require up to 2 m more underkeel clearance than sliding doors. These problems are overcome with sliding doors, which are also activated by hydraulic cylinders.

As an alternative to bottom doors, bottom valves can be employed. Bottom valves can be operated in shallow water, but with greater caution than is necessary with sliding doors. Bottom valves are not affected by sea conditions.

All bottom door and valve arrangements present some restriction to the outward flow of the hopper contents. This problem is greatly alleviated by split hull construction (see Figure 13 and Figure 36). With this arrangement the entire hull of the dredger is divided longitudinally. Heavy hinges at deck level join the two halves of the hull and large hydraulic cylinders assist the opening and closing of the two halves during discharge. The system allows the rapid discharge of even the most difficult materials.

Discharge systems suitable for various materials and operating conditions are given in Table 23.

The main dredge pumps are used in the pump discharge operation. A system of special pipework and valves allows the dredge pumps to draw spoil directly from the hopper, rather than via the trailing arm suction pipes. The hopper contents are diluted by means of an auxiliary pump, which draws seawater via a submerged valve in the hull. The main dredge pump suction draws from a pipe or culvert arrangement in the bottom of the hopper well. The flow of spoil into this cavity is controlled by doors or valves set in a false bottom floor to the hopper. On the pressure side of the pumps, special pipework over the side or over the bow of the dredger permits connection to an onshore or floating link pipeline.

All discharge systems, whether bottom dumping or pump discharging, may be assisted by a hopper flushing system, designed to speed the flow of spoil from all areas of the hopper.

A.3 Stationary suction hopper dredger

NOTE See **4.3**.

A.3.1 *General*

Due to the many similarities between the stationary suction hopper dredger and the trailing suction hopper dredger (see **4.2** and **A.2**), only those areas of construction and operation specific to the stationary suction hopper dredger are discussed here.

The stationary suction hopper dredger is the original form of suction hopper dredger from which the trailing suction hopper dredger has evolved. Unlike the trailing suction hopper dredger, the stationary suction hopper dredger does not dredge while under way, but first anchors and then loads the hopper while stationary. This provides a pit in the sea bed in the form of an inverted cone. This method is not well suited to the formation or maintenance of channels or level areas.

Many small dredgers employed exclusively on the winning of concrete aggregates are converted coasters (commonly called “sand suckers”), fitted with unsophisticated dredging equipment. Dedicated aggregate dredgers usually incorporate screening equipment, which permits oversized or undersized material to be rejected and discharged overboard. The type of dredger described here is the modern purpose-built vessel, which may be quite sophisticated, but the basic principles of which are similar to the basic “sand suckers” from which they are derived.

Table 23 — Suitability of hopper discharge systems for various conditions

Condition	Hinged doors	Sliding doors	Bottom valves	Split hull	Pump	Scraper	Grab
Clean silts	1	1	1	1	1	N	3
Most sands	1	1	1	1	1	1	1
Very soft clays	1	1	2	1	2	N	1
Gravels	1	1	1	1	2	1	1
Soft to medium clay	3	3	3	1	N	N	2
Medium or stiff clay	N	N	N	1	N	N	2
Boulders	3	N	N	2	N	N	2
Highly fragmented rock	2	2	2	1	N	2	1
Randomly fragmented rock	2	N	N	1	N	N	1
Materials containing debris	3	2	3	1	3	3	1
Calm sea conditions	1	1	1	1	1	1	1
Rough sea conditions	3	1	1	2	2	3	3
Shallow water	3	2	3	1	2	2	2
Disposal to sea	1	1	1	1	N	N	N
Disposal to reclaim (at quay)	N	N	N	N	1	1	1
Disposal on shore or beach	N	1	3	1	1	N	N

Key

1 = Suitable; 2 = Acceptable; 3 = Marginal; N = Not usually suitable

NOTE 1 Other factors not referred to may influence the choice of hopper discharge system.

NOTE 2 Pump discharge rating assumes discharge via pipeline. Some dredgers also use pump discharge at sea.

NOTE 3 Licence conditions in the UK may prohibit the disposal of boulders, or debris at sea.

NOTE 4 Scraper and grab discharge are usually only used to discharge at a quay or jetty.

A.3.2 *Method of operation*

The important features are shown in Figure 13.

Following arrival at the dredging area, the dredger is anchored and the suction pipe intake is lowered to the sea bed. Loading of the hopper then commences. As the role of the stationary suction hopper dredger is most commonly the winning of granular material for a specific end use, the dredger may also be equipped to load barges that moor alongside. This arrangement has the benefit of increasing the productivity. It is of particular value where the distance from the dredging area to the point of end use for the dredged material is great.

The dredger may be used to remove granular material from beneath unwanted overburden, such as clay or peat. In order to permit this, the suction pipe is articulated and the lower section can be maintained in a vertical attitude. The suction pipe is progressively lowered through the overburden and into the desired granular material. The granular deposit in the region of the suction intake is fluidized by the action of water jets, drawn into the suction intake and from there conveyed to the hopper or to barges alongside. Subject to the in situ properties of the granular deposit being suitable, this method may be employed to dredge material from a considerable depth.

The stationary suction hopper dredger is well suited to the winning of fill or aggregate materials where the sea bed deposits are of substantial thickness or, in the case of the more sophisticated types of dredger, are at considerable depth.

It is also relatively easily moved from site to site under its own power.

A.3.3 *Production cycle*

Only the loading part of the production cycle is significantly different from that of the trailing suction hopper dredge (see **A.2.3**).

Loading time is dependent on the soil characteristics, the dredging depth and the particular dredger. If the dredger is used to load independent hopper barges, loading may be continuous, subject to an adequate supply of barges being available. Loading time can not be accurately calculated and has to be largely judged from experience. The limiting maximum theoretical production and hence minimum loading time can be calculated, given adequate information on the soils.

Daily production is the product of average hourly production and working time. Working time is influenced by similar factors to those that affect the trailing suction hopper dredger, but the stationary suction hopper dredger is normally more sensitive to sea conditions.

A.3.4 *Limiting factors*

There are limits on where the stationary suction hopper dredger can operate and what it can achieve. General guidance to these limitations is given in Table 10.

A.3.5 *Ancillary equipment*

A.3.5.1 *General*

The normally independent operation of the stationary suction hopper dredger does not require a wide range of ancillary equipment. The main variations that may occur concern the suction head and the method of discharge. These are not discussed in detail here but the main options are identified.

A.3.5.2 *Suction heads*

Apart from the particular arrangement of the suction head, various methods may be employed to improve the suction performance, particularly at the greater operating depths. One way in which the limitations of a suction head can be overcome is by mounting a centrifugal dredge pump part way down the submerged pipe. A similar effect can be achieved by mounting a jet pump at the suction end of the pipe. Other refinements may be included to improve the flow of mixture in the intake or to fluidize the deposits in the region of the suction intake. The latter effect is achieved by means of high pressure water jets.

A.3.5.3 *Discharge mechanisms*

A.3.5.3.1 *Bottom discharge*

Bottom discharge mechanisms are the same as for the trailing suction hopper dredger (see **A.2.5.3**).

A.3.5.3.2 *Side discharge booms*

As an alternative to loading the hopper of the dredger, the pumped mixture may be diverted via alternative pressure pipework to side discharge booms. These booms can be swung outboard by means of davits and winches so that they discharge several metres beyond the side of the dredger. At the end of the side booms, diffusers are fitted to minimize turbulence within the hopper of the receiving vessel. The design of diffusers varies greatly, but the most common type consists of a large diameter, horizontal, perforated pipe, mounted at right angles to the direction of flow.

A.4 Cutter suction dredger

NOTE See **4.4**.

A.4.1 *General*

The cutter suction dredger is most often used in works of land reclamation or other hydraulic filling, where its ability to dredge in a wide variety of materials and to transport and deposit, all in a continuous process, is a major advantage.

The disadvantages of the cutter suction dredger include a pronounced sensitivity to sea conditions among all but the largest dredgers, a fairly limited distance through which spoil can be economically conveyed, fairly severe dilution of the dredged spoil, a fairly limited dredging depth and high mobilization costs.

