6. Dredging

SUMMARY

Dredging and underwater excavation are an important aspect in the design and construction of certain key elements of a fishing harbour's infrastructure. Capital dredging may also be an important aspect in the design of a new port if access channels or water deepening of a basin are required for the first time. Maintenance dredging is essential to keep certain access channels, fishing port basins and canals subject to high sedimentation open to navigation.

This chapter reviews the various types of dredging techniques that exist in relation to the characteristics of the material to be dredged. Thus the reader will be able to assess the dredging requirements for small ports and be able to suggest the most suitable method of dredging in whatever type of material.

CONTENTS

6.1 REQUIREMENTS FOR DREDGING

The basic requirements to assess dredging works are:

- an accurate estimate of the volumes to be excavated or dredged; and
- an accurate evaluation of the nature of the material to be excavated.

6.1.1 Volume estimates

Accurate volume estimates are important for the choice of dredging plant, production estimates, times of execution and ultimately project costs. Expressed in quantities, a dredging operation can extend from a few hundred cubic metres to many millions of cubic metres. In order to arrive at an accurate dredging volume, the following is required:

- a detailed design layout showing areas to be dredged and the design depths required together with the relevant cross-sections;
- a Class 2 hydrographic survey of the area with bathymetric contours at 1 metre intervals for extensive projects (see Figure 14 in Chapter 5) or a Class 1 hydrographic grid with bathymetric contours at 0.25 metre intervals for isolated structures (see Figure 15 in Chapter 5); and
- a geotechnical survey, including borehole logs, *in situ* and laboratory test results and samples.

6.1.2 Characterization of materials

An evaluation of the physical, chemical and biological characteristics of the sediment to be dredged is necessary to determine potential dredging methods, beneficial use, disposal options and potential environmental impact.

6.1.2.1 Physical characteristics

The nature of the material to be dredged decides the type of equipment or method to be adopted to carry out the work thereby influencing the cost of the project, especially when mobilizing the plant from a distant site.

In practice, no sea bed material will fall precisely into a certain predetermined category, so combinations of types must be described accurately. When a specialist soil-investigation contractor is given the task of classifying the materials to be dredged, soil classification problems do not arise. Problems do arise, however, with artisanal-scale projects, where the volumes to be dredged are usually very small and the construction budgets are very limited.

In the absence of detailed geotechnical studies (i.e. on very small projects), clear descriptions should be noted down in addition to the collection of the samples in air-tight glass jars. Typical examples of such descriptions include:

(i) In sand and silt deposits:

- compacted, coarse, angular sand mixed with scattered broken sea shells;
- loose, rounded, fine to medium sand with coarse gravel;
- brown, rounded, slightly compact fine sand;
- hard, brown clay containing sand and gravel;
- soft, grey/blue, sand silt; and
- stiff, fissured, grey clay.

(ii) In clay or clayey deposits:

- very soft, may be squeezed easily between fingers;
- soft, easily moulded by fingers;
- firm, requires strong pressure to mould by fingers;
- stiff, cannot be moulded by fingers, indented by thumb; and
- hard, tough, indented with difficulty by thumb nail.

In granular deposits, it is useful to remember that if all the sand grains are visible to the naked eye, then the material is entirely sand. If individual particles are invisible, the sample is classified as silt or silty sand. Gravel may be described as rounded, irregular, angular, flaky or elongated. Its texture may be classified as polished, smooth or rough. The general classification for granular material is as follows (Table 1):

TABLE 1
Classification of granular materials (diameter in mm)

Cobbles	Gravel		Sand		
	Coarse	Fine	Coarse	Medium	Fine
256 – 76	76 – 19	19 – 5	5 – 2	2 – 0.42	0.42 – 0.074

6.1.2.2 Chemical characteristics

In 1972, the general interest in the importance of the environment resulted in the holding of the United Nations Conference on the Human Environment in Stockholm, Sweden. As part of the preparatory process for the conference an Inter-Governmental Working Group on Marine Pollution held its first meeting in London in 1971 and the Stockholm conference recommended that governments ensure that "ocean dumping by their nationals anywhere, or by any person in areas under their jurisdiction, is controlled and the governments continue to work towards the completion of and bringing into force as soon as possible of an over-all instrument for the control of ocean dumping...". In response to this recommendation, the United Kingdom of Great Britain and Northern Ireland convened a conference which met in London from 30 October to 13 November 1972 and adopted the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the "London Convention" for short).

The Convention entered into force on 30 August 1975 and the first meeting of Contracting Parties in December that year agreed to designate the International Maritime Organization (IMO) to be responsible for the Secretariat duties in relation to the Convention. The Convention's purpose is to control all sources of marine pollution and prevent pollution of the sea through regulation of dumping into the sea of waste materials. It covers materials transported to sea for the purpose of dumping. The Convention is a living document that responds to new information, pollution issues and environmental concerns through a process of consultative meeting, scientific and legal debates, consensus building and the addition of new member nations.

Past amendments and proposed future actions to the Convention reflect our growing knowledge of or different approaches to waste management or of the potential harm from certain substances or processes. The London Convention, in October 1996, adopted revisions resulting in the 1996 Protocol to the Convention. This Protocol prohibits ocean disposal, except for a few types of wastes. Dredged material is one of these.

The screening for the presence of chemical agents in the material to be dredged is required to determine where and how the material will be disposed. The screening for chemical agents is based on a step-by-step investigation of any number of the following parameters:

- verifiable data from previous chemical tests on material in the vicinity of the proposed dredging;
- known major geochemical characteristics of the sediment;
- potential routes by which contaminants could reasonably have been introduced to the sediment;
- probability of contamination from agricultural and urban runoff;
- spills of contaminants in the area to be dredged;
- industrial and municipal point discharges, past and present; and
- prior use and source of the sediment.

The sampling of the sediments from the proposed dredging site should be representative of the vertical and horizontal distribution and variability of the properties of the materials to be dredged. The sampling procedures should also anticipate the information required for the evaluation and selection of the dredging and disposal techniques.

6.1.2.3 Biological characteristics

If the potential impacts of the dredged material cannot be assessed on the basis of the physical and chemical characteristics and available benthic information, biological or effects-based testing should be considered. It is important to consider information about species known to occur in the area which may be affected and the potential effects of the sediments to be disposed on the said organisms. Biological tests should incorporate species that are considered appropriately sensitive and representative and should determine, where appropriate:

- acute toxicity;
- chronic toxicity covering an entire life cycle;
- potential for bio-accumulation; and
- potential for tainting.

