HYDROGRAPHY FOR THE SURVEYOR AND ENGINEER

Second Edition

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Preface to Second Edition

Since the first edition was written ten years ago there have been rapid and significant advances in the instruments and systems of offshore surveying and, with the exceptions of charting and port conservancy work, the sea surveyor has experienced a change of emphasis. In the 1970s the geophysicist was the surveyor's constant team mate – frequently his master! – and exploration seismic and drilling operations were the rule with pipelaying and production platform emplacement in fairly low-key.

In the interim, oilfield development has proceeded apace and the surveyor's services now commonly include the precise positioning of drilling templates, the survey of tow-out routes for giant 'jackets' (production platforms) and the installation of those structures over the templates, the survey of ever more crowded routes for pipelines – frequently criss-crossing with others – and the monitoring of established pipelines for siltation and erosion and their general condition, the connection via 'spoolpieces' of pipelines to the well-head blowout preventers (BOP) and debris removal surveys following the abandonment of a borehole.

Instruments have developed according to the changing needs. Automated data handling is now commonplace. Much more accurate positioning systems offer ranging mode for several users simultaneously, together with redundant lines of position (LOP) and flexibility of choice of control stations for optimum fix-geometry. The lattice and manually-plotted trackchart have largely been replaced by microprocessor-reduced data, visual display unit (VDU) and x/y plotter. Underwater acoustic positioning systems have reached a high level of sophistication comparable with contemporary surface systems and their use with manned and unmanned submersibles and deep-towed sensors is common. Echo sounder and sonar instrumentation has also advanced in the areas of increased data acquisition (e.g. as in swathe sounding) and commensurate data processing and interpretation methods.

Only the techniques and principles of surveying have remained unchanged and they can be found alive and well in the contexts of traditional sextant surveys and integrated satellite and acoustic surveys equally.

With the present-day predominance of 'magic-box' equipment and a capability of complete surveys being accomplished at the flick of a switch it is important that the underlying principles of surveying are fully understood. For this reason, much of the detail of the first edition with respect to the sextant fix and lattices has been retained. The state-of-art systems and methods are described, of course, and the factors which link the old with the new are emphasised so as to convey the understanding of sea surveying which is so vital to the professional practitioner.

For this edition I am proud to acknowledge the help received from the individual and corporate members of the Hydrographic Society. It is largely through that organisation that surveyors have not had to suffer too much from the paucity of up-to-date information and literature since its formation in 1972. Through the Society's workshops, symposia, teach-ins, seminars and - linking all these and adding much more - the Hydrographic Journal and Special Publications, there has been little excuse for a sea surveyor to be ill-informed. All of these services can only stem from the efforts of the members of the Society and it is to them that I have turned in the up-dating of this book. Special mention is merited for the contributions of Dr Paul Cross and Dr Bob Britton, both of them colleagues at the North East London Polytechnic, Land Surveying Department: Dr Cross for the formulae of hyperbolic lattices and the Global Positioning System equations in Chapter 3, and Dr Britton for the larger part of the redrafted Chapter 5. Other individuals and companies worthy of special mention are acknowledged in the appropriate part of the text and, to all of them I extend my warmest thanks.

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Contents

Preface vii

Introduction 1
1 The Elements of Hydrography 4
2 Planning 7
3 Position-fixing Afloat 14
4 Acoustic Measurement and Investigation 67
5 Miscellaneous Aspects of Hydrography 94
6 The Processing of Hydrographic Data 112
Bibliography 125

Index 130

Introduction

Activity offshore was centred, until the 1950s, almost entirely on the fisheries and shipping industries. Since World War II there has been a remarkable increase in interest in the resources of the sea and seafloor, of which the recovery of hydrocarbons - oil and gas - represents by far the greatest industrial investment.

Offshore engineering technology and the shipping industry have progressed at a phenomenal rate. Compare the typical, long-established harbours with the civil engineering achievements of today. The one occupies a sheltered location adjoining shallow waters, comfortably able to accommodate vessels which seldom exceed 10 m in draught, and conveniently close to road and rail distribution links. The other may be a drilling rig or production platform 150 km offshore and subjected to violent storms and 20 m high waves, or an exposed tanker terminal with depths exceeding 25 m alongside, or a pipeline from oil well to shore, traversing areas of rapid current and shifting seafloor sediments.

In addition to offshore drilling and harbour construction, the totality of industrial activity embraces the following operations:

- dredging, for harbour conservancy, mineral recovery and reclamation;
- coast protection engineering;
- salvage;
- desalination of seawater to improve fresh water supplies;
- the extraction of minerals and chemicals from seawater;
- the provision of recreational facilities such as beaches and marinas;
- the prevention or elimination of pollution;
- the development of communications and distribution routes by shipping lane, submarine cable and underwater pipeline;
- the development of the fishing industry.

The impact of this proliferation of activity on the engineer and surveyor has been profound.

Seawater is a notoriously corrosive substance and this, together with the forces of current, tide and storm sea and the great pressures on structures at depth, constitutes formidable factors with which the engineer must contend in the marine environment. For him to do so successfully these factors must be quantified.