A.4.2 *Method of operation*

The important features of the cutter suction dredger are shown in Figure 14.

The material is cut, dislodged or broken by a powerful crown cutter. The cutter may have plain-edged or toothed blades according to the ground conditions.

The suction pipe, which is usually supported by a steel frame called the ladder, includes a section of heavy reinforced flexible hose immediately prior to its entry through the hull bulkhead, which imparts the necessary flexibility to permit movement. The ladder/suction pipe assembly is normally raised and lowered by a winch, but on some small dredgers the ladder movement may be controlled by hydraulic cylinders.

Generally, on small dredgers, power/distribution is diesel/hydraulic and on larger dredgers it is diesel/electric.

The dredger may be anchored and moved by a system of winches or by spuds and winches. The more common combination of spuds and winches employs two swing winches and two spuds. One spud is located within fixed gates at the opposite end of the pontoon to the cutter (normally the stern). The other "working" spud may also be fixed at the stern or may be tilting or may be mounted in a carriage that can move longitudinally on the centreline of the dredger. The carriage typically has an overall movement of 6 m and is powered by a hydraulic cylinder.

When dredging, the working spud is "spudded in" to the sea bed. The underside of the cutter is maintained at a level just below the desired finish level and traversed across the arc-shaped face, with the dredger rotating about the working spud, by hauling in on one swing winch and paying out on the other. When a large depth of material is to be removed, several cuts across the face may be necessary before the final level is achieved. In loose materials, the depth (or thickness) of cut may be several times the diameter of the cutterhead. In stiff clays or rock, the depth of cut may be less than the diameter of the cutterhead.

Upon completion of a cut or series of cuts to the desired level, the dredger is advanced into the face a distance approximately equal to the height (front to back) of the cutterhead. This advance may be achieved by stepping with fixed spuds (see Figure 15), tilting of the working spud or advancing the carriage holding the working spud, depending upon the particular system employed. The procedure is repeated in each production cycle. At longer intervals it is necessary to move anchors as the original positions fall too far astern. The anchor line should normally not exceed an angle of 45° to the cut centreline.

A.4.3 *Production cycle*

The relative importance of the component parts of the production cycle varies according to the site conditions and requirements. For example, stepping ahead time may be relatively unimportant when dredging to remove a large thickness of hard material or may be the limiting factor when removing a small thickness of soft material. Ultimately, the production rate is influenced by one of the following four factors:

a) the head available for pumping;

b) the horsepower available for pumping;

c) the ability of the cutter to break down the material; and

d) the rate at which the dredger can be advanced into the face.

The main components of the cycle are as follows.

1) *Traverse face.* The speed of traverse is governed by the characteristics of the material to be dredged, the depth of cut, the pumping distance and the dredging depth. These govern hauling winch speed and cutter revolutions.

2) *Time to traverse face.* The time to traverse face is given approximately by dividing the length of face (in metres) by the winch speed (in metres per minute). The time of traverse is also affected by the direction of traverse, due to the fact that the crown cutter is normally most efficient when undercutting. In hard materials, overcutting may be impractical, in which case a nonproductive return swing is necessary.

3) *Number of cuts.* The number of cuts across the face to produce the finished depth is dependent on the thickness of the material to be removed and the depth of each cut. The depth of each cut is governed by characteristics of the material to be dredged. Normally, one final cleaning up cut is required. The number of cuts is given by dividing the depth to be removed (inclusive of any necessary overdredge) by the depth of cut and adding one.

4) *Advance into face.* The advance into face is entirely dependent on the spud system employed. The time occupied is a minimum when using a spud carriage or tilting spud and is maximum for fixed spuds. If the dredger is located only by winches, moving time may be reduced, but at the expense of poor positional control and hence irregular contact with the face.

Daily production is the product of the average hourly production and the effective working hours per day. The effective working time is the total available hours that the dredger is manned, less any lost time.

For a well-managed dredger, under average site conditions, the lost production time may be 10 % to 30 % of the theoretically available working time. Special site conditions may however result in far higher losses.

A.4.4 *Limiting factors*

There are limits on where the cutter suction dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply to economic operation is given in Table 10.

A.4.5 *Ancillary equipment*

A.4.5.1 *General*

The cutter suction dredger may employ a wide variety of ancillary equipment. Anchors, to which the swing winch wires are secured, should be chosen to suit the particular ground conditions of the site. Attendant equipment, such as work boats and discharge pipelines, should be well matched to the needs of the dredger. Versatile floating lifting equipment is important for an efficient operation.

A.4.5.2 *Discharge pipelines on shore*

NOTE See **4.4.2**.

If the pipeline diameter is too small, head losses due to friction may be unacceptably high. If the diameter is too great, the flow velocity may be inadequate to maintain the solids in motion or the power requirement may become excessive.

The pipes are generally laid on the ground. Pipelines may branch along their route, either to serve alternative deposition areas or to discharge at different points within an area. This arrangement permits a better distribution of the spoil, particularly for heavy soils, and allows the addition of more pipes to a particular line without the need to cease dredging. Valves at the point of bifurcation (normally gate or vizor valves) provide for the switching of flow. At the point of discharge, the pipe may be fitted with a diffuser or “spoon”, which assists in giving a more even distribution of spoil.

A.4.5.3 *Floating discharge pipelines*

NOTE See **4.4.2**.

Floating pipelines are categorized best in terms of their strength and flexibility. Flexibility is important in confined working areas and particularly when work is in exposed sea areas where significant wave activity can occur.

Self-floating rubber pipelines, if of high strength, are most appropriate for use with large dredgers in exposed coastal locations.

Where complete flexibility is less important, a composite pipeline construction, which includes self-floating steel pipes (steel flanged pipes with a buoyant outer jacket) may be employed. The composite construction results in a lower capital cost, depending on the relative proportions of steel and rubber pipe. A compromise is alternate lengths of rubber and steel pipe, where each component has an individual length of approximately 12 m. Occasionally, the proportion of steel to rubber may be raised to two to one, but any higher proportion is unlikely to provide sufficient flexibility and the pipe may be prone to damage.

In calm water, the proportion of steel pipe can be greatly increased, but some flexibility has to be retained. This may be provided by rubber sleeve connections between lengths of rigid steel pipe or more commonly by steel ball joints. Ball joints have the advantage of a much greater resistance to wear and stronger construction, but offer only limited flexibility. An angular movement of 22.5° either side of centre is the normal maximum. Where greater angular movement is required, this may be provided by a swivel assembly.

Pipelines that are of predominately steel construction may be supported by a buoyancy jacket but are more commonly mounted on steel pontoons.

Pontoon design is very varied, ranging from simple rectangular boxes to more elaborate shapes with lower resistance to waves and current. The bulk of most pipeline pontoons results in high transport costs between work sites and some types are designed to permit more efficient stacking to alleviate this problem.

A.4.5.4 *Anchors*

NOTE See **4.4.3**.

There is a diverse range of anchors that may be used with cutter suction dredgers. The most common types have a large fluke area to provide high holding power, even in soft ground. Details of different anchors are given in BS 6349-6.

A.4.5.5 *Cutterheads*

The main types of crown cutterheads are described in **4.4.4**. The crown cutterhead is the most common type in use. Each consists of a number of specially shaped blades (usually five or six) designed to break out the sea bed material efficiently and convey it towards the suction intake.

A wide variety of quite different cutterheads have been developed for specific applications but few have been widely adopted. The horizontal auger head, which consists of two horizontally opposed continuous flight augers feeding inwards to a suction intake, is particularly well suited to the dredging of clean, fine sediments, and very high solids concentrations are possible with this type of head. When fitted with this type of head the dredger has to be advanced directly into the face.

A thin strip of material, usually slightly wider than the dredger hull, is removed on each successive pass of the dredger. The working method is therefore similar to that of the dustpan dredger (see **4.12**).

A.5 Bucket wheel dredger

NOTE See **4.5**.

A.5.1 *General*

The bucket wheel dredger or wheel dredger is in most respects similar to the cutter suction dredger, but has a different cutter arrangement, which consists of a series of buckets or cutters arranged around the circumference of a wheel-like assembly.