See Section 6.3.2 on the classification of the sediments to be dredged. Within the London Dumping Convention regulations, dredged material may be exempted from further testing if it meets one of the criteria listed below:

- dredged material is excavated from a site away from existing and historical sources of appreciable pollution, so as to provide reasonable assurance that the dredged material has not been contaminated; or
- dredged material is composed predominantly of sand, gravel and or rock; or
- dredged material is composed of previously undisturbed geological materials.

If any one of the above applies and if the geological records do not indicate the presence of potential leachates from heavy metal mineral deposits, it may be assumed that the dredged material has not been contaminated from human sources to an extent that necessitates further investigation. The evaluation and assessment procedure in these cases may normally be restricted to proper site selection and evaluation of physical impacts. Dredged material which does not meet any of the above criteria will require further investigation.

6.2 DREDGING TECHNIQUES

Dredging is most likely to be in one of the following types of sediment:

- cohesionless deposits, such as sand or weakly cemented granular deposits;
- cohesive clayey deposits;
- silty mud from inside existing port areas; and
- rock, ranging from soft coral limestone to the much harder granite;

Depending on the consistency of the deposits, various dredging techniques may be employed. The most common techniques or equipment are:

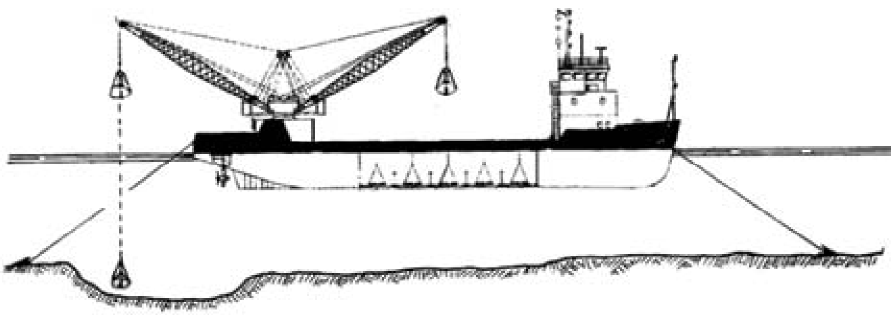
- pontoon-mounted grabbing;
- pontoon-mounted (or shoreline) dragline;
- pontoon-mounted pumping;
- self-propelled trailing suction dredging;
- blasting, using high explosives or low-power explosives;
- bucket dredging;

- cutter-suction dredging;
- backhoe dredging;
- chiselling; and
- airlift.

6.2.1 Pontoon-mounted grabbing

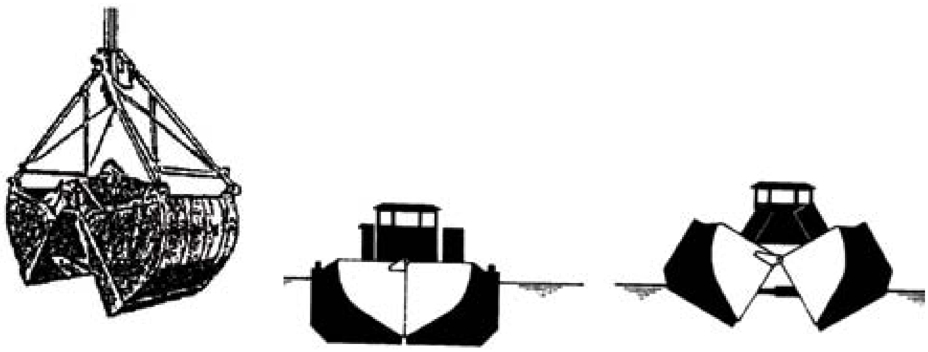
Figure 1 illustrates an ocean-going grab dredger, consisting of a self-propelled vessel with various on-board hoppers with a crane or cranes mounted on the deck. A pontoon dredger, on the other hand, consists of a barge-mounted crane, propelled by a tug and assisted by two hopper barges (see Figure 3).

FIGURE 1
Self-propelled grab dredger



A grab dredger lowers, closes and raises a single grab by means of wire rope. In operation, the clamshell grab, Figure 2 (left), is dropped to the sea bed in the open position and bites into the sediment due to its weight and the action of the closing mechanism. The materials thus dredged are either dumped into the on-board hopper wells (in ocean-going dredgers) or into adjacent hopper barges, Figure 2 (right), for transport to the authorized dump site.

FIGURE 2
The standard clamshell grab (left) and the split hopper barge



The advantages of the grab dredger are:

- flexibility of use in maintenance dredging in all kinds of marine sediments, for which a variety of grabs are available;
- efficient to depths of 35 metres, beyond which the free-fall effect of the grab limits efficiency; and
- very suitable for working along quays and in the corners of harbour basins.

The disadvantages are:
- when stationary in a navigation channel it causes an obstruction to sea traffic; and
- it leaves irregular bottom topography.

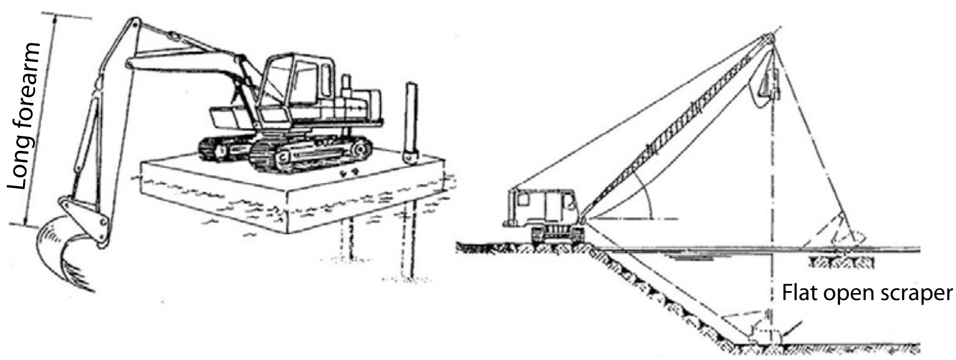
FIGURE 3
Pontoon-mounted grab dredging below a quay wall

6.2.2 Dragline

Figure 4 (right) illustrates the technique of dredging by dragline. This method consists in dragging an open steel bucket along the sea bed until it fills up. When full, the bucket is lifted and its load dumped on the shore or into a barge.

The dragline is not used much outside North America. It tends to spill much of the dredged sediment during operation and gives rise to considerable turbidity. Most of the functions of a dragline nowadays are performed more efficiently by backhoes, both from the shoreline as well as mounted on a barge, Figure 4 (left).

