5. Hydrographic surveys

SUMMARY

In the past, many artisanal shelters and fishing ports were built at convenient locations, with no particular attention paid to such environmental factors as wave heights, sudden changes in water depths, uncharted reefs, currents, tidal streams, seaweed and mobile beaches (sand drift). Many of the structures were subsequently expanded and, in countless cases around the world, many of the problems that used to be considered minor have now developed into major ones, with some shelters, for example, fouling up with seaweed or silting up (shelter mouth facing the wrong direction) or just being inaccessible in rough weather (reefs too close to entrance channel).

A hydrographic survey, also known as a bathymetric survey, is therefore essential if the correct design decisions are to be made right from the project inception stage to ensure that the landing is easy to use and free of major maintenance problems under all conditions.

This chapter (related to Chapter 7) reviews the various types of hydrographic surveys and equipment that exist in relation to the amount of detail required during the design stage and illustrates clearly how this can be applied at the artisanal level. Consequently, the reader will be able to draw up appropriate terms of reference for hydrographic surveys.

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5.1 HYDROGRAPHIC STANDARDS AND CLASSIFICATIONS

5.1.1 Introduction

The results from a hydrographic survey are normally plotted to produce a bathymetric contour map, which is a plan of the depth of the sea bed arranged in such a manner as to show lines of equal depth from the coastline. In a hydrographic survey, the actual measurement of the water depth is the easy part. The main problem is not knowing how far the survey boat is from the coastline when the depth is recorded.

Boat A in Figure 1, for example, has no point of reference in relation to the coast. Boat B, on the other hand, is using a calibrated float line to obtain a "FIX" or position with respect to the coastline; in this case, 20 metres away on the straight line between the peg and the buoy. Hence, for each vertical depth recording, a horizontal position "FIX" is also required. Both vertical depth measurements and horizontal position measurements may be carried out either manually (low tech, low cost) or using sophisticated depth and position fixing equipment (high tech, high cost), depending on the end use of the survey.

Hydrographic surveys are required for a wide variety of purposes, ranging from simple reconnaissance (at project formulation, for instance) to payment for work carried out underwater, such as dredging or reclamation. The size of the area to be surveyed also influences the methodology to be used and hence the equipment required. In ascending order of accuracy, hydrographic surveys may be broadly classified as:

- Reconnaissance or Class 3
- Project condition or design or Class 2
- Contract payment or Class 1

Levels of accuracy for hydrographic surveys are intended to correspond directly to these three classes (Table 1). Class 3 is the lowest accuracy standard, Class 2 is a medium accuracy standard, and Class 1 is the highest accuracy standard.

Since expensive horizontal positioning and depth measurement equipment may be installed aboard a particular survey vessel, this same equipment may be typically used for all three classes. Any accuracy distinction between the classes is primarily a function of the field procedures used, along with recognized equipment limitations.

FIGURE 1
Fixing a vessel's position offshore

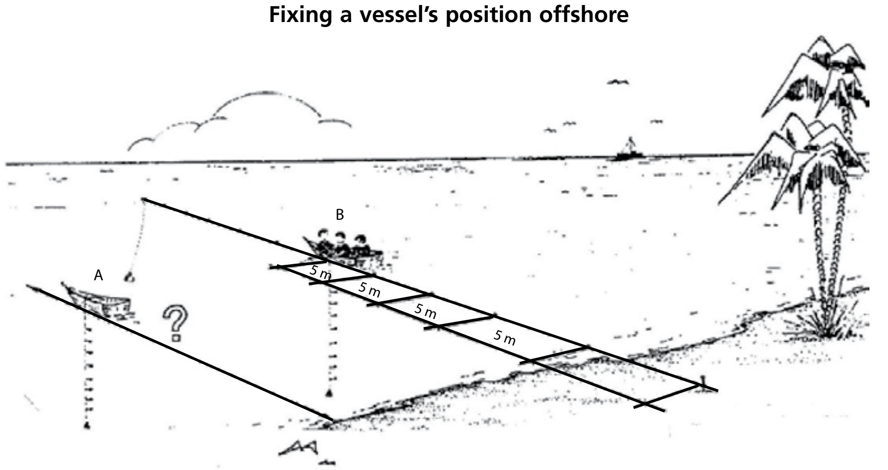


TABLE 1
Maximum allowable errors in hydrographic surveys

Type of survey	Class 3	Class 2	Class 1
Vertical accuracy	500 mm	300 mm	150 mm
Horizontal positioning	100 metres	12 metres	6 metres

5.1.2 Methodologies

There are various methodologies in use nowadays to carry out a hydrographic survey, depending on the end use of the survey and the size of the area to be surveyed. Vertical depth measurements may be carried out using:

- hand-held calibrated lead sounding line;
- simple engineering echosounder recording on paper; and
- advanced engineering echosounder recording on a data logger and linked to position fixer via integrated software (fully automated).

Horizontal position fixing measurements may be carried out using:

- hand-held optical square in conjunction with a float line;
- single theodolite in conjunction with a float line or twin theodolites;
- constant range tracking electronic positioning system (EPS); and
- differential Global Positioning System (GPS).

5.1.3 Vertical depth measurements

Figure 2 illustrates the hand-held calibrated lead sounding line, right, and on the left, the simple engineering echosounder (transducer not shown).

FIGURE 2
Echosounder and lead line

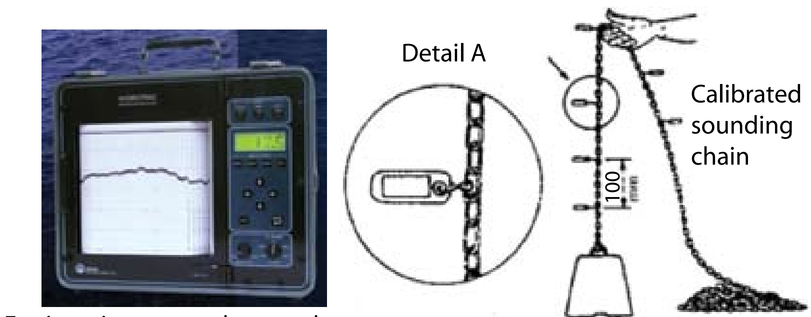


Figure 3 illustrates an advanced echosounder of the type used in modern Class 1 surveys. The echosounder is linked to a software package and yields electronic contour maps directly. This type of echosounder is also used for real-time monitoring of dredging works.