If used with care, spill from a bucket wheel may be less than for a crown-type cutter, which may be an important advantage in mining applications, where the material most prone to spillage, because of its higher relative density, is the most valuable.

A.5.2 *Production cycle*

In most respects, the cycle for the bucket wheel dredger is the same as that for the cutter suction dredger (see **4.4** and **A.4**). The most significant differences arise through the different cutting actions. The much larger diameter of the wheel cutter allows a greater advance into the face at the commencement of each new cut. The symmetrical form of the cutter allows cuts to be made with equal efficiency in either direction. The reduced spill from the wheel cutter may in some situations eliminate the necessity of making a final cleaning pass across the face. The relatively small front to back dimension of the individual cutters or buckets requires a smaller increment of depth increase at the commencement of each new cut (see Figure 16).

A.5.3 *Limiting factors*

There are limits on where the bucket wheel dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger. An indication of the extreme limits that apply to economic operation is given in Table 10. These limits apply to the smallest (minimum) and largest (maximum) bucket wheel dredgers in common usage.

A.5.4 *Ancillary equipment*

The bucket wheel dredger employs the same ancillary equipment as the cutter suction dredger (see **4.4** and **A.4**).

A.6 Suction dredger

A.6.1 *General*

The suction dredger is of similar construction and appearance to the cutter suction dredger (see **4.4** and **A.4**), the essential difference being that the stationary suction dredger has no cutter. Consequently, the construction of the ladder and front end generally may be lighter than with the cutter suction dredger. The mode of operation of the suction dredger is similar to that of the stationary suction hopper dredger (see **4.3** and **A.3**), but whereas the latter normally loads dredged material into its own hopper, the suction dredger discharges either via a pipeline or into independent hopper barges (see **4.4.2** and **A.19**).

A.6.2 *Production cycle*

The nature of the production cycle depends on the particular application. When simply winning sand, production may be almost continuous, provided that the sand deposit is very thick and free running. However, it will normally be necessary to move the dredger periodically as the supply of free sand runs out. Occasionally, in suitable soils, the suction dredger may be employed to create new channels or similar formations.

Daily production is the product of the average hourly production and the effective working hours per day. The effective working time is the total available hours that the dredger is crewed and available to work, less any lost time. Time can be lost for a number of reasons, depending upon the site characteristics and work.

For a well-managed dredger that is sand winning under average site conditions, the lost production time may be 5 % to 15 % of the theoretically available working time. Special site conditions may however result in far higher losses.

A.6.3 *Limiting factors*

There are limits on where the suction dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply to economic operation is given in Table 10. These limits apply to the smallest (minimum) and largest (maximum) suction dredgers in common usage.

A.6.4 *Ancillary equipment*

Suction dredgers may employ a variety of methods of improving the concentration of solids entrained into the suction flow. In this, they are very similar to stationary suction hopper dredgers (see **4.3** and **A.3**). The dredged spoil may be discharged via a system of pipelines, as in the case of the cutter suction dredger (see **A.4.5**). Alternatively, the dredger may be used to load barges (see **A.19**).

A.7 Grab hopper dredger

NOTE See **4.7**.

A.7.1 *General*

The general construction of the grab hopper dredger is that of a ship, similar to the stationary suction hopper dredger, but usually smaller and with loading by grabbing crane rather than by pumps (see Figure 17).

The hopper may be loaded by a single rope-operated grab crane or by multiple cranes. Occasionally, hydraulic grabs or backacters may be fitted in preference to rope-operated grabs.

Compared with suction dredgers, the grab loading system is relatively insensitive to debris, but some large or difficult items, such as wires or chains, may become entangled with the hopper door mechanism. These problems are avoided by an experienced crew, who will separate potentially difficult materials and stow them on deck for later disposal.

A smooth and level dredged formation is not easily achieved by the grab dredger. In order to minimize or eliminate high spots remaining upon completion of dredging, it may be necessary to overdredge by a significant amount, particularly in cohesive soils.

A.7.2 *Method of operation*

The grab hopper dredger dredges while moored on a pattern of anchors. The attitude of the dredger in relation to the working face depends on the number of grab cranes employed. The object is to allow each crane to cover the maximum working area without encroaching upon the working area of other cranes. Limited overlap is desirable to avoid leaving material behind, but if significant overlap occurs and is unavoidable, leading cranes may be required to dredge at a higher level than following cranes to maintain good production.

When each crane has removed all material to the required depth within its radius of operation, the dredger is moved into an adjacent area. This procedure is continued until the hopper is fully loaded, whereupon the anchors are lifted and stowed and the dredger sails to the spoil disposal area.

A.7.3 *Production cycle*

The main variables of the cycle are as follows and the most significant are loading time and sailing time.

a) *Mooring.* Depends on the situation and the number of anchors deployed. It may range from a few minutes to half an hour in exceptional conditions.

b) *Loading time.* Depends primarily on the characteristics of the material to be dredged and the effects that it may have on the percentage bucket filling achieved on each bucket closure and raising. If the soil has a high resistance to penetration of the bucket edge or teeth, the percentage filling is reduced, perhaps to something very small. If the material is very loose and very fine, some of the initial bucket contents may be lost as the bucket is raised through the water. The total water depth also has a bearing. Total loading time is dependent on the number of grab cranes.

c) *Subcycle.* Swing to mark: small variation, dependent on swing angle.

Lower grab: directly related to water depth as a function of winch speed.

Close grab: approximately constant but dependent to some extent on material.

Raise grab: directly related to water depth as a function of hoist winch speed.

Swing to discharge: small variation, dependent on swing angle.

Discharge: small variation normally but may be extended in certain “sticky” cohesive materials.

The average cycle time of each grab crane may not vary significantly for a given dredger, but the percentage bucket filling may be very variable. The time to fill the hopper is given by dividing the total hopper capacity by the product of the cycle rate, the grab capacity, the percentage filling (may be greater than 100 % in soft clayey silts) and the number of grab cranes.

d) *Sailing time to disposal point.* Given by dividing sailing distance to disposal point by the average speed loaded.

e) *Time to discharge.* Dependent on the characteristics of the dredged spoil. Normally for silts or sands, it is only a few minutes, but for sticky clays the period may be extended significantly. Complete discharge may be impossible.

f) *Sailing time to work site.* Given by dividing the total sailing distance to the work site by the average speed.

Daily production is the sum of the hopper contents for each complete cycle achieved. The number of cycles is given by the total working time divided by the average cycle time. The total working time is the total hours that the dredger is crewed and available for work, less any lost time.

For a well-managed dredger under average site conditions, the lost production time may be 15 % to 30 % of the theoretically available working time. Special site conditions may however result in much higher losses.

A.7.4 *Limiting factors*

There are limits on where the grab hopper dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply to economic operation is given in Table 10. These limits apply to the smallest (minimum) and largest (maximum) grab hopper dredgers in common usage.

A.7.5 *Ancillary equipment*

The independent operation of the grab hopper dredger does not require a wide range of ancillary equipment. The main variations that may occur concern the type of grab bucket used.

The bucket should be carefully selected in the light of the known characteristics of the material to be dredged. When dredging in soft silts and clays, a plain lightweight bucket of the maximum size for which the crane is rated can be used. For stiff clays or very soft rocks (the grab is only able to dredge directly the very softest rocks economically), a heavy toothed bucket of reduced capacity should be employed. For most applications, a twin jaw configuration is appropriate but for special applications, such as the recovery of loose boulders or rock, a cactus or orange peel grab may be more appropriate.

A.8 Grab pontoon dredger

NOTE See **4.8**.

A.8.1 *General*

The grab pontoon dredger is pontoon mounted (see Figure 18) and has no hopper. The grabbing crane is mounted towards one end of a pontoon, normally rectangular in plan. The pontoon may be located simply by winches or may combine the more positive location of spuds during dredging, with winches for pontoon relocation. The capacity of grab buckets may range from 1 m^3 to 20 m^3. Large units may incorporate living accommodation for the crew within the pontoon structure.