FIGURE 4
A normal dragline (right) and a barge-mounted backhoe (left)



6.2.3 Pontoon-mounted pumping

The pontoon-mounted pump dredger consists of a large submersible pump suspended from a pontoon and dunked into the sea bed (see Figures 5 and 6). The slurry (11 percent sand by weight) is pumped away via floating pipes. For slurries containing extremely fine-grained sand particles, the velocity in the discharge pipe should exceed 1.50 m/s and for coarser sands 3 to 4 m/s. The advantage of the pontoon pump is that

FIGURE 5
A pontoon-mounted electric pump

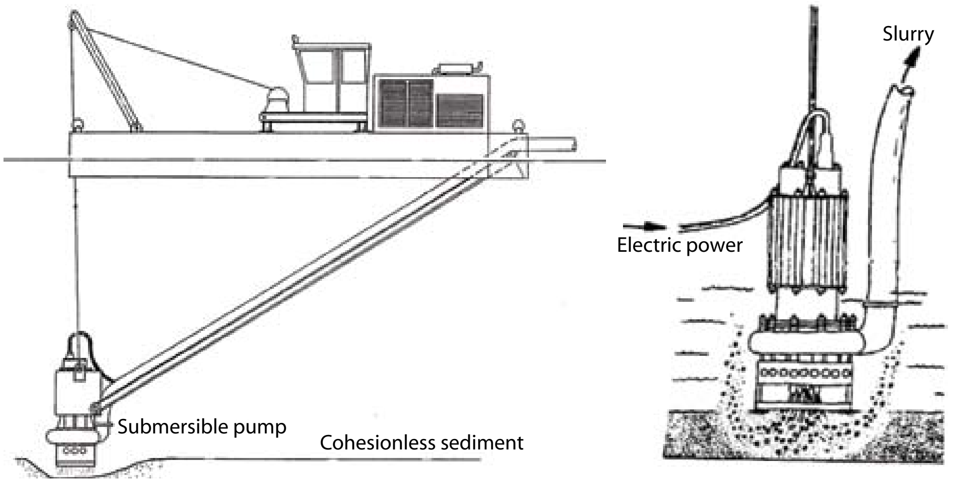


FIGURE 6
Very compact pontoon-mounted pumps

it is capable of a larger output than any other dredger of comparable size. Some pumps are also equipped with cutter blades to handle sea grass and weeds. This method, together with the airlift, is also very suitable for dredging in areas known to contain archaeological remains.

The disadvantages are:

- rough seas, especially swell, hamper this kind of dredging due to the fact that the pump does not always contact the sea bed;
- the range of sediments which can be dredged efficiently is very limited;
- it leaves an irregular bottom topography; and
- when stationary in a navigation channel it causes an obstruction to sea traffic.

6.2.4 Trailing suction

When dredging large volumes of cohesionless sediment, a trailing suction dredger is normally used. A trailing suction dredger is a hopper vessel with a trailing arm suspended over the side and dragged over the sea bed, Figure 7 and Figure 8.

The vessel usually steams forward at around 6 knots, automatically compensating for swell and tidal variations while maintaining the drag head in contact with the sea bed by means of a computerized hydraulic system.

The water/sand mixture is drawn on board by powerful pumps, passed through a series of decanters and the solids deposited inside the internal hoppers whose capacity ranges from 2 000 to more than 25 000 cubic metres. The relatively clear, decanted seawater is dumped overboard. The maximum dredging depth without intermediate

pumps is around 35 metres. With one or even two intermediate pumps the dredging depth may be extended to 80 and 120 metres. These dredgers are fully automated and dredging generally takes place over a 24-hour period, non-stop. The dredged sand in the hoppers is either dumped offshore if clean or pumped onshore for reclamation via pipes laid out ashore.

The advantages of trailing suction dredgers are:
- minimum interference to sea traffic;
- versatility in handling both cohesionless and cohesive sediments;
- the dredged load may be pumped ashore as reclamation; and
- constructed in various sizes to suit most project sizes.

The disadvantages are:
- the final dredged depth is less precise, necessitating some overdredging; and
- mobilization costs can be considerable.

FIGURE 7
Trailing suction dredger

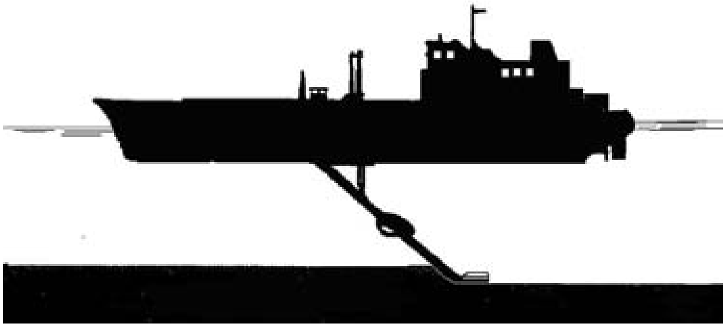


FIGURE 8
A suction-trailer approaching the shore discharge pipe (1). The hopper overflow (2) and trailing arm (3) clearly visible

6.2.5 Blasting

When thick layers of rock or isolated rocky outcrops need dredging, blasting is an efficient method of excavation. In this method, a series of closely spaced holes is drilled into the sea bed, charged with explosives and fired. The holes in the sea bed may be drilled either from above water level, Figure 9, or directly from the sea bed, Figure 10. The hydraulic power to operate the driller is supplied from a shore-based power pack via floating or submerged lines. Both systems are generally carried out by specialist subcontractors.

FIGURE 9
Drilling blasting holes from a jack-up platform

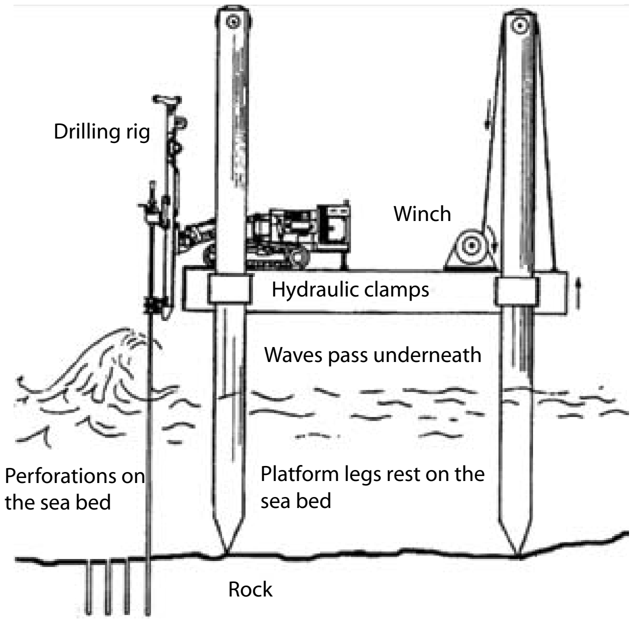
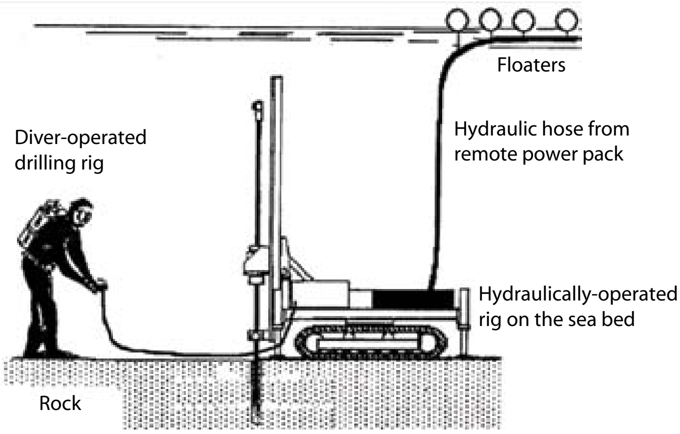