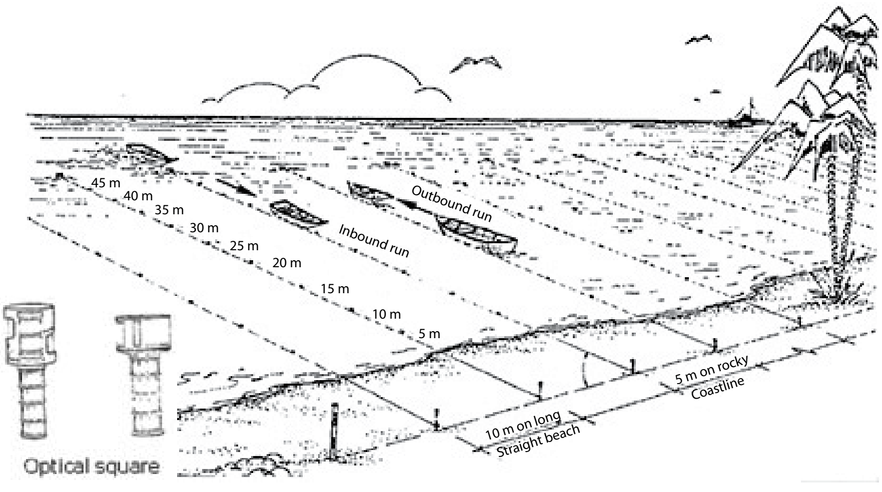
FIGURE 3
Advanced echosounder integrated with survey software (www.reson.com)

5.1.4 Horizontal position fixing

5.1.4.1 Method 1

The hand-held optical square in conjunction with a float line method, also known as the parallel line method (Figure 4), is the most basic and consists in setting out a straight baseline along the beach, say 100 metres long or more, depending on the extent of the hydrographic survey, with a ranging rod placed at either end. At every 5 or 10 metres from either end (5 metres for irregular terrain and 10 metres for flat beach), a steel peg is driven into the ground and, by means of an optical square (or theodolite), a buoy is dropped offshore at right angles to each peg.

FIGURE 4
Parallel line method



One end of the float line is anchored to the steel peg and the other to its corresponding buoy offshore. By tying in the baseline to the topographic survey, the depth readings may be plotted on paper in the right place. It is always a good practice to extend the survey about 100 metres on either side of the proposed shelter or landing.

The actual depth of the water may be read by simply lowering the calibrated sounding chain every 5 or 10 metres and the person using the chain calls out the readings to another person in the boat who records the figures on paper in the correct order. This type of recording yields a grid with spot levels only. If an engineering echosounder is available with an experienced operator, the actual soundings may be recorded on the special thermal paper roll by the instrument itself. In this case, only the operator need accompany the boat pilot on the survey vessel up and down the graduated float lines. A continuous bottom profile is thus obtained on a continuous strip chart and sounding levels scaled off the chart.

When carrying out the hydrographic survey:

- The sounding chain must reach the bottom in a vertical line; when using a sounding chain the vessel must be still when the actual reading takes place. If the area is subject to strong tidal streams, the weight of the sinker should be increased by attaching further weights to the chain.
- The depth reading must be recorded with the time at which the recording was made to allow for changes in the level of the tide.
- If an echosounder is being used, inbound runs are preferred to outbound runs. By starting an inbound run, say 50 metres away from the float, the vessel's skipper will be in a better position to place the boat parallel to the floating line.
- In both cases, stormy or windy days should be avoided as should the flood and ebb periods in strong tidal areas. The sea should be perfectly calm.

- In rocky areas, before removing the float lines, a swimmer wearing a pair of goggles (or diver) should then swim up and down the surveyed line looking for submerged rock outcrops or wrecks. The diver should point these out by placing small floats near them and measure the depth of water over the obstacle. These floats should then be plotted on the survey map by taking a series of fixes from the baseline with the theodolite, Method 2, triangulation.

FIGURE 5
A soundings plot using the parallel line method

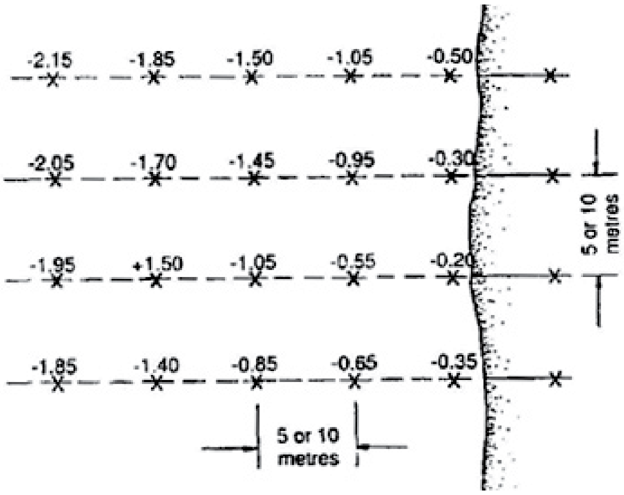
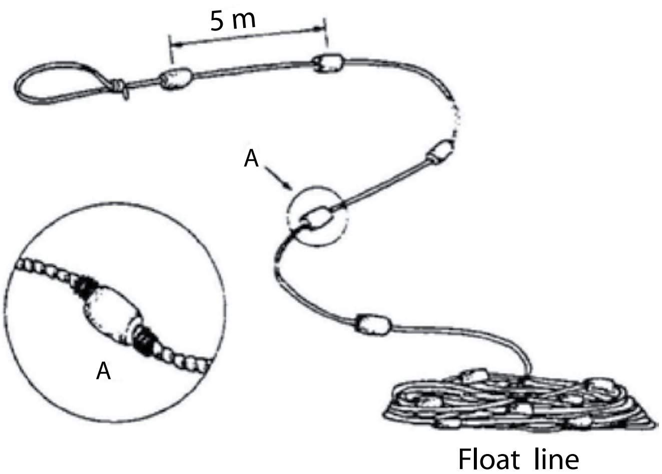


Figure 5 illustrates the type of plotted soundings derived by this method of survey. This method is considered acceptable for all three classes of surveys with a maximum offshore distance of 200 metres and is suitable for fish landing areas, small fishing ports, breakwater construction, minor reclamation and minor excavation and/or dredging.