As on land, environmental data are acquired by the geologist and geophysicist, who base their work on the surveyor's map. At sea, in addition, the oceanographer plays his part in determining the seawater parameters. All of these turn to the hydrographer for information on the physical limits of the marine environment. The data supplied by the hydrographer, and his function in the sea surveying operation, are illustrated in Fig. 1. It should be noted that there is a considerable overlap of scope and function of the specialists concerned, each being essentially a *team*-member working with the others towards a common goal. Hydrography is similar in many respects to land surveying and many of the techniques employed are the same as, or extensions of, land surveying practice. Some factors serve to differentiate between the two, however, and whilst some are obvious, all must be appreciated and taken into account.

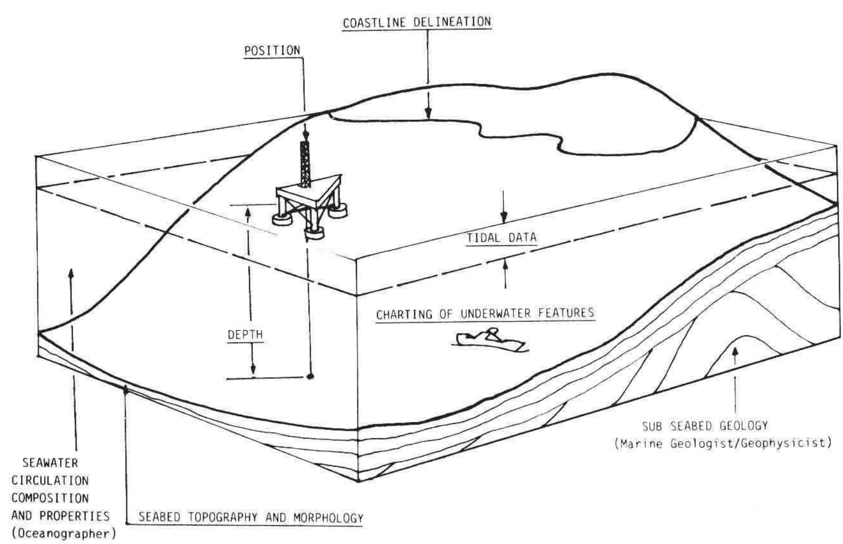

Fig. 1. The data requirements of offshore industry. (Those with which the hydrographic surveyor is commonly concerned are underlined.)

The chart is the marine equivalent of the topographic map. Both use spot measurements of height/depth and contours to portray relief, but where the user of the map is able to verify by visual inspection the detail shown, the seafloor topography is obscured. The chart-user therefore relies implicitly on the accuracy and thoroughness of the hydrographer's work.

In establishing the control for a topographical survey the land surveyor occupies a number of stations in turn, observing angles and measuring distances with all the care, precision and number of repetitions required to achieve the specified order of accuracy. The hydrographic surveyor likewise performs this control procedure in most instances. Once afloat, however, the fixation of position becomes a dynamic operation. Not only does the observing platform (the survey vessel) occupy a position for an instant only, but the level of the seawater surface changes constantly under the influence of tide and wave. The hydrographic operation has been likened to a levelling survey onshore, but using a telescoping staff and a level which is mounted on a well-sprung trolley! Admittedly this type of surveying is less precise than the shore-based equivalent, but this does not mean that less careful, less thorough work is adequate. On the contrary, the utmost care is essential to ensure that the rather more coarse measurements which are combined to make the chart are not further degraded by slapdash methods.

The nature of the sea environment is probably the most fundamental single factor which separates land from sea surveying. The effect of the sea on the common surveying techniques has been mentioned, but more important still is an appreciation of the vicissitudes of the sea which not even a manual of seamanship can properly explain. Experience is the only real solution, which both engineer and land surveyor will most probably lack. In its stead, an honest humility towards the sea and the seaman in whose care the surveyor will be placed is strongly recommended.

Always bearing this sobering thought in mind, it is the intention in this book to give the reader having a familiarity with surveying ashore an insight into the special techniques and problems of surveying afloat.

1

The Elements of Hydrography

The first object of a hydrographic survey is to depict the relief of the seabed, including all features, natural and manmade, and to indicate the nature of the seabed in a manner similar to the topographic map of land areas.

Two factors define the location of a single point on the earth's surface taken in isolation, and for the sea survey these are:

(i) the position of the point in the horizontal plane in, for example, latitude and longitude, grid co-ordinates or angles and distances from known control points;

(ii) the depth of the point below the sea surface, corrected for the vertical distance between the point of measurement and water level and for the height of the tide above the datum or reference level to which depths are to be related.

The problem, then, is how to apply these factors in order to obtain a pictorial representation of the seabed relief.

In surveys ashore, photogrammetric techniques apart, contours are derived from an accumulation of spot heights obtained by levelling or other means, often in a grid system. The lead-line survey would be exactly analogous, except for the necessary allowance for tidal height which makes each depth measurement unique in time. A depth thus measured is termed a *sounding*. When the corrections have been applied, the depth