FIGURE 10
Drilling blasting holes directly from the sea bed



Blasting is a relatively quick method for dealing with small amounts of very hard rock formations like outcrops. Large quantities of hard rock are nowadays excavated by rock-cutter suction dredgers or bucket dredgers.

The disadvantages are:

- the blasting must be accompanied by grabbing for the removal of the spoil;
- unless carried out from the sea bed, both drilling and grabbing cause an obstruction to sea traffic;
- the indiscriminate loss of sea life during blasting;
- the percentage of fines generated by the fragmentation of coralline rock are very hard to predict; and
- mobilization costs can be considerable.

6.2.6 Bucket dredging

The bucket dredger, also known as the ladder dredger, consists of an endless bucket chain scraping the sea bed while the dredger is moved across the area to be dredged by means of a series of anchor ropes (Figure 11).

FIGURE 11
Bucket ladder dredger

Although most bucket dredgers nowadays have been replaced with cutter-suction dredgers, quite a few of these dredgers are still around. The maximum dredging depth is normally around 25 metres, although 34 metres is possible with the largest dredger of this type. The buckets range in size from 50 litres to 1 000 litres.

The advantages of a bucket dredger are:

- capability of dredging a level bottom topography;
- ability to work in narrow or restricted areas;
- versatility in handling a wide range of sediments; and
- side loaded barges are generally filled with a high solids-to-water ratio.

The disadvantages are:

- when stationary in a navigation channel it causes an obstruction to sea traffic;
- rough seas, especially swell, hamper this kind of dredging; and
- bucket dredgers are noisy and in urban areas they may be prohibited from working at night.

6.2.7 Cutter-suction

Cutter-suction dredgers are among the most popular type of dredger, available in a wide range of sizes ranging from the small portable units that fit on a large road trailer to ocean-going vessels over 100 metres long.

A small cutter-suction dredger is able to handle small volumes of weakly cemented sediments as well as weeds (Figure 12). The maximum discharge pipe diameter rarely exceeds 150 mm for the portable or demountable type of dredger.

FIGURE 12
Small cutter-suction dredgers

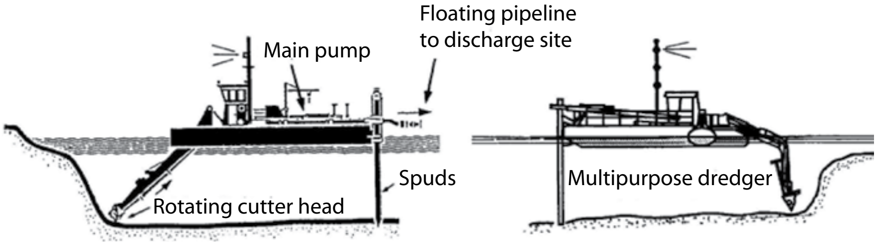


Figure 13 shows the most popular range of cutter-suction dredgers, consisting of two demountable pontoons and a centrally hinged dredging ladder capable of dredging from -3.0 metres to -7.0 metres. The power on the cutting head (Figure 14, left) may range from 40 hp on the smaller versions to 1 200 hp on the larger models, making them suitable for dredging in soft limestone. Discharge pipe diameters range from 250 to 800 mm.

Figure 14, right, shows the full-size dredger commonly used for large-scale dredging operations. Typically, the sand/water mixture is pumped a distance away and longer-than-normal distances are achieved by the installation of booster pumps along the discharge line.

The advantage of a cutter-suction dredger is:

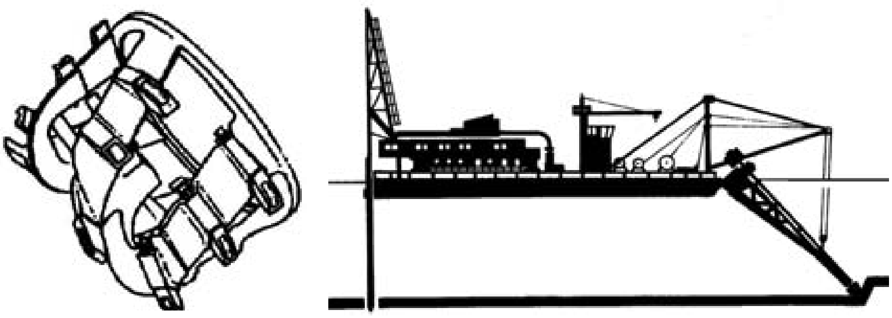
- suitability for dredging in a wide range of sediments.

The disadvantages are:

- in the presence of coralline limestone, the cutter head invariably generates considerable fines in the 10 micron range that are difficult to settle;
- the water-to-sand ratio of the dredged material is so high that it must be pumped directly to the disposal site;
- rough seas, especially swell, hamper the smaller dredgers; and
- when stationary in a navigation channel it causes an obstruction to sea traffic.