The pontoon draught is normally small and the grab pontoon dredger can therefore work in shallow water, provided that the attendant hopper barges are not of sigificantly greater draught. A further and most important advantage is the ability to dredge narrow trenches. Dredging to considerable depth may be possible, with the deep dredging capabilities generally being superior to those of other types of plant of comparable size. Construction and operation are relatively simple and hence inexpensive. The crane unit is generally a standard production unit with all the attendant advantages of series production.

Unlike most other types of dredger, the excavating process (i.e. bucket filling) is only a small part of the production cycle. The proportion decreases with increasing depth and the virtue of a very flexible dredging depth is countered by the decreasing efficiency.

Overdredging may be substantial and may tend to increase with increasing bucket capacities due to the bucket pulling into the bed during closure, particularly in cohesive soils. No force can be applied to assist the penetration of stiff or hard materials, other than the weight of the grab bucket.

A.8.2 *Method of operation*

The grab pontoon dredger is moored on a pattern of anchors or with spuds, with the centreline of the dredger on the centreline of the proposed cut and the grab crane closest to the working face. All material within the working radius of the grab crane is methodically removed down to the required level and loaded into a hopper barge (see **A.19**) moored alongside the pontoon. When no more material remains within reach, the pontoon is advanced towards the face by adjustment of the mooring winches. This procedure continues until a barge is fully loaded, by which time an empty barge should be moored on the opposite side of the pontoon and the loading of this barge can commence, without any interruption to the dredging operation. On occasions, there may be insufficient room to accommodate barges simultaneously on each side of the pontoon, in which case a small delay will occur while barges are changed over.

A.8.3 *Production cycle*

Daily production is given by the product of working hours divided by average cycle time, and bucket capacity multiplied by the average percentage bucket filling. The total working time is the total available hours that the dredger is crewed and available to work, less any lost time. For a well-managed dredger under average site conditions the lost production time may be 20 % to 25 % of the theoretically available working time. Special site conditions may however result in much higher losses.

A.8.4 *Limiting factors*

There are limits on where the grab pontoon dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply to economic operation is given in Table 10. These limits apply to the smallest (minimum) and largest (maximum) grab pontoon dredgers in common usage.

A.8.5 *Ancillary equipment*

Ancillary equipment is limited to the various types of grab bucket (see **A.7.5**) and hopper barges (see **A.19**).

A.9 Bucket chain dredger

NOTE See **4.9**.

A.9.1 *General*

The main features of the bucket chain dredger are shown in Figure 19.

The bucket chain dredger usually loads into independent hopper barges, but occasionally, in canal works, may discharge to a short conveyor system, or very rarely to a mixing chamber for pump discharge.

The bucket chain dredger has the advantage of a continuous dredging process, which is unique among dredgers that dredge by bucket action. As with all bucket systems, dilution of the spoil by water is not very significant and therefore high load factors can be reached in the barges without excessive overspilling.

The continuous dredging action allows a good bottom finish to be achieved, with a good control of dredging depth. The amount of overdredging necessary to achieve the required level is not excessive. The dredging process is not particularly sensitive to debris or small boulders.

Breakout force is dependent on the size and mass of the dredger, the bucket shape, construction and capacity and the power and characteristics of the drive system to the top tumbler.

Construction of the bucket chain dredger is heavy and the labour requirements are high compared with some other dredgers of similar productive capacity. Consequently, both capital costs and operating costs may be higher.

The bucket chain dredger is normally towed by tug to each new work site. If the distance is long or includes areas where rough seas may be encountered, the bucket chain has to be dismantled to improve the stability. Mobilization costs may be high.

The bucket chain dredger is normally rated in accordance with the maximum capacity of each individual bucket. These may range from 150 L to 1 250 L.

A.9.2 *Method of operation*

A pattern of six anchors is laid out, as shown in Figure 20. The heavy headwire anchor is laid well ahead, preferably several hundred metres away, to maximize holding power and minimize the radius of the cut face and the frequency of movement of the anchor.

As is the case for all dredgers in which the cutting mechanism is supported by a ladder construction, the full dredging depth and face height have to be established progressively. In soft materials, the bucket dredger may, depending upon its size, be able to remove several metres of material in a single pass. The maximum face height depends on the stability of the face material. In more difficult materials, the depth of cut has to be compatible with the power available on the chain drive.

When a face has been established, dredging is a continuous process of swinging the dredger across the face with the side winches. The speed of traverse across the face and the speed of the bucket chain are adjusted to suit the particular site conditions. Dredging efficiency is not affected by the direction of traverse. Speeds have to be reduced in difficult materials.

When a cut(s) across the face has been completed to the required finish level, the dredger is advanced into the face by hauling in on the head winch. The increment of advance depends on the size of the dredging buckets and the nature of the sea bed material. Normally the advance is 0.3 m to 2.0 m. This process is repeated continuously until it is necessary to move the head anchor further away.

Barge loading is continuous. When a barge is fully loaded, a tilting hopper diverts the discharging spoil to an alternative discharge chute on the opposite side of the dredger and filling of an empty barge commences. Barges are secured alongside the dredger and moved longitudinally to achieve an even distribution of spoil by means of warping winches on the dredger deck.

A.9.3 *Production cycle*

The relative importance of the component parts of the production cycle varies a little according to the site conditions and requirements. The main effects caused by difficult materials are to slow down the whole process and to reduce bucket filling. The main components of the cycle are as follows.

a) *Traverse face.* Speed of traverse, governed by the cutting characteristics of the material to be dredged, the depth of cut, the amount moved ahead and the bucket chain speed. The time to traverse the face is given approximately by dividing the length of face (in metres) by the winch speed (in metres per minute).

b) *Number of cuts.* Number of cuts across the face to produce the finish depth is dependent on the thickness of material to be removed and the depth of each cut. Depth of each cut is governed by characteristics of material to be dredged. Sometimes, one final cleaning up cut is required. The number of cuts is given by dividing the depth to be removed (inclusive of any necessary overdredge) by the depth of cut, and adding one if a cleaning up cut is necessary.

c) *Advance into face.* Dependent on the material to be dredged and the face height. The time occupied may be a few minutes if the ladder has to be raised, but is normally less than 1 min. The distance is advanced between 0.3 m and 2.0 m. To establish a completely new face requires much longer.

d) *Change barges.* Normally there is no loss of production, but if restricted working allows access to only one side of the dredger, 10 min to 20 min may be required.

e) *Move anchors.* Very dependent on the experience of the crew. A good crew under favourable conditions may be able to limit disruption to those occasions when the head anchor has to be moved ahead. For this, 15 min to 30 min may be required. An additional 10 min to 60 min may be required for each additional anchor move.

Daily production is given by the product of working hours, average bucket speed in buckets per hour and average bucket filling expressed as a percentage. The effective working hours are the total available hours that the dredger is crewed and available to work, less any lost time. For a well-managed dredger under average site conditions, the lost production time may be 15 % to 40 % of the theoretically available working time. Special site conditions may however result in much higher losses.

A.9.4 *Limiting factors*

There are limits on where the bucket dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply to economic operation is given in Table 10. These limits apply to the smallest (minimum) and largest (maximum) bucket dredgers in common usage.

A.9.5 *Ancillary equipment*

The bucket dredger may employ a variety of different buckets for different materials, but the average dredger is unlikely to be equipped with more than two different bucket sizes or types.

A special pontoon is sometimes used to support the head wire above water level and prevent it from dragging through the sea bed.

Different anchors may be used in different ground conditions. See BS 6349-6.

The number, capacity and type of hopper barge used for spoil disposal should be selected to suit the particular site requirements (see **A.19**).

A.10 Backhoe dredger

NOTE See **4.10**.

A.10.1 *General*

The main features of the backhoe dredger are shown in Figure 21.

Bucket tear-out force decreases with increasing dredging depth, as does the total mass that can be handled. Therefore, for dredging soft rock at maximum depth, a much smaller bucket than the maximum should be used.

The land-based origins of the backhoe dredger often mean that the main dredging machinery is in series production, with a consequent reduction in capital cost and a more fully developed and tested product. The dredging operation requires only one man, although normally the crew number at least two and usually three for safety and to assist in pontoon movement and maintenance.