FIGURE 6
The calibrated float line – maximum length 200 metres

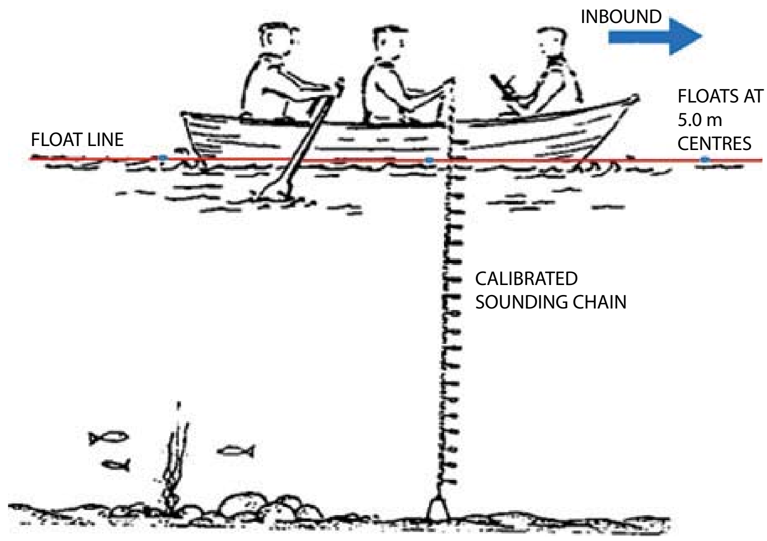


Material	Nylon	Polyethylene	Polypropylene
Stretch (elasticity)	High elongation	Low elongation	Low elongation
Weight of 200 m	20.6 kg	16.0 kg	14.5 kg
	Not suitable	Suitable	Most suitable

The calibrated float line, illustrated in Figure 6, should be made up from a length of 12 mm diameter polypropylene rope with coaxial coloured floats at 5 and 10 metre intervals. One large spherical red float should be installed every 50 metres to ease chain readings from the survey vessel. The completed float line may be either wound on a purpose-made plastic drum or stowed inside a large fishermen's basket and paid out over the bow or stern of the vessel.

The float line is rather difficult to keep stretched in a perfect line in the presence of wind, waves or current. It is therefore recommended that survey work involving float lines be carried out when the sea is perfectly calm (Figure 7).

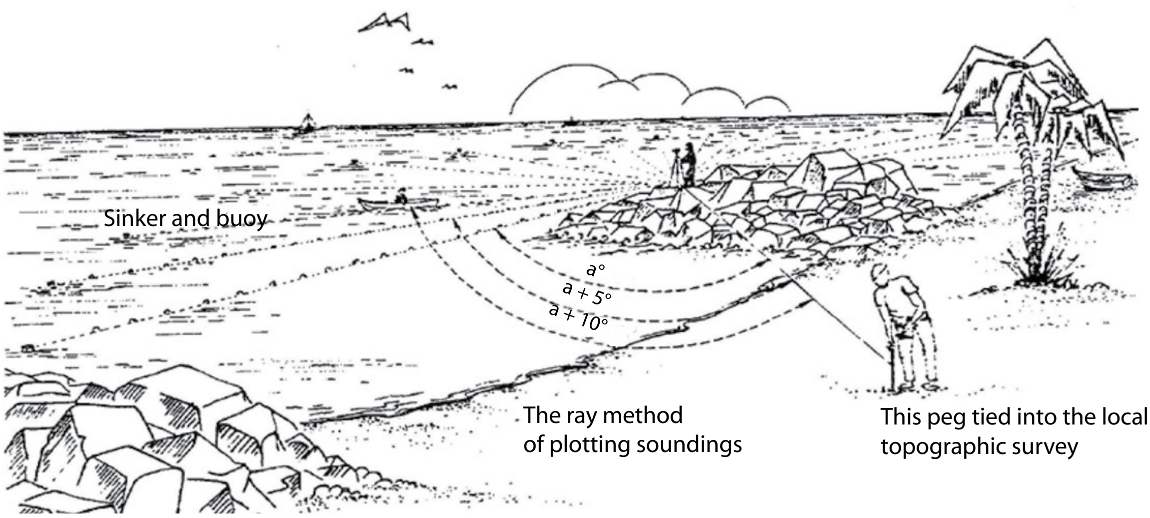
FIGURE 7
Recording the soundings manually at 5 m centres



5.1.4.2 Method 2

The single theodolite, in conjunction with a float line (ray method) or twin theodolite intersection (triangulation method), is the second most basic method of fixing positions offshore. In the past, positioning by these methods from baseline points onshore was often used to position vessels on near-shore projects.

FIGURE 8
The ray method



Although it is no longer commonly employed, this method is considered acceptable for all three classes of surveys with a maximum offshore distance of 300 metres for the ray method, Figure 8, and around 1 000 metres for the triangulation method. Beyond this distance it may be difficult to collimate the theodolite on small objects, especially during hot summer days. More often, this method is used to perform EPS calibration when fixed points are inaccessible to the vessel. Triangulation positioning techniques are labour intensive. Two shore-based transit or theodolite observers are required, along with communication equipment with which to transmit the observed angles (or direction azimuths) to the surveyor. Due to the higher precision and stability of the instruments, the resultant positional accuracy can be quite good, provided observing procedures are properly executed.

Simultaneously observed positional "fixes" are usually radioed over to the survey boat. Fixes may be at equal time intervals or as called for on a random or as-needed basis, such as during EPS calibration. Advance warning is made of upcoming fix events so that observers can initiate precise tracking of the boat. A defined point aboard the vessel (mast or aerial) is normally tracked. This well-marked point should be centred over the echosounder transducer.