FIGURE 13
Small- and medium-sized cutter-suction dredgers

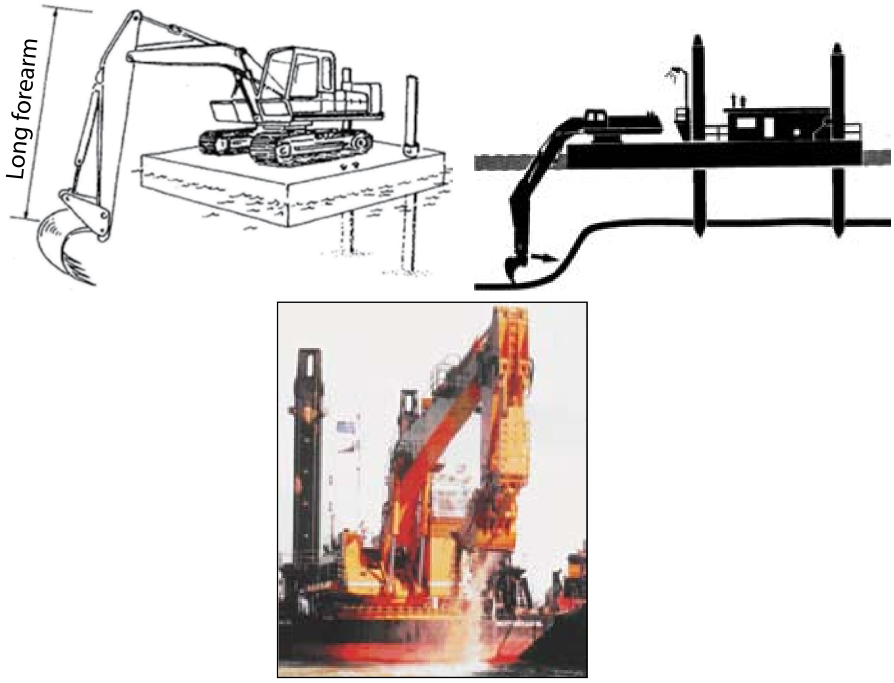
FIGURE 14
The cutter head and a typical full-size cutter-suction dredger



6.2.8 Backhoe dredgers

Backhoe dredgers are land excavators mounted on a pontoon equipped with spuds like a cutter-suction dredger (Figure 15). As with land-based excavators, various fittings are available for tackling different kinds of sediments.

FIGURE 15
Backhoe dredgers, from the smallest size (left) to the largest size (bottom)



The maximum operating depth is limited to around 18 metres.

The advantages of a backhoe dredger are:

- ability to work in narrow or restricted areas;
- versatility in handling a wide range of sediments; and
- side-loaded barges are generally filled with a high solids-to-water ratio.

The disadvantages are:

- when stationary in a navigation channel it causes an obstruction to sea traffic; and
- rough seas, especially swell, hamper this kind of dredging.

6.2.9 Chiselling

Rock breaking may be carried out by a steel chisel dropped through a height by a crane. Normally it is only used in low volume cases where trimming of rock is required. Production rates are very low.

6.2.10 Other methods

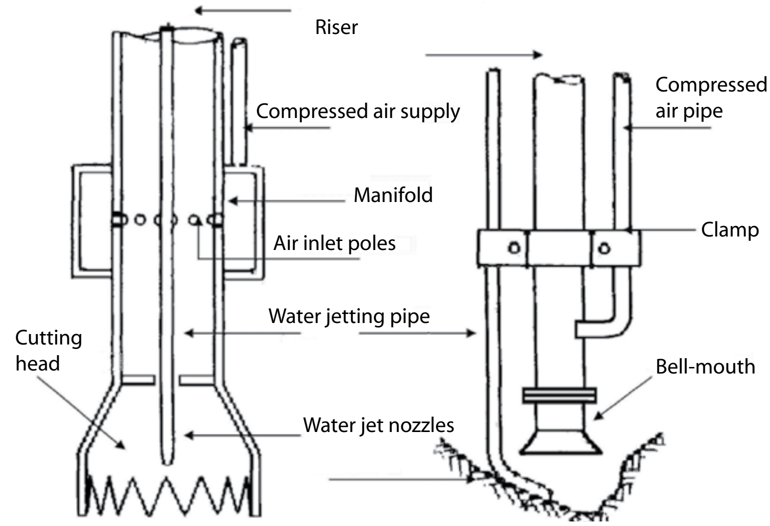
Various other methods may be encountered in practice but they range from specific experimental adaptations to exotic plant.

Airlifting, for example, is frequently used when clearing buried wrecks, but in construction, air lifting is only used to clear underwater foundation trenches from silt drift during construction. An airlift may be used to dredge very small volumes of fine cohesionless deposits only. In the presence of soft clays or clayey silts, airlifts merely form a vertical-sided hole and the material does not tend to slump towards the airlift unless assisted by independent water jets.

Figure 16 shows two types of assisted airlifts typically used in the excavation of foundations in clayey conditions. The airlift in Figure 16 (left) has been used with success on the excavation of bridge foundations in the United States of America. It consists of a 254 mm ejector pipe supplied with air through a 63.50 mm pipe at

11 cubic metres per minute, giving an up-flow velocity of 3 metres per second which is capable of lifting 60 mm gravel. The soil is loosened by a 150 mm jetting pipe operated independently of the airlift. The jetting pipe fed 4 swivelling nozzles of 38 mm diameter fed by two 7 cubic metre per minute pumps delivering water at 34 bar pressure.

FIGURE 16
Types of airlift in use in construction



6.2.11 Dredging adjacent to quay walls

Maintenance dredging adjacent to existing quay walls in fishing ports requires careful assessment of both the material to be dredged as well as the human-made rubbish discarded on the sea bed like tyre fenders, anchors, lengths of chain or wire rope, polyester rope and nets (Figure 17). In most cases, a visual inspection by divers is necessary to verify conditions on the sea bed to be dredged prior to deciding on the type of equipment to be used (cutter-suction versus grab).

In the presence of the aforementioned material, the dredging should be carried out by a grab dredger as illustrated in Figure 3.

FIGURE 17
Cutter-suction heads fouled by discarded items

6.3 DISPOSAL OF DREDGED SEDIMENTS

6.3.1 Introduction

The type of material to be dredged will greatly influence the method of disposal. However, costs can be turned into profits if the dredged material can be used to reclaim land (a process known as reclamation) for industry, roads, housing or leisure. Materials vary in their suitability for reclamation. Sand is the most suitable material for reclamation but all types of granular materials (crushed limestone, gravel, etc.) are suitable. Silt can be used for reclamation if sufficient time is available for drying out and settlement. Due to its fine texture, silt does not dry out as quickly as sand. Instead, before drying out to a fine powdery consistency, it goes through the "muddy" stage, which can take anywhere up to a few months to dry. However, mixed with sand, silty deposits tend to dry out much faster. Sand also improves the consistency of the reclaimed land. Soft clay, once churned up by a cutter-suction dredger, is not suitable as a fill unless it is dried out. This material is only suitable as agricultural fill and cannot be used for foundations or roads. Stiff clay forms into clay balls during the dredging operation and again it is only suitable as agricultural fill.

6.3.2 Classification of dredged sediments

Before deciding on the method of disposal, the dredged sediments must be first classified according to their potential to contaminate the environment where they are due to be deposited. Sediments may be classified under one of three classes:

- Class 1 – clean material, allowable for placing in any type of open water disposal site (open placement on sea bed);
- Class 2 – slightly contaminated, allowable for placing in certain open water disposal sites but requiring careful placing (inside a pit or depression of the sea bed); and
- Class 3 – contaminated material, in principle, not suitable for open water disposal but to be confined in either very strict or well-controlled disposal sites (capped atolls or reclamation).