Occasionally, the pontoon may be self-propelled, but generally self-propulsion is intended only for movement about the work site or for undertaking short journeys, and not for long distance travel between different work sites.

Bottom finish may be irregular. Maximum dredging depth is limited and the force available to break out material from the sea bed decreases sharply with increasing dredge depth. The accuracy of bottom finish achieved is particularly operator dependent.

Production is related to the depth of material to be removed. When this is small, as in some maintenance works, the resulting inefficiency may be uneconomic.

A.10.2 *Method of operation*

The dredging action of the backhoe dredger can be likened to the action of the human hand and arm. The single digging bucket is located at the extremity of a pin-jointed arm. Between the bucket and the main structure of the machine are three points of rotation, all in the same plane. The movement of each section relative to the other is controlled by high pressure hydraulic cylinders.

The two components of the boom that carry the bucket are the dipper arm (or “stick”), to which the bucket is attached, and the monobloc, which is attached to the main machine structure. In order to begin dredging, the bucket is lowered to present its open face, or in hard ground its digging teeth, to the sea bed. The bucket is then rotated or “crowded” and lowered simultaneously to achieve penetration and loading.

The backhoe dredger is normally used to load a barge moored alongside the pontoon. Occasionally, such as in trench excavation, the dredged spoil may be cast to one side of the trench, but outreach is limited and the possibility of spoil re-entering the excavation should be considered.

The depth and configuration of the bucket and arm may be indicated in the operator's cabin by a simulating scale model. This device is an important aid to accurate working. The discontinuity of the dredging operation tends to result in an uneven bottom finish. Upon completion of each cut across the face and before the pontoon is moved, a sweep across the face with the bucket held at the design finish level should be made to check for high spots and to level any minor peaks.

Movement of the pontoon is normally achieved with the digging arm. Prior to movement, the bucket is lowered into the sea bed and the two forward spuds are raised clear of the sea bed. The stern "walking" spud, which may be tilting or carriage mounted, remains in the sea bed to maintain the pontoon on the centreline of the cut. The pontoon is then either pushed back from the face or pulled into the face with the digging arm, aided by the spud carriage hydraulics if fitted. The same method can be used to move the dredger over short distances about the work site.

A.10.3 *Production cycle*

The production cycle for a given machine is most affected by the material to be dredged and the dredging depth. There may be a significant variation in the minimum cycle time between machines of different manufacture, due to variations in the capacity and configuration of the hydraulic systems. The rate of production depends on the average percentage bucket filling, which in turn depends on the characteristics of the material to be dredged. The main components of the cycle are as follows.

a) *Loading*. Swing to mark: small variation, dependent on the swing angle and slewing rate.

Lower bucket: directly related to water depth as a function of hydraulics speed.

Crowd bucket: dependent on the resistance to penetration of the material to be dredged.

Raise bucket: directly related to water depth as a function of speed of hydraulics.

Swing to discharge: small variation, dependent on swing angle and slewing rate.

Discharge: small variation normally but may be extended in certain "sticky" cohesive materials.

Move pontoon: fairly constant, normally only a few minutes. Regularity of pontoon movement depends on depth and width of cut face and dredging depth.

b) *Change barges*. Dependent on sea conditions, current and working area. Normally 5 min to 20 min. Frequency of barge changing dependent on barge capacity.

Daily production is given by the product of working hours divided by average cycle time, and bucket capacity multiplied by the average percentage bucket filling. The total working time is the total hours that the dredger is crewed and available to work, less any lost time. For a well-managed dredger under average site conditions the lost production time may be 10 % to 40 % of the theoretically available working time. Special site conditions may however result in much higher losses.

A.10.4 *Limiting factors*

There are limits on where the backhoe dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply to economic operation is given in Table 10.

A.10.5 *Ancillary equipment*

A.10.5.1 *General*

Apart from the various types of hopper barge (see **A.19**) that may be employed for spoil disposal, there is little ancillary equipment involved with the backhoe dredger. The main variations that occur are in the size of digging bucket employed and the size and geometry of the monobloc or dipper arm. All of these should be selected to suit the particular operation required. Where the strength of rock is too great for direct dredging to be carried out economically, the bucket may be replaced with a single ripper tooth or with a percussion chisel.

A.10.5.2 *Percussion chisel attachments*

The "blind" operation, which is a feature of all underwater excavation or pretreatment, detracts from the efficient deployment of percussion tools for rock destruction. Where the area requiring treatment is small and the cost of mobilizing additional large items of plant are uneconomic, however, the use of a hydraulic or air-driven chisel may be attractive (see **9.5.2**).

A.11 Dipper dredger

NOTE See **4.11**.

A.11.1 *General*

The basic features of the rope-operated type are shown in Figure 22. Hydraulic types are essentially similar to the hydraulic backhoe (see Figure 21), but with forward facing bucket and different arm geometry.

A.11.2 *Method of operation*

The bucket, which faces forwards into the face, is lowered to the required dredging depth. The bucket is then forced forwards and upwards breaking into and up through the material. The considerable force that can be applied is resisted by heavy spuds, which locate the main pontoon structure. The bucket is raised through the water and simultaneously swung to port or starboard in the direction of the barge to be loaded. When over the barge, the bucket is discharged, either by tipping in the case of a hydraulic backhoe or by the release of a door in the back of the bucket on rope-operated machines.

The main pontoon structure is in all cases located by heavy spuds, two towards the front end of the pontoon and one centrally positioned at the stern. Forward movement is normally achieved by tilting the stern spud, but alternatively this may be carriage mounted. The dipper arm is used to control the dredger during forward movement.

A.11.3 *Production cycle*

Production is most affected by the material to be dredged and by dredging depth. Hydraulic machines are faster than rope-operated types but can be more limited in their dredging depth. The main components of the cycle are as follows.

a) *Loading*. Swing to mark: small variation, dependent on swing angle and slew speed. Average time is consistent for a given machine.

Lower bucket: direct function of water depth.

Break out material: dependent on material type.

Raise bucket and swing to barge: direct function of water depth and dump height.

Discharge bucket: small variation, cohesive materials of high plasticity or that are large compared to the bucket capacity may cause problems.

Move pontoon ahead: fairly consistent, normally only a few minutes. Frequency of pontoon movement dependent on depth of face and width of cut.

b) *Change barges*. Dependent on sea conditions, current and working area. Normally 5 min to 20 min. Frequency of barge change-over is dependent on barge capacity.

Daily production is given by the product of (working hours divided by average cycle time) and (bucket capacity multiplied by the average percentage bucket filling). The total working time is the total hours that the dredger is crewed and available to work, less any lost time.

For a well-managed dredger under average site conditions, the lost production time may be 10 % to 40 % of the theoretically available working time. Special site conditions may however result in much higher losses.

A.11.4 *Limiting factors*

There are limits on where the dipper dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply to economic operation is given in Table 10.

A.11.5 *Ancillary equipment*

Apart from the various types of hopper barge (see **A.19**) that may be employed for spoil disposal, there is little ancillary equipment involved with the dipper dredger. The main variations that occur are in the type and size of digging bucket employed and the size of dipper arm, which should be selected to suit the particular operation required.

A.12 Dustpan dredger

NOTE See **4.12**.

A.12.1 *General*

The dustpan dredger does not work on spuds, but is located and moved by winches. This has the advantage that the dredger can move freely and quickly over the ground and can work effectively in relatively shallow water.

The dustpan dredger is most effective in the removal of river shoals in large rivers where mobile bed deposits infringe on the navigation channel. If required, the dustpan dredger can pump discharge into onshore containment areas, but the requirement for a fixed onshore connection restricts the dredger's freedom of movement.

A.12.2 *Method of operation*

The dredger works on a pattern of winches as shown in Figure 24.

The dredger is normally employed in a river or channel with unidirectional flow. The dredger arrives at the dredging area and proceeds to a point some distance upstream of the area to be dredged and drops the head anchor. The dredger then drops back downstream paying off the head winch wire until at the downstream limit of dredging, where a stern anchor may be dropped. These two anchors may be sufficient, but in some cases additional side anchors may be dropped to allow coverage of a greater width of river bed, or a second head anchor, spaced apart from the first, may be employed.