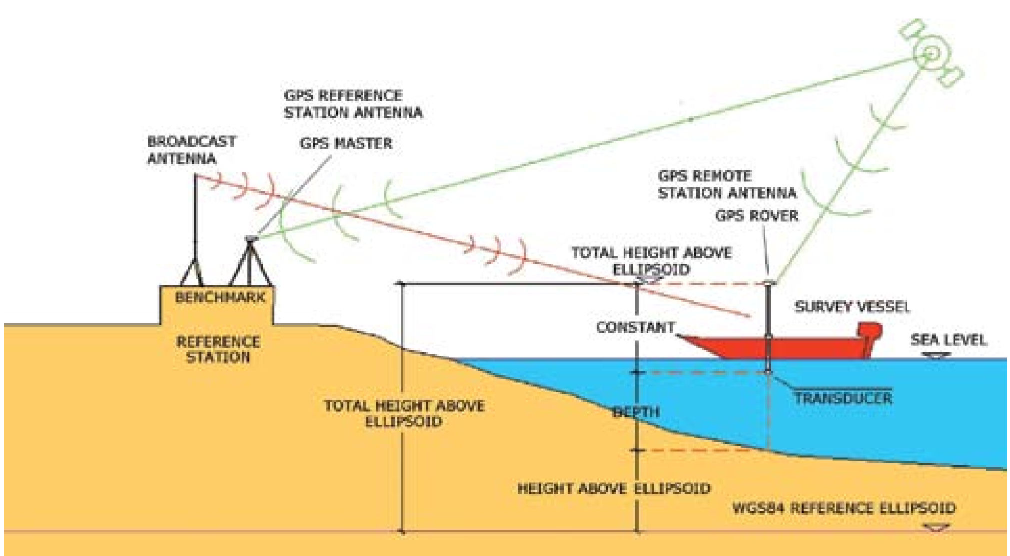
5.1.4.3 Method 3

The constant range tracking EPS used to be the most commonly employed positioning method. This method replaced the triangulation theodolites with electronic microwave ranging EPS which utilize range-range positioning techniques. This method has now been superseded by GPS techniques.

5.1.4.4 Method 4

Differential GPS is the primary survey reference for all types of present-day engineering and construction activities. GPS is a continuous, all-weather, worldwide, satellite-based electronic positioning system. It is available to the general public and is known as a standard positioning service. Over the past several years, a technique has been developed to process signals from two GPS receivers operating simultaneously to determine the 3-D line vector between the two receivers. This technique is known as "*differential positioning*" (DGPS) and can produce real-time positions of a moving vessel, Figure 9.

FIGURE 9
Differential GPS real-time measurement of position of survey vessel



5.2 EFFECTS OF VESSEL ROLL PITCH AND HEAVE

Correcting observed depths for the superimposed effects of vessel roll, pitch and heave is perhaps the most difficult aspect of hydrographic surveying since all three conditions can occur simultaneously and at different periods. Roll and pitch introduce bias error in depth, resulting in a deeper reading over a level bottom (Figures 10 and 11). On side-mounted transducers, this bias error is compounded by the random up and down motion (heave) of the vessel.

Unless reliable motion compensation devices are used, the only practical method of minimizing vessel motion effects is to limit the maximum allowable sea states under which a particular class of survey may be performed.

Such limitations are highly subjective and can have significant economic impacts, due either to delayed survey work or to inaccurate payment when a Class 1 survey is performed under adverse conditions. Maximum sea state limitations must also factor

FIGURE 10
The effect of vessel roll on depth soundings

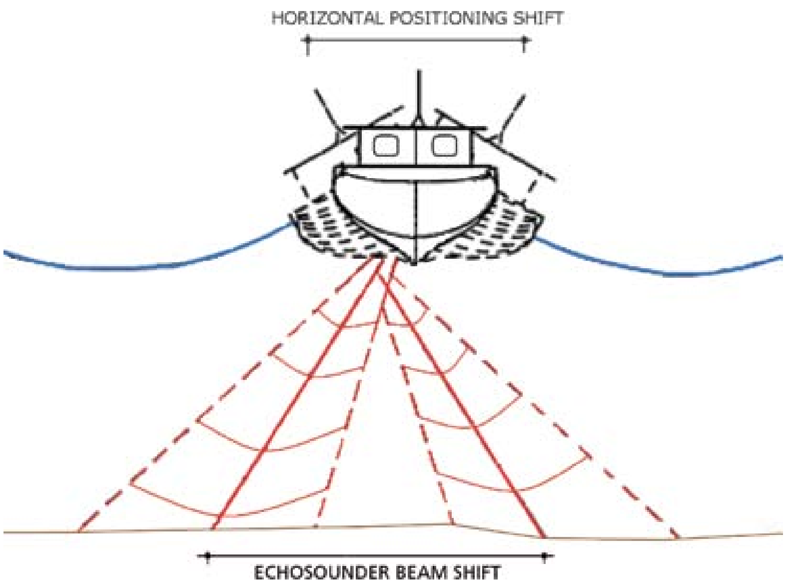
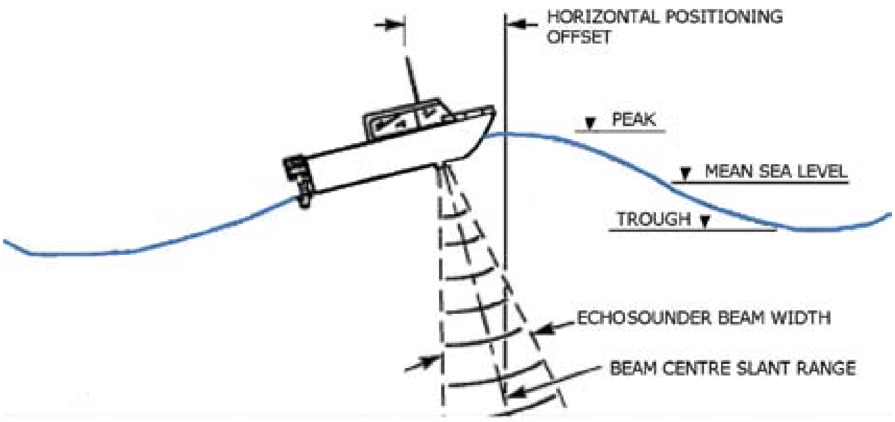


FIGURE 11
The effect of vessel pitch and heave on soundings



in the size and relative stability of the survey vessel (Figure 12), along with the effects of the prevailing wave direction relative to the survey lines or cross-sections. Thus, a simple maximum allowable wave height criterion is difficult to specify. Hence, hydrographic surveys are best performed during calm weather spells.