Various tests on the standard of pollution are required by international legislation and range from the simple water leaching test to multiorganism benthic bioassays or laboratory-controlled tests on selected marine organisms.

The elutriate test is a water leaching test using one part sediment to be dredged to four parts water taken from the proposed dump site. This test, in use since 1973, has been evaluated under an extremely wide range of conditions and is useful for evaluating the short-term release of contaminants from dredged sediments into open water.

The multiorganism benthic bioassays comprise a range of laboratory tests on such organisms as algae, zooplankton, filter feeders (bivalves), deposit feeders (crustaceans) and burrowing species (polychaetes). The tests range from simple physical disruption to direct toxicity and bioaccumulation and consider the liquid, suspended and solid phases of the dumping. Even though bioaccumulation may occur from all three phases, the liquid (or leaching stage) and the suspended (dust plume) phases are of secondary concern due to their short-term occurrence. The solid phase, however, must be assessed for its bioaccumulation potential due to the long-term contact between the dumped sediment on the sea bed and marine organisms.

6.3.3 Environmental impacts of dredging

Strictly speaking, even capital and maintenance dredging in Class 1 sediment (clean material) are an environmentally disruptive exercise and an environmental impact assessment should always be carried out prior to any dredging. Dredging is characterized by three distinct operations:

- the removal of material from an existing environment;
- the method of removal of the material; and
- the dumping of the unwanted material in another environment.

The removal of the material in itself has many potential impacts on the environment and great care should be exercised in distinguishing each and every one of these impacts. For example:
- the sea bed may be used by fish for spawning (some fish require soft sand to dig a nest);
- most shellfish live in sand; and
- if seaweed is also anchored to the sea bottom, the area may serve as a nursery ground for juvenile fish.

The method of removal also has many potentially negative impacts and careful planning is required prior to mobilizing equipment. For example:
- A cutter-suction dredger is very fast but under certain conditions (especially in the presence of coral, coralline limestone and clay) it creates a dust plume visible for miles around the dredger; this plume blocks out sunlight (not particularly good for live coral) and chokes fish by depositing fine dust on their gills.
- High explosive blasting is a quick method of removing obstacles but it also kills marine life indiscriminately in the vicinity of the project.
- A leaking clam-shell grab is not suitable for dredging in a sensitive environment (clear water coral environment) due to the dispersion of fines in the water column.

Finally, the physical and chemical impacts of the actual dumping of the unwanted sediment must also be investigated. Ideally, if the material is clean material, then it should be used for reclaiming land or for filling. However, when the material consists of clay (not suitable for reclamation) mud or silt, it is usual to dump it offshore with a hopper barge, Figure 2. Dumping of Class 1 sediment, for example, may still:
- stifle growth in certain bivalve species through smothering with fine silt; and
- indefinitely render the water murky with the slightest wave agitation if the silt portion is too high.

Dumping of Class 3 sediment, for example, may:
- transpose contaminants from one environment to another and contaminate potentially fertile environments used in fisheries.

Class 3 sediments must be capped whether dumped at sea or on land.

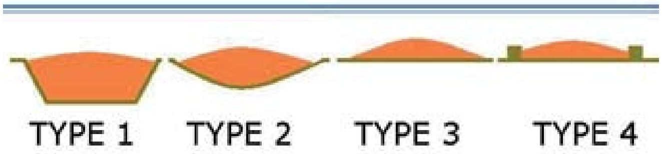
6.3.4 Open water disposal

Since dumping of dredged materials at sea is still a major means of disposal of Class 1 and Class 2 sediments, the selection of dump sites should be carried out by matching the characteristics of the sediment and the site.

Figure 18 illustrates the four basic types of aquatic disposal of sediments up to Class 2 level of contamination. Type 1 consists of a human-made depression in the sea bed (dredged or excavated channel), Type 2 consists of a natural depression in the sea bed, Type 3 consists of a level sea bed and Type 4 is lateral confinement. In all cases, the material deposited may need to be capped with a layer of clean material to isolate it from the surrounding environment.

Permission for the aquatic disposal of dredged sediments at a specific site must be sought from the delegated competent authority.

FIGURE 18
Types of open-water or aquatic disposal

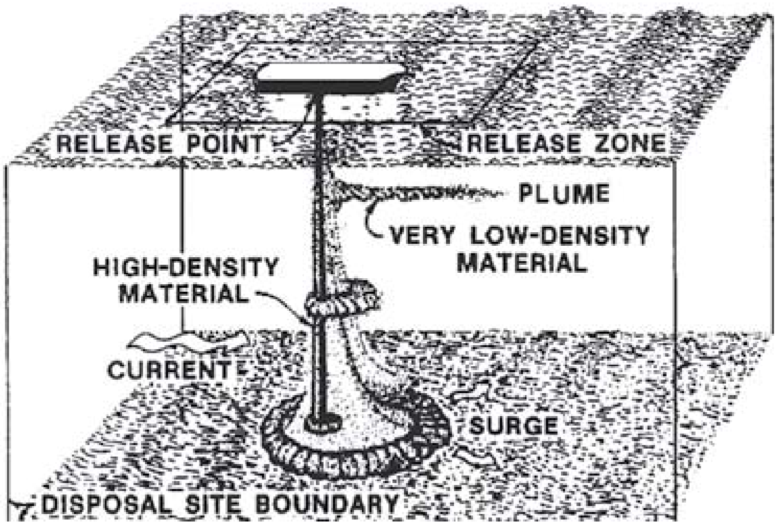


The permit conditions for a site should be designed such that:

- only those materials which have been characterized and found to be acceptable by the environmental impact studies (EIS) are placed at the site;
- material is placed within the site boundaries;
- that the dredging and disposal management techniques have been identified by the EIS; and
- that monitoring requirements are fulfilled and the results reported to the competent authority.

The transboundary drift of the dredged sediments plume, Figure 19, during or after dumping has taken place is a matter of concern when the selected dumping ground is close to territorial boundaries (see Section 1.4.10 on transboundary impacts). In such cases, the permit conditions must include the installation of real-time GPS equipment on the dumping barge and monitoring requirements must ensure that seasonal currents do not transport the plume across national boundaries.