The discharge end of the floating pipeline is moored in the area where the dredged material is to be placed.

With all necessary anchors positioned, the suction head is lowered to a depth just below the required finished level and the head winch is engaged. The dredger moves upstream into the face at a speed appropriate to the depth of material to be removed and continues until running into clear water.

If the depth of deposit to be removed is large, more than one pass may be made over the area in this way. Subject to the nature of the material to be dredged and to the water depth, dredging may take place in either direction.

If the width to be covered is greater than the width of the suction head, side winches or a second head anchor may be employed to align the dredger along an adjacent cut. Alternatively, the head and stern anchors may be relocated. The particular method used depends upon the dimensions of the area to be covered.

A.12.3 *Production cycle*

The dustpan dredger does not have a clearly defined cycle. The most important factor that affects production is the area that can be covered from a given anchor pattern and the depth of material to be removed. The main components of the limited production cycle are as follows.

a) *Lay head anchor*. Move dredger to upstream limit of dredge area and drop anchor.

b) *Position dredger*. Drop dredger downstream on head wire.

c) *Commence dredging*. Lower suction head to required depth and move ahead on head winch adjusting lateral position by use of second head winch or side winches.

d) *End of pass*. Make return cut or drop back for second cut or recover anchors and move to new location.

Daily production is highly dependent on the extent of the area to be covered and, in the case of shoal removal, the time to travel between shoals. Due to the normally free nature of the material to be dredged and the short discharge distance, unit production may be high. Daily production is given by the product of effective working hours and the average hourly production of solids through the pump. The effective hours are the total available hours for which the dredger is crewed and available to work, less any lost time.

A.12.4 *Limiting factors*

There are limits on where the dustpan dredger can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply is given in Table 10.

A.12.5 *Ancillary equipment*

The dustpan dredger is basically a simple tool, which works independently. Occasionally, it may be reliant on barges for the disposal of dredged material (see **A.19**). A variety of types of floating pipelines may be employed (see **4.4.2** and **A.4.5**). A variety of anchor types may be employed to suit particular ground conditions (see **4.4.3** and **A.4.5.4**).

A.13 Side casting dredger

NOTE See **4.13**.

The side casting dredger has no production cycle as such, production being continuous other than when turning at the end of each run.

The side casting dredger works independently without ancillary equipment. The dredging equipment, such as the pumps and dragheads, are selected to suit the particular site conditions under which the dredger has to operate and thereafter are unlikely to be varied except with changing technology.

A.14 Jet pump dredger

A.14.1 *General*

The jet pump may be well suited to mining operations, such as aggregate extraction, where an abrasive, free flowing material is to be dredged and pumped a relatively short distance to an onshore stockpile or processing plant. An example of a jet pump for such applications is shown in Figure 25.

A.14.2 *Production cycle*

In most applications, the production cycle and the factors that affect working time are the same as for the suction dredger (see **4.6**).

When used in a mining application, unmanned continuous operation may be possible with only periodic intervention to relocate the dredger upon exhaustion of the deposit at the current location.

A.14.3 *Limiting factors*

There are limits on where the jet pump can operate and what it can achieve. These vary according to the size and characteristics of the particular dredger, but an indication of the extreme limits that apply to economic operation is as follows.

minimum water depth to operate	1.0 m
minimum water consumption	300 m^3/h
maximum water depth to dredge	50 m (theoretically no limit)
maximum particle size (occasional)	250 mm
maximum soil compactness	loose

These limits apply to the smallest (minimum) and largest (maximum) jet pumps in common usage.

A.14.4 *Ancillary equipment*

The ancillary equipment that may be employed is similar to that of the suction dredger (see **4.6** and **A.6**) and the cutter suction dredger (see **4.4** and **A.4**). Where discharge pipelines are long, a booster pump (see **A.18**) is necessary.

A.15 Air-lift dredgers

NOTE See **4.15**.

A.15.1 *General*

The principle of the air-lift operation is shown in Figure 26. The air-lift achieves flow in a pipe by the injection of air under pressure at the lower end of the pipe. The entrained air results in reduction in the air/water mixture density and hence a decrease in pressure. As a result, the mixture within the pipe is forced upwards by the greater external water pressure and water flows into the pipe. The velocity of inflow increases with an increasing depth of submergence. Sea bed material in the vicinity of the pipe inlet is eroded, entrained into the flow and carried upwards.

The advantage of the air-lift is its simplicity and the total absence of any submerged mechanism. The disadvantages of the air-lift are very low head characteristics, a relatively low limit on the density of the entrained mixture and a restriction to loose and relatively fine materials, unless aided by a mechanical cutting head.

A.15.2 *Production cycle*

The hand-held equipment used by divers has no production cycle as such. Larger equipment may take a similar form to the suction dredger (see **4.6**) and has a similar production cycle.

A.15.3 *Limiting factors*

Apart from the simple diver-operated types of air-lift, there are few that conform to any particular standard or share many common features. Consequently, maximum and minimum capabilities can not be conveniently expressed. However, a most important attribute of the air-lift is the virtual absence of any depth limitation.

A.16 Amphibious dredgers

NOTE See **4.16**.

Amphibious dredgers may employ mechanical or hydraulic dredging methods. Some amphibious dredgers rely upon a track-laying mechanism for leaving the water to travel on land, others employ hydraulically motivated legs, which terminate in large pressure pads or buoyancy pods.

There is no established standard method of providing dredgers with an amphibious capability and the function is not therefore dealt with in detail.

A.17 Bed-levellers and ploughs

NOTE See **4.17**.

A.17.1 *General*

The basic features of the bed-leveller are shown in Figure 27. The bed-leveller (sometimes called a plough or scraper) is not a true dredger because it only moves material through a short distance in a manner that is analogous to a bulldozer on land. Consequently, it is most commonly used in conjunction with true dredgers, particularly with the trailing suction hopper dredger. However, it may be used to move small volumes of material, which occur as high spots, into adjacent deeper water and therefore prolong the interval before dredging becomes necessary.

A.17.2 *Method of working*

When used to retrieve material that is inaccessible to a trailing suction hopper dredger, the tug carrying the bed-leveller is reversed into the area to be cleared and the bed-leveller blade is lowered, under winch power, until just biting into the sea bed. The tug is then moved forward into the area where the material is to be deposited. When deeper water is reached the captive material falls off the blade and another cycle begins. In this way, material close to quays and jetties and in entrances or restricted corners can be removed inexpensively without recourse to conventional dredging equipment.

If the required task is to remove high spots, the bed-leveller works in a similar way, but merely seeks to move material above the required level into adjacent areas which are below level.

If the bed material is compact or the object is to force material into suspension, water jets may be fitted to the bed-leveller blade to loosen and agitate the material.

A.17.3 *Production cycle*

The main component of the cycle is as follows.

Blade off material. Position tug, lower blade to sea bed, move ahead into area of deposition. Speed ahead at 1 kn to 2 kn.

Reverse to start point at 1 kn to 3 kn, or turn and sail ahead and turn at between 2 kn and 4 kn.

Repeat until required depth is achieved.

Move onto adjacent cut, repeat as above.

Continue until area is satisfactory.

A.17.4 *Limiting factors*

The maximum water depth for operation depends on the size of tug employed and the method of connection between the blade and the tug. For a rigid connection, maximum depth is about 15 m, but for a flexible (wire) connection greater depth is possible.

The limits on economic operation depend on the size of tug from which the bed-leveller is deployed. Indications of the limits for the minimum and maximum sizes in common use are as follows:

minimum water depth to operate	3 m
maximum depth to operate	30 m
maximum wave height	1.0 m
maximum swell	1.0 m
maximum cross current	1.5 knots
maximum transport distance	100 m
maximum soil compactness	loose or medium dense

A.17.5 *Ancillary equipment*

Water jets fed from a high pressure pump on board the tug may be used to loosen deposits. Teeth may also be used for the same purpose.

Compressed air nozzles, fed from a compressor on board the tug, may be used to increase the suspension of fine sediments where the object is to achieve dredging by agitation (see **3.6.6**).