FIGURE 12
Typical small vessel outfitted for hydrographic surveys

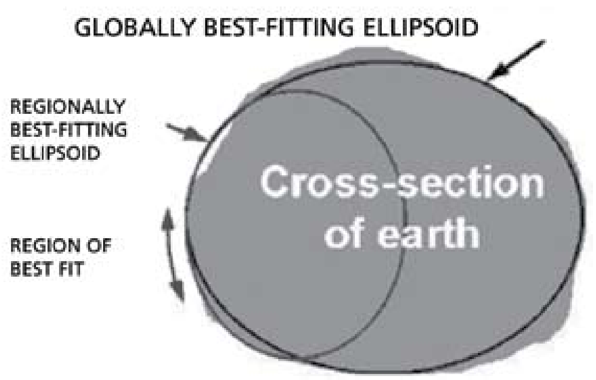
5.3 THE WGS84 DATUM

In Figure 9, GPS readings of the roving antenna are given above a datum called the WGS84 (World Geodetic System 1984). A cursory look at the topographic and oceanographic details of the globe indicates that the Earth is a very irregular and complex shape. To map positions of those details, a simpler model of the basic shape of the Earth, sometimes called the "figure of the Earth", is required.

The science of geodesy, on which all mapping and navigation is based, aims firstly to determine the shape and size of the simplified "figure of the Earth" and goes on to determine the location of the features of the Earth's land surface – from tectonic plates, coastlines and mountain ranges down to the control marks used for surveying and making maps. Hence, geodesists provide the fundamental points of known coordinates which cartographers and navigators take as their starting point. The first question of geodesy, then, is "What is the best basic, simplified shape of the Earth"?

The Earth is very nearly spherical. However, it has a tiny equatorial bulge that makes the radius at the equator about 0.33 percent bigger than the radius at the poles. Therefore, the simple geometric shape which most closely approximates the shape of the Earth is a biaxial ellipsoid, which is the three-dimensional figure generated by rotating an ellipse about

FIGURE 13
Best-fitting ellipsoid on the shape of the Earth



its shorter axis. The shorter axis of the ellipsoid approximately coincides with the rotation axis of the Earth. Because the ellipsoid shape does not fit the Earth perfectly, there are many different ellipsoids in use, some of which are designed to best-fit the whole Earth and some to best-fit just one region (Figure 13). The datum used for GPS positioning is called WGS84. It consists of a three-dimensional Cartesian coordinate system and an associated ellipsoid, so that WGS84 positions can be described as either XYZ Cartesian coordinates or latitude, longitude and ellipsoid height coordinates. The origin of the datum is the geocentre (the centre of mass of the Earth) and it is designed for positioning anywhere on Earth. The WGS84 datum is a set of conventions, adopted constants and formulae and includes the following items:

- The WGS84 Cartesian axes and ellipsoid are geocentric; that is, their origin is the centre of mass of the whole Earth including oceans and atmosphere.
- The scale of the axes is that of the local Earth frame.
- The orientation of the ellipsoid equator and prime meridian of zero longitude coincide with the equator and prime meridian of the Bureau Internationale de l'Heure at the moment in time 1984.0 (that is, midnight on New Year's Eve 1983).
- Since 1984, the orientation of the axes and ellipsoid has changed such that the average motion of the crustal plates relative to the ellipsoid is zero. This ensures that the Z axis of the WGS84 datum coincides with the International Reference Pole, and that the prime meridian of the ellipsoid (that is, the plane containing the Z and X Cartesian axes) coincides with the International Reference Meridian.

5.4 SPECIFYING HYDROGRAPHIC SURVEYS

Although hydrographic surveys have become fully automated through the use of custom-designed software, they are still considered expensive surveys to carry out, especially when the survey equipment has to be moved in from far afield.

The size of the area to be surveyed depends greatly on the project being attempted and some basic rules-of-thumb are appropriate (Table 2).

TABLE 2
Class of hydrographic surveys

Project design stage	Outline	Preliminary	Final
Phase of studies	Formulation	IEE	EIS/EIA
Standard required	Navigation chart	CLASS 3	CLASS 2
Type of construction	**Port**	**Dredging**	**Reclamation**
Standard required	Class 1	Class 1	Class 1

5.4.1 Outline design and project formulation

During project formulation no physical surveys are required. A sea chart at the appropriate scale is more than enough for selecting potential sites to insert in a shortlist for further detailed studies.

5.4.2 Preliminary design

At preliminary design or project preparation, a Class 3 survey is adequate. This can be an all manual survey carried out from a local fishing vessel using locally available equipment. If the project is located on or near a sandy beach, the area covered by the survey should extend at least 250 metres on either side of the project and down to the 7 metre contour.

5.4.3 Final design

During the final design of a port project, a physical or mathematical model may need to be built and run to determine the potential impacts of the port on the adjacent coastline. A Class 2 survey is required. If the port project is located on a rocky coastline, the area covered by the survey should extend at least 500 metres on either side of the project. If the port project lies on a sandy coastline, the survey should extend 1 000 metres on either side of the project. In both cases, the offshore extent of the survey must reach the 20 metre contour.

5.4.4 Construction phase of a port

During the construction phase of a port, a new and more detailed survey is required for the purposes of payment. Monitoring surveys may also be required in areas prone to erosion or accretion. Class 1 surveys are normally required at this stage and the extent of the survey does not need to exceed the submarine footprint of the port structures.