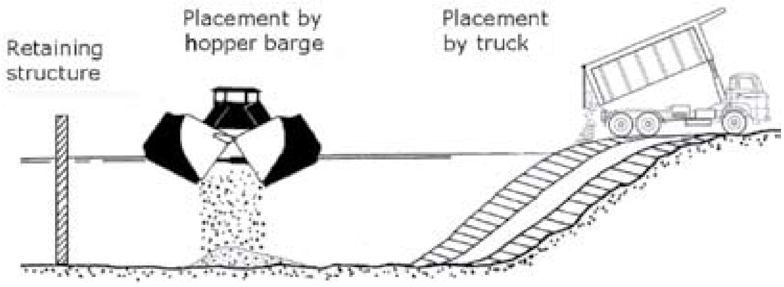
FIGURE 19
Offshore dumping by barge



6.3.5 Confined shore disposal

If dredging (granular material) is being carried out by a grab dredger, hydraulic excavator or drag line, then the material may be loaded onto trucks, carted away and tipped behind a retaining structure (a quay wall) as backfill. Typically, such material will come to a rest at a slope ranging from 1 on 2 to 1 on 6 depending on the size and roughness of the individual particles; the smaller and smoother the particles, the flatter the slope, Figure 20.

FIGURE 20
Placing of backfill behind a quay wall by dumping or tipping



If the dredging is being carried out by a suction or a cutter-suction dredger, then it may be pumped onshore via floating pipes or via a shore connection, Figures 8, 21 and 22.

FIGURE 21
Placing of backfill behind a quay wall by pumping

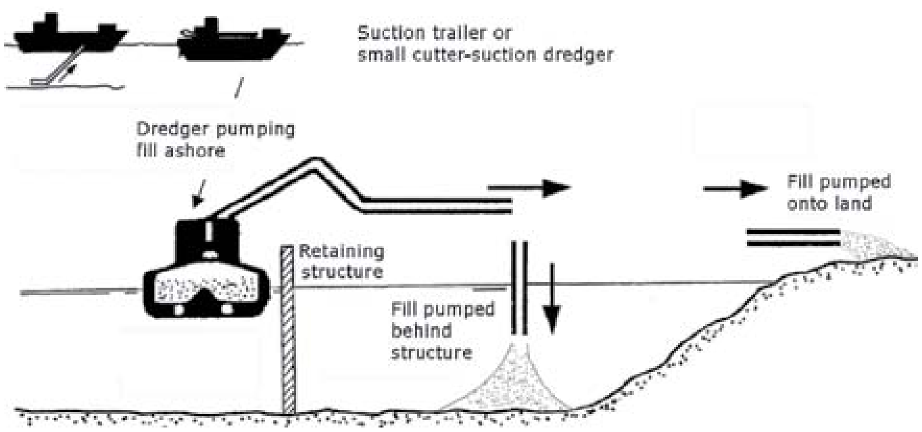
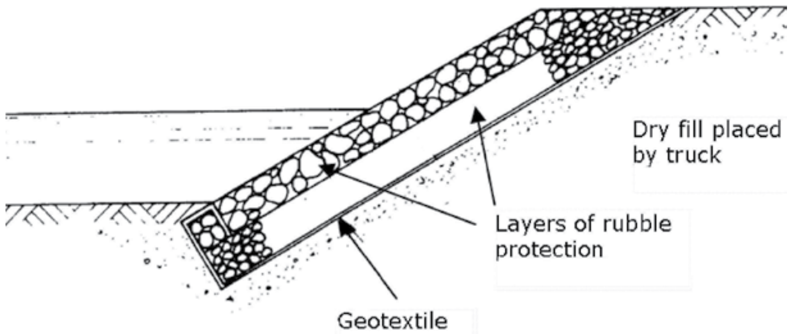


FIGURE 22
Placing of backfill behind a quay wall by pumping

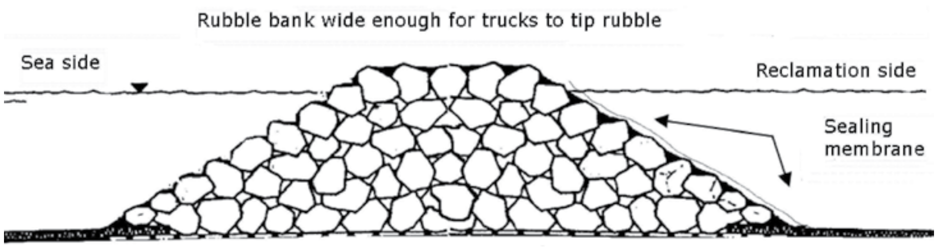
Land reclaimed by forward tipping should be protected by a geotextile filter mat (to prevent sand loss and eventual settlement of the reclaimed area) and a layer of at least 2 metres thick of graded stone, as shown in Figure 23. A mass concrete kerb may also be placed at the summit of the rubble bank to prevent vehicles from driving into the water and falls built into the paving to drain surface water away to sea.

FIGURE 23
Rubble slope protection



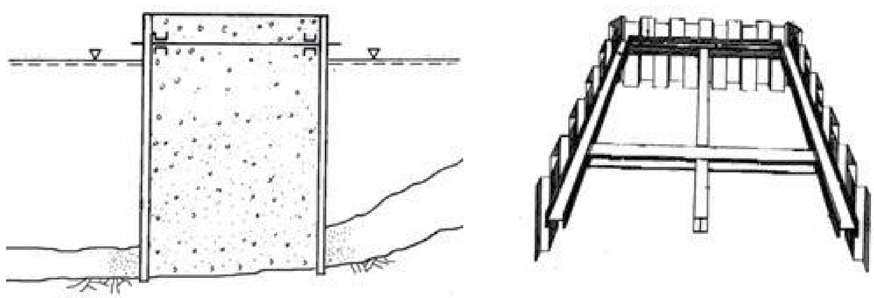
Small-to medium-sized earth retaining structures, such as bunds or quay walls, may be constructed in a variety of ways. The simplest bund is a rubble or stone bund, forward tipped by truck and sealed on the landside by an impermeable layer, Figure 24.

FIGURE 24
Rubble bund



Small quay walls may also be constructed in mass concrete by pumping concrete inside a sheet pile cofferdam, Figure 25.

FIGURE 25
Sheet pile cofferdam



Quay walls may also be constructed with conventional rectangular blocks, Figure 26; “I” section blocks in-filled with stone (lighter to handle than a rectangular block), Figures 27 and 28; “L” shaped units, Figure 29; and annular rings, Figure 30.

Deeper water solutions may be in sheet piles or caissons.

FIGURE 26
Rectangular blocks (20 tonnes)

FIGURE 27
“I” section blocks (10 tonnes)

FIGURE 28
“I” blocks in-filled with rock

FIGURE 29
“L” section blocks (12 tonnes)

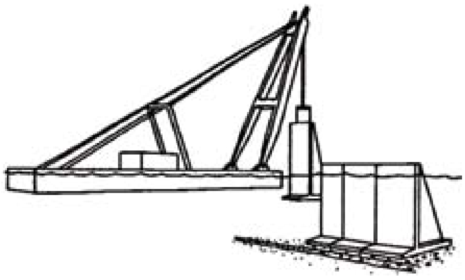
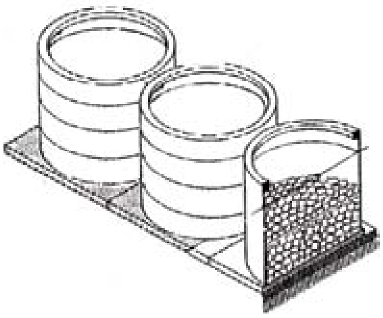


FIGURE 30
Annular rings filled with rock



6.4 DREDGING OF FAIRWAYS

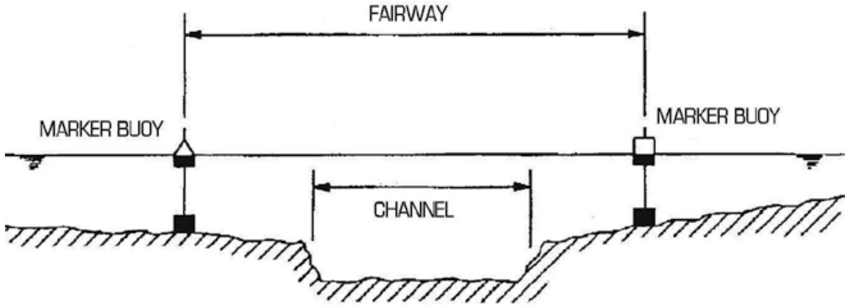
6.4.1 Minimum width

Access channels or fairways are defined in Figure 31. In many dedicated channels the navigation markers are placed close to the edge of the channel to indicate the limits for safe navigation.

In determining the channel width, some or all of the following should be considered:

- basic maneuverability of the vessels intending to use the channel;
- cross-winds, which may cause vessels with high windage to drift sideways;
- cross-currents, which may also cause deep-draft vessels to drift sideways; and
- wave action, which may be heading or following (affecting pitch and heave) or beam (affecting roll and heave).

FIGURE 31
Channel and fairway definitions



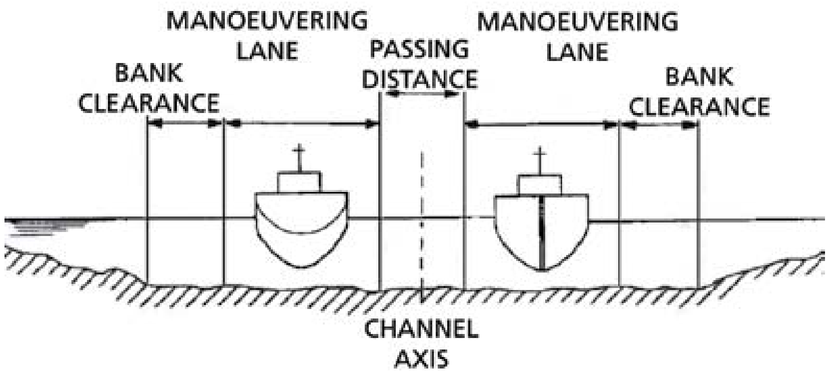
If a two-way channel is proposed, then allowance must be made for vessels to pass each other safely. Such a distance, Figure 32, must ensure that vessel-to-vessel interaction is reduced to an acceptable limit and it is usual to allow for a central safety strip, known as the "passing distance".

Bank clearance should be large enough to reduce bank effects to a minimum, especially in the presence of mobile or unstable deposits such as sand or mud. As a rule of thumb, the minimum fairway width should not be less than eight times the width of the largest vessel to enter the fishing port.

In channels with a wide range of traffic, the fairway markers should be positioned in such a way as to allow the passage of smaller vessels on either side of the dredged channel. In some cases, both the deep-water dredged channel and the shallower outer lanes for smaller vessels may be marked.

There may also be a maximum permissible speed imposed to avoid bank erosion due to backwash from the passage of vessels.

FIGURE 32
Components of channel width

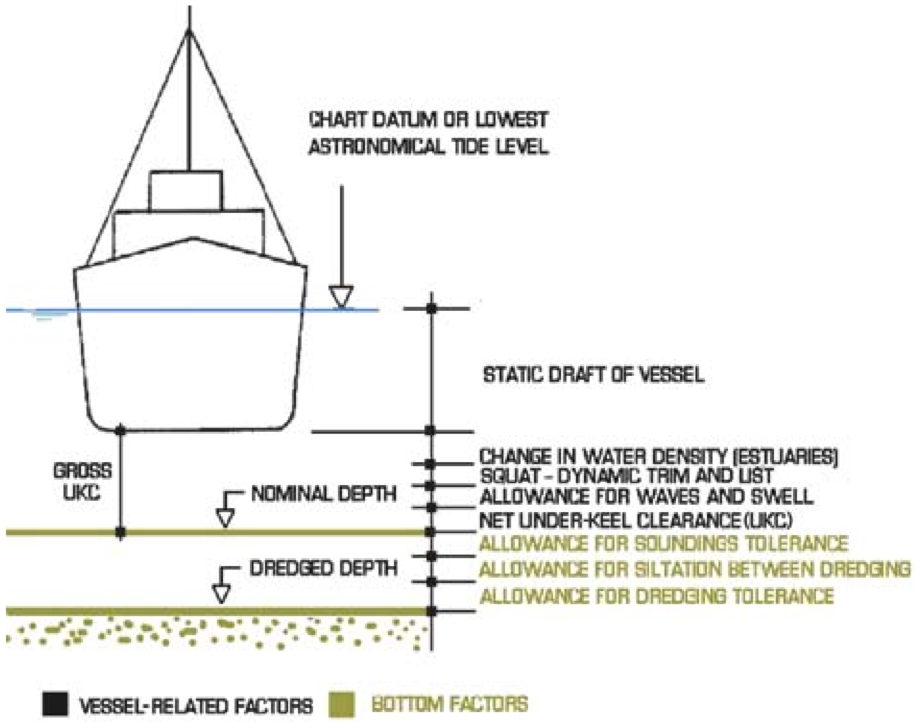


6.4.2 Minimum depth

For a vessel to safely transit the access channel or fairway, it must have adequate clearance under the keel. The under-keel clearance, also known as UKC, depends on a variety of different parameters. These parameters are related to the vessel, the type of sea bed and the water level, Figure 33.

The net under-keel clearance is the minimum margin remaining between the channel bed level and the keel of the vessel in fully loaded condition and in the most unfavourable weather condition. The net under-keel clearance should not be less than 0.50 metre for a soft sea bed (silt or sand) and not less than 1.0 metre for a hard sea bed (rock).

FIGURE 33
Components of channel depth



6.5 BIBLIOGRAPHY AND FURTHER READING

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