The bed-leveller assembly may be substituted by a multitine rake for the removal of surface, or near-surface, debris, particularly abandoned ropes, wires, nets, etc. If it is to be used as a tool for the preliminary clearance of polluted areas prior to dredging, the tine length should be as long as possible (not less than 0.5 m) and the overall mass should be sufficient and so distributed as to provide adequate penetration of the tines into the sea bed.

A.18 Booster pump stations

Booster pump stations are used in long discharge pressure pipelines when additional pump head is required, either to overcome friction or to overcome static head.

Boosters are regularly used in conjunction with cutter suction dredgers (see **4.4**), suction dredgers (see **4.6**) and pump discharging trailing suction hopper dredgers (see **4.2**). Occasionally, they may also be used with other types of hydraulic dredgers.

The booster pump, a centrifugal solids-handling pump, may be mounted within or on a floating pontoon, or may be skid mounted or wheel mounted on land. The pump may be driven by a diesel engine or driven electrically.

The additional pumping head provided by each pump depends on the particular pump characteristics, but is normally 50 m to 80 m of water column when pumping water and about 10 % less when pumping a solids water slurry. The additional length of horizontal pipeline through which the slurry can be pumped depends on the pipeline diameter and mixture velocity. For medium sand it normally ranges from about 900 m for a 300 mm diameter pipeline to about 3 000 m for a 800 mm diameter pipeline.

A.19 Hopper barges

A.19.1 *General*

Hopper barges, frequently referred to simply as barges or hoppers, are used to transport dredged material. The barge capacity may range from less than 50 m^3 to more than 2 000 m^3. The barge may be dumb (without a means of self-propulsion) or may be self-propelled and may be suitable only for operation in sheltered water, or may be seagoing. The method of discharging the barge contents may be via bottom doors or a split hull or by pumping.

Barges are most commonly employed with the various bucket-type dredgers, but are also used with the suction-type dredgers. Construction detail may vary considerably depending upon the intended application. If the barge is to be used for the transport of fine silty materials, the sealing arrangement of the doors will be important. If the barge is to be used to transport rock, replaceable protective liners should be fitted.

A.19.2 *Non-propelled (dumb) barges*

The non-propelled barge is generally of simple construction.

Travel between the dredging area and point of discharge is made with the assistance of a tug. The barge may have a small crew or the dumping mechanism may be controlled by radio from the towing vessel.

Barge capacity may be as much as 2 000 m^3 but more commonly is 500 m^3 to 1 000 m^3. The loaded draught is generally less than 4 m.

In general, non-propelled barges are not designed for operation in exposed sea conditions and while commonly used for the disposal of dredged material at sea, this is in relatively sheltered coastal conditions or during calm weather.

The advantages of the non-propelled barge are its relatively low capital and operating costs. A fleet of non-propelled barges can be used to advantage where the relation between the production of the dredger and the distance to the point of discharge is such that a number of barges can be handled by a single tug. The shallow draught of most non-propelled barges may also be advantageous at times.

The disadvantages of the non-propelled barge are the relatively low speed of towing, the potential hazard to other navigation, the disruptive effect that rough seas may have on operations and problems of safety.

A.19.3 *Self-propelled barges*

The self-propelled barge may be a simple barge fitted with an outboard propulsion unit (see Figure 36) or may be constructed to full seagoing and shipbuilding standards.

The advantages are those of independent operation and, in the case of barges built to seagoing standards, the ability to continue working in more severe sea conditions and to travel at higher speeds.

The disadvantages are higher capital and operating costs (costs for a seagoing barge may be almost as high as those for a small trailing suction hopper dredger) and normally a deeper draught.

A.19.4 *Bottom door discharge*

Bottom door discharge may be used for both propelled or non-propelled barges. Doors are normally of the hinged type and open and close by means of winches or hydraulic cylinders, which are attached to the doors by chains or links.

Bottom doors have the advantage of relatively simple construction and actuation. When doors can be opened individually or in a predefined pattern, better control of the dumping process may be possible, which can be advantageous in some situations.

A disadvantage of doors is the greater obstruction to discharge that occurs due to the door frames and control mechanism. This may cause problems when the dredged material includes large fragments of rock or boulders, or debris such as old chains, ropes and hawsers. Bottom doors are also susceptible to damage when discharging in shallow water or in rough sea. A common problem is damage to door sealing, due to either distortion of the door or damage of the seal fabric, where fitted.

A.19.5 *Split hopper discharge*

The split hopper barge discharges by opening of the hull. The hull is constructed in two halves, which are joined by heavy hinges at deck level. Opening and closing are normally achieved by hydraulic cylinders (see Figure 36).

The split hopper arrangement allows for the easier discharge of large fragments of rock or boulders and may be particularly advantageous when handling cohesive clay materials. The absence of any protrusion below the keel allows dumping in shallow water.

The disadvantages of the split hopper arrangement are a higher capital cost and, subject to design, less control of the dumping process.

A.19.6 *Pump discharge (barge unloader)*

When dredged material is to be disposed of on land or used as filling, it may be more convenient to discharge the barges by pumping. This is achieved with a barge unloader, sometimes called a reclaimer (see Figure 30). The barge unloader is simply a shore-based or floating pump-set for the discharge of barges by suction. A water pump is used to fluidize the material to be discharged. Barges used permanently for pump discharge do not have any mechanical discharge mechanism, but consist only of hopper space as in the case of any other bulk cargo carrying barge.

A.20 Work boats

A.20.1 *General*

Almost any kind of boat may be used as an attendant work boat in dredging operations, but certain particular characteristics are desirable if reasonably efficient work is to be achieved. These include sturdy construction (which normally means welded steel), adequate power, good manoeuvrability, adequate clear deck space, towing ability and shallow draught. Other characteristics that may be desirable in certain situations include lifting capability, survey capability, fuel or water bunkering capacity, tolerances of silt-laden water and personnel carrying capability.

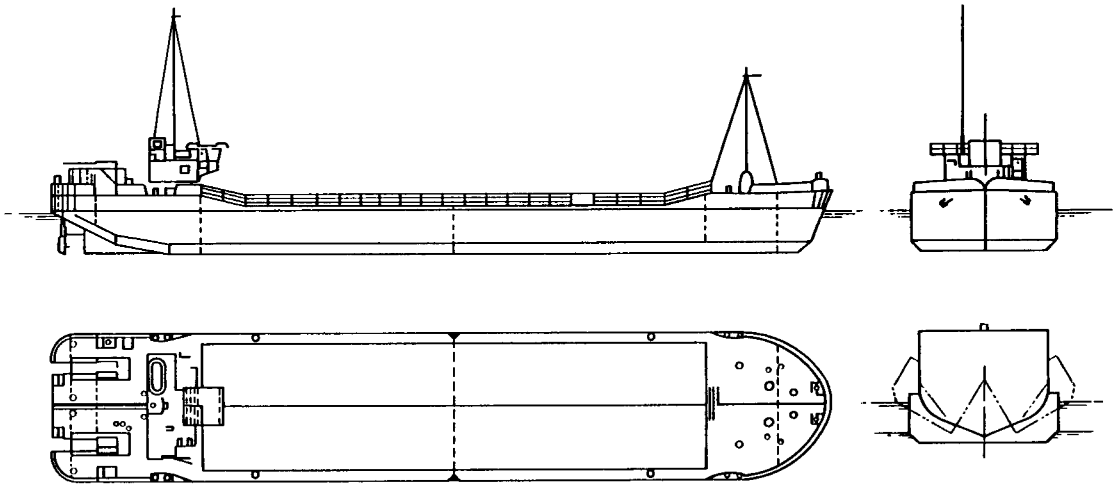


Figure 36 — Simple self-propelled split-hull hopper barge

It is not generally possible to combine satisfactorily all of the listed characteristics in a single craft. However, two types of boat will satisfy most needs and these are covered in **A.20.2** and **A.20.3**.

A.20.2 *Pontoon-type work boats*

The pontoon-type work boat is shown in Figure 10. The boat is constructed of steel and has inboard diesel engines. The form is of a shallow rectangular box. This form provides the maximum clear deck space for the transport of dredging equipment and stores and the maximum stability for lifting duties.