5.4.5 Maintenance dredging and reclamation

Only Class 1 surveys are required and the extent does not need to exceed the submarine footprint of the dredging works.

5.5 SAMPLE SURVEYS

Figures 14 and 15 are examples of the type of precision required at different stages in the design and construction process of a port. Figure 14 is a Class 2 survey that was commissioned during the environmental impact studies (EIS) for a new port to determine the behaviour of waves impacting the site via the construction and operation of a physical model. The vertical resolution required at this stage was 1.0 metre (with a Class 2 accuracy) with a horizontal grid of 100 metres (also with a Class 2 accuracy). Figure 15 illustrates a Class 1 survey utilized for the final payment of the contractor for the excavation work carried out for the construction of the breakwater. The vertical resolution is now 10 centimetres with a horizontal grid of 2.50 metres, both well below the maximum Class 1 accuracy.

FIGURE 14
A Class 2 survey used for the EIS of the breakwater (in red)

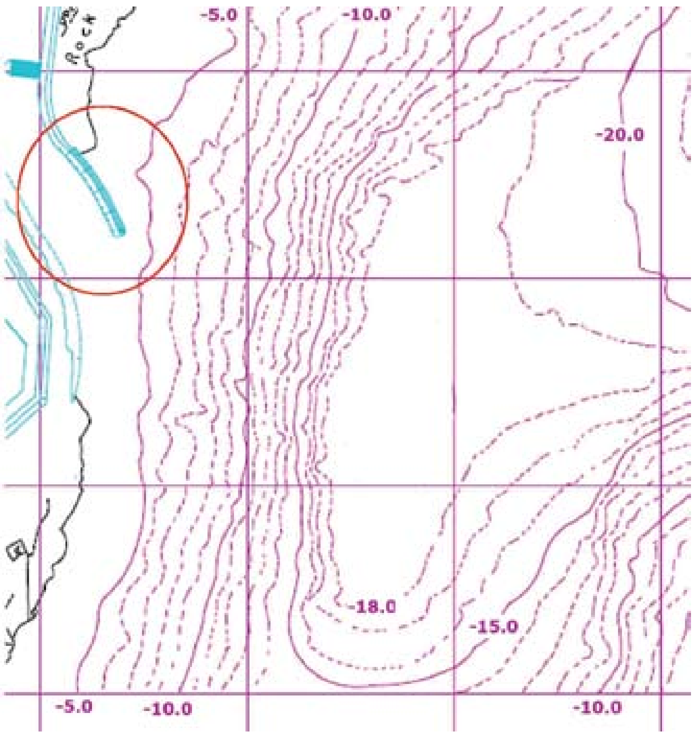
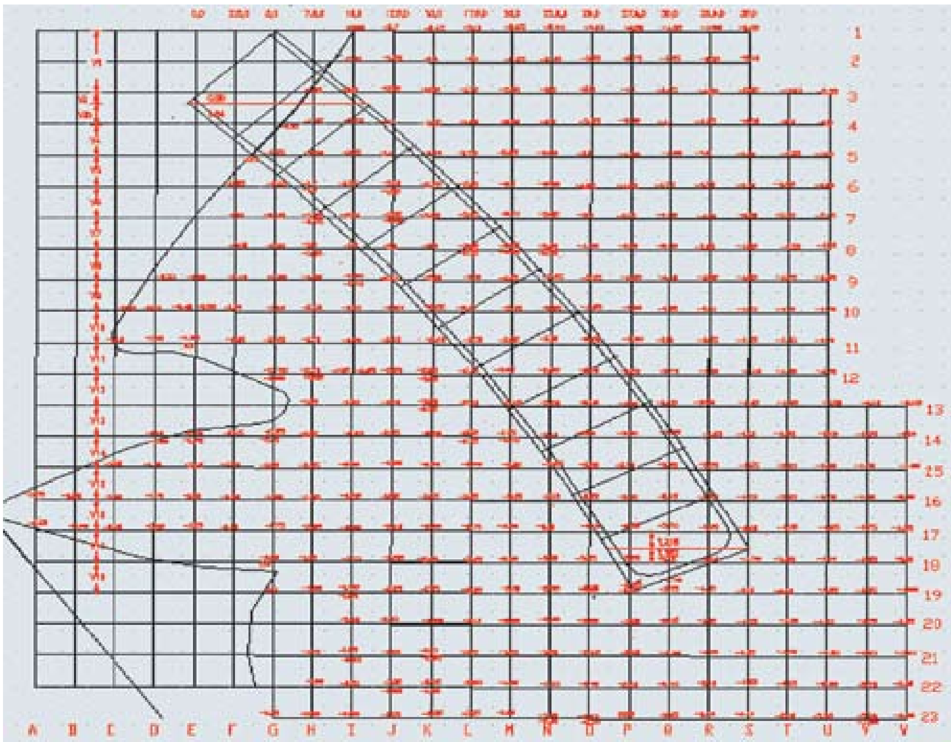


FIGURE 15

A Class 1 survey used for the payment of the excavation of the same breakwater



5.6 TIDE SURVEYS

5.6.1 Tides

"Tides" should not be confused with "tidal streams", although loose terminology has undoubtedly come to use the word "tide" for both. A tide is a periodic vertical movement in the level of the sea, whereas a tidal stream, even though resulting from a tide, is a periodic horizontal movement. Tides affect the depth of water at a place; tidal streams affect navigation courses.

A tide is a periodic vertical movement in the level of the sea. In consequence of the solar cycle, at times of new and full moon, at a place the highest high waters (HHW) and the lowest low waters (LLW) of a tide cycle – SPRING TIDES – will be experienced and **7-¼** days after these, with the first and last quarters of the moon, the lowest high waters and the highest low waters of a tide cycle – NEAP TIDES – will occur.

There are thus two separate tide cycles: height fluctuations from SPRINGS to NEAPS twice each in a lunar month (29 days), Figure 16, and height oscillations of each tide from high water to low water twice each in each lunar day.

5.6.2 Tide datum

The hydrographic surveys in tidal areas should be referenced to a base elevation or chart datum, Figure 16, normally taken as the lowest astronomical tide level, or LAT, also referred to as LLWS (Lower Low Water Spring) in some countries. This level is the result of the effect of celestial bodies only and does not include the additional effects of:

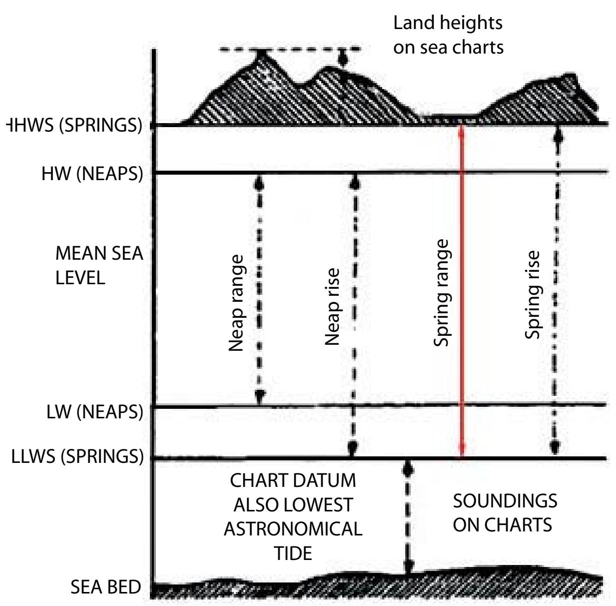
- atmospheric pressure (low pressure increases tide level);
- storm surge (increases tide level);
- wind (landward wind increases tide level); and
- heavy rainfall (increased flow in estuaries increases tide level).

In areas where this is not possible, hydrographic surveys in tidal areas should be referenced to a base elevation which has been determined by measuring the tide heights over the Tidal Datum Epoch. The Tidal Datum Epoch is the specific 19-year period or Metonic cycle (where the moon returns to exactly the same place at the same longitude and against the same constellation in the sky with the same phase) over which tide observations are taken and reduced to obtain mean values (e.g. Mean Lower Low Water or MLLW) for tidal datums.

Due to the long-term rise in global sea level and land subsidence, tidal datum readings are constantly changing and require continuous monitoring and updating.

To facilitate the process of establishing tidal datum readings, tide stations are operated at various locations (at all major and secondary port cities) for long- (primary), medium- (secondary), and short-term (tertiary) durations.

FIGURE 16
Tide datum



5.6.3 Primary tide stations

Long-term tide stations are referred to as primary control tide stations. These are tide stations at which continuous observations have been made over a minimum 19-year Metonic cycle. Their purpose is to provide data for computing accepted datums needed for a project and the predicted tides are normally published as a tide almanac. Nowadays, with the advent of the Internet, tidal predictions are available for most parts of the world, Figure 17. Tidal datum readings may also be determined by recovery of nearby tidal benchmarks from a former datum determination or by new tidal observations conducted in accordance with the correct procedures, Figure 18.

A length of plastic tape stapled to a length of steel tube makes an ideal tide board. This may either be buried in a concrete weight on a sandy bed or cemented to a rocky coast as illustrated in Figure 18. In both cases, the tide board should be installed in a sheltered area and observations carried out for at least one month. The longer the observation period, the more accurate the establishment of the tidal datum.

5.6.4 Tidal streams

The tidal phenomenon described above gives rise to tidal streams – periodic horizontal movements of the water. In open ocean this horizontal movement is either non-existent or negligible, but in inshore and coastal waters where there is any appreciable vertical movement a horizontal movement also can be expected.

The cause of tidal streams is primarily a change in water levels.

The average velocity of tidal streams depends upon the average height of the advancing tide wave: in deep ocean where this height is small the stream rate is either very feeble or negligible; where the height is large the velocity will be correspondingly great. As a tidal stream encounters any obstruction to its to-and-fro movement, its direction and velocity are affected.

FIGURE 17
Typical predicted tides for a total station showing the neap tide

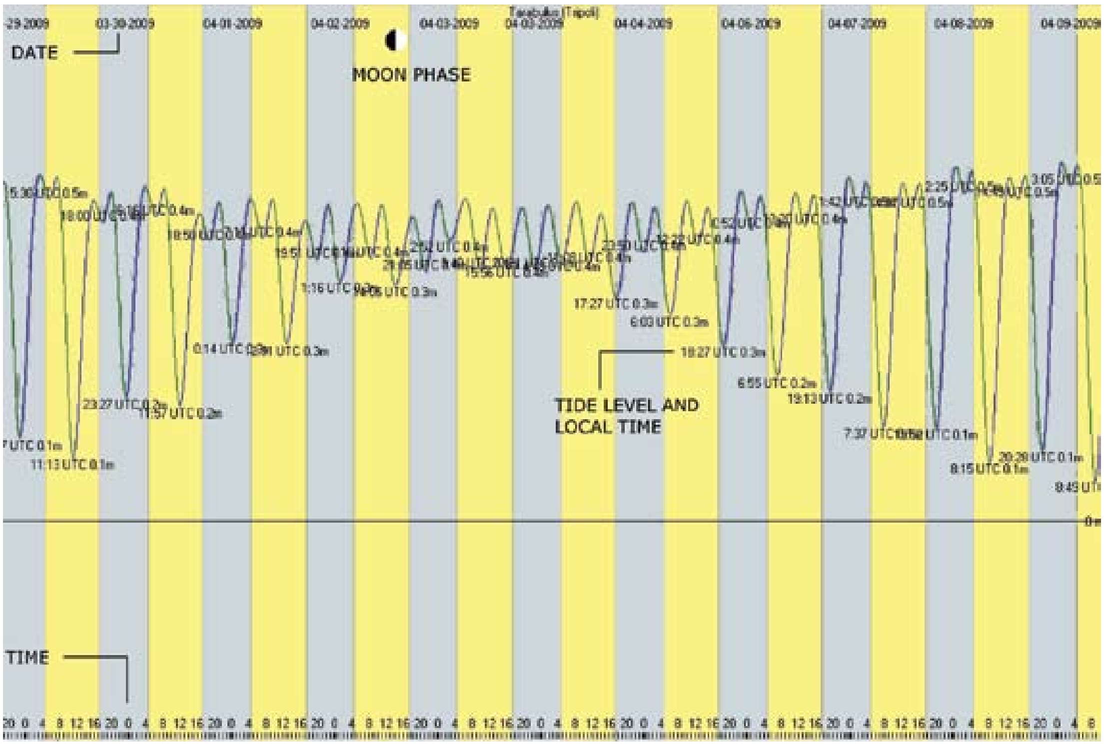
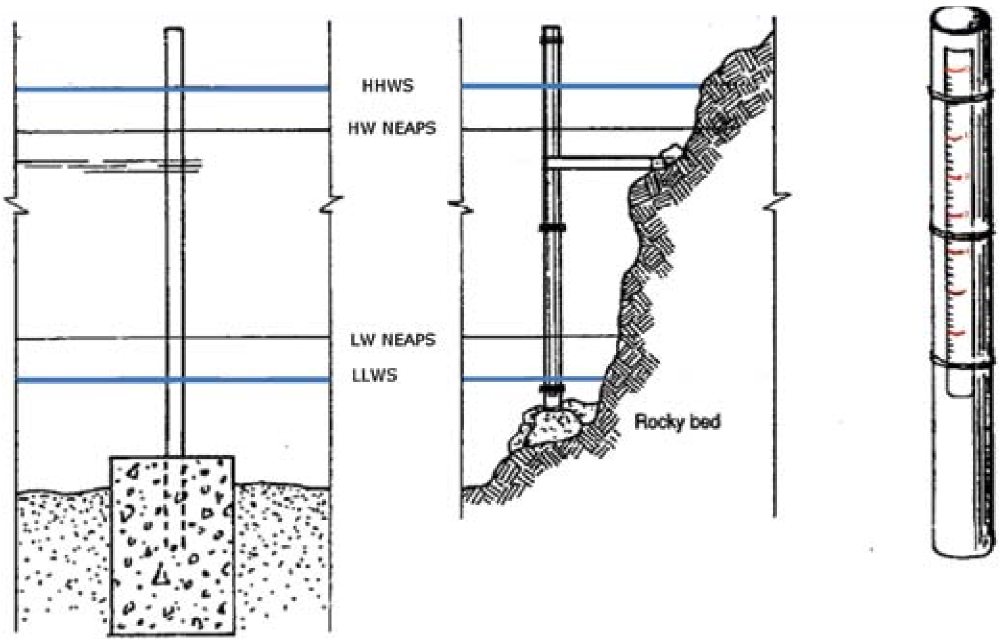
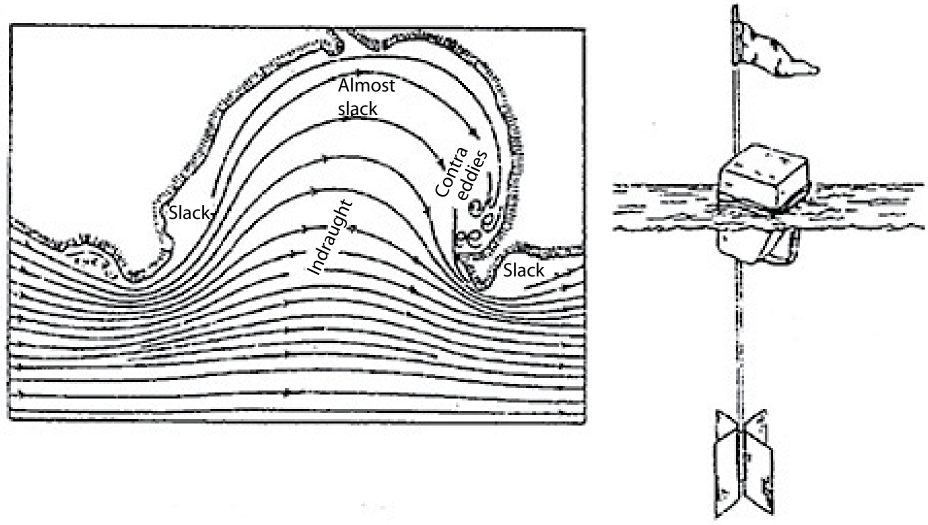


FIGURE 18
Re-establishment of tidal benchmarks



So when a tidal stream meets a headland it is deflected around it, and usually immediately off the headland its velocity is locally increased. In Figure 19 above, its direction is deflected round the headland into the bay beyond, causing an indraught of indefinite direction and velocity. In the bay itself the spreading out of the effect of the stream, combined with the fact that the real strength runs from headland to headland leaving comparatively unmoved water in between, causes a diminished velocity.

FIGURE 19
Tidal streams and a tidal float used for measuring currents



In the absence of tides, feeble sea currents may be experienced during strong sea storms. These currents, though not very great when compared to tidal streams, should be observed closely because they usually carry weeds uprooted from offshore areas.

Currents in general make navigation more difficult but not impossible. In the presence of seaweed or flotsam (including timber and vegetation carried down by rivers), however, navigation may be hindered by weeds fouling up propellers. Flotsam, or floating debris, may also prove troublesome if it piles up inside a harbour by a prevailing tidal stream or sea current. Using a simple can-float, Figure 19 right, with a counterweight hanging about a metre below water level, the strength of a current may be measured by timing it to travel a known distance along the coast, or across a bay. When measuring currents at sea, the following points should be observed:

- the general direction and duration of the storm or incoming waves, if the currents are storm generated;
- if seaweed appears, after how many hours of storm does it make its first appearance; and
- if flotsam or driftwood appears, their landfall, in many instances one particular spot or bay may accumulate more debris than adjacent ones, in which case it should be discarded as a potential harbour site.

5.7 BIBLIOGRAPHY AND FURTHER READING

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International Hydrographic Organization (other publications) (www.iho.shom.fr)

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- General Bathymetric Chart of the Oceans (GEBCO)
- FIG/IHO International Advisory Board on Standards for Hydrographic Surveyors
- Technical aspects of the Law of the Sea
- Technical assistance to developing hydrographic offices

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