Lifting duties are normally performed by a general-purpose hydraulic loader, but may be by means of a bow-mounted A-frame.

Draught is shallow and a keel cooling system can be incorporated without difficulty. The pontoon form provides adequate carrying capacity, which may include fuel for other plant.

The pontoon work boat is normally restricted to operating in close contact with the dredging plant. Low speed and minimal covered accommodation render the boat unsuited to travel over long distances on a regular basis.

A.20.3 *Launch-type work boats*

An example of a launch-type work boat is shown in Figure 11. The boat is constructed of welded steel and has inboard diesel engines. The hull form is shaped to provide a reasonable compromise between water resistance, carrying capacity and stability.

Boats of this kind can be used for light towing duties, personnel transport, survey work and light anchor movement. Draught is reasonably shallow and, if required, limited bunkering capacity can be incorporated.

The more streamlined hull form allows greater speed and hence the boat can range economically over greater distances than the pontoon-type work boats.

A.21 Pretreatment pontoons

A.21.1 *Introduction*

Pontoons are required for carrying out various types of rock pretreatment prior to dredging. The pretreatment may take the form of blasting, drilling and blasting, or rock breaking by mechanical means (see **9.5**).

Pontoons are normally rectangular in shape with equipment mounted either over one side or over a central rectangular well. The craft is equipped with anchors, mooring wires and winches, which are often centrally controlled to facilitate accurate positioning. Movement to and around the site is effected with the assistance of a tug or work boat. However, there are a few self-propelled pontoons that may move without assistance. Once on station, the pontoon is designed to either remain floating during pretreatment or, particularly in more exposed locations, be raised on spud legs whether partially or wholly out of the water (see Figure 31 and Figure 32).

Most pontoons are of steel bulkhead construction and either form into a permanent craft or comprise a number of linked units, which can be dismantled at the end of the project. On the larger units the pretreatment machines are mounted so as to be movable either along the side of the craft or on a bridge unit spanning the central well. Small pontoons usually have their machines fixed in position.

Pontoons with rigs mounted over the side have to be repositioned fairly frequently, which may be a disadvantage if weather or sea conditions make repositioning a lengthy procedure. On the other hand, they can change drilling pattern or cope with irregularly shaped rock areas with comparative ease.

Pontoons with rigs mounted on a bridge spanning a central well are less adaptable but usually more efficient when large areas of rock are to be treated. For larger units the pontoon with a central well is probably more common.

A.21.2 *Production cycle*

The production cycle for the process of drilling and loading a borehole with explosives is described in **9.5**. The following cycles are for the three main types of pontoon and apply to pretreatment by breaking or blasting.

a) *Floating pontoon with machines mounted over the side* (see Figure 31)

Move pontoon into position
Pretreat rock
Move machines, etc.
Subcycle repeated as required to cover area
Move off position
Move anchors if necessary
Detonate explosives

NOTE 1 The number of subcycles depends on the number of holes drilled for blasting or the area covered before it is necessary to move anchors.

b) *Floating pontoon with machines mounted on bridge over central well*

Move pontoon into position
Pretreat rock
Move bridge, etc.
Subcycle repeated as required to cover area
Move off position
Move anchors if necessary
Detonate explosives

NOTE 2 The number of subcycles depends on the area covered by the well or the maximum number of holes that can be blasted at one time.

c) *Spudded pontoon with machines mounted on bridge over central well*

Move pontoon into position
Jack up spud legs to desired height
Pretreat rock
Move bridge, etc.
Move off position
Subcycle repeated as required to cover area
Move anchors if necessary
Detonate explosives

NOTE 3 The number of subcycles depends on the area covered by the well or the maximum number of holes that can be blasted at one time.

A.21.3 *Limiting factors*

The pretreatment pontoon, like all other dredging craft, is susceptible to the elements (see **3.2**). Interruptions to the working cycle caused by inclement conditions, swell of excessive height or the passage of vessels nearby can often lead to reductions in productivity far more serious than the duration of the interruption would indicate. This is particularly so when explosives are being used.

Many dredging operations are of a cyclic nature where the actual process of dredging is only a small proportion of the total cycle time. In such circumstances an interruption to the cycle may mean that the effective dredging component of the cycle is shortened while the total cycle remains much the same. When a drilling and blasting operation is disturbed by the passage of a nearby vessel, the actual delay may be only 10 min. However, it is considered unsafe and is frequently impossible to continue a drilling and blasting programme after an interruption unless the barge has been moved off position and the charges have been detonated; a process that could take 1.5 h.

In principle, pontoons can be used on any site when the ambient conditions are less severe than the limiting values. In practice, this may mean that in exposed locations a pontoon can only work one day out of three, while in sheltered conditions the site may be workable at all times. It is therefore advisable to try to provide work nearby in sheltered conditions when an exposed site is being worked.

Other factors that should be examined include the following:

a) the ability of the sea or river bed to hold anchors;

b) the ability of the sea or river bed to take the load imposed by the spuds of a jack-up pontoon;

c) environmental conditions associated with the pretreatment process selected (see **10.5**).

A.21.4 ***Ancillary equipment***

Pretreatment pontoons require the services of a tug or work boat to assist on towage to site, laying of anchors and crew changing and to act as a warning vessel before blasting takes place. It is good practice to ensure that there is always a support vessel available in the near vicinity of the pontoon during operations. An additional craft is sometimes required to act as a warning vessel prior to and during blasting.

Appendix B Estimation of mass of material in a hopper

B.1 General

The mass of material, including water, contained in a hopper is reflected by the change in displacement of the vessel as a result of loading. Displacement is measured in terms of the change of draught of the vessel. For reasonably accurate draught determination, measurements should be made fore and aft and port and starboard. Most modern trailer suction dredgers (see **4.2**) are fitted with load indicators based upon the measurement of draught at two or more points.

B.2 Calculation

The average change in draught can be used to determine the change in displacement by reference to the official calibration of the particular vessel.

When the change in displacement is known (this is not easily found with acceptable accuracy), the mass of dry solids in the hopper W_s (in t) may be calculated from the following equation:

$$W_S = [W - V\rho_w][1 - (\rho_w / \rho_w)]^{-1}$$

where

W_s is the mass of solids in the hopper (in t);

W is the total mass of the dredged load (in t);

V is the volume of solids (in m^3);

ρ_w is the density of water (in t/m^3);

ρ_s is the density of the dry solids (in t/m^3) (generally 2.65).

If the density of the sea bed material is known, the volume of sea bed material loaded into the hopper V_b (in m^3) can be calculated using the equation:

$$V_b = \frac{\rho_h - \rho_w}{\rho_u - \rho_w} \times V_h$$

where

ρ_h is the density of mixture in the hopper (in t/m^3);

ρ_u is the in situ density of the material to be dredged (in t/m^3);

V_h is the volume of mixture in the hopper (in m^3);

V_b is the volume removed from the sea bed (in m^3).

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BS 1377, *Methods of test for soils for civil engineering purposes.*

BS 1377-4, *Compaction-related tests.*

BS 5228, *Noise control on construction and open sites.*

BS 5228-1, *Code of practice for basic information and procedures for noise control.*

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

BS 5930, *Code of practice for site investigations.*

BS 6031, *Code of practice for earthworks.*

BS 6349, *Code of practice for maritime structures.*

BS 6349-1, *General criteria*4).

BS 6349-2, *Design of quay walls, jetties and dolphins*4)5).

BS 6349-3, *Design of dry docks, locks, slipways and shipbuilding berths, shiplifts and dock and lock gates*4)3).

BS 6349-4, *Design of fendering and mooring systems*4)3).

BS 6349-6, *Design of inshore moorings and floating structures*4).

BS 6349-7, *Guide for the design and construction of breakwaters*3)6).

ASTM D 3155 Test method for lime content of uncured soil-lime mixtures7).

ASTM Special Technical Publication No. 402 (1966).

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4) Published as a code of practice.

5) Referred to in the foreword only.

6) In preparation.

7) ASTM = American Society for Testing and Materials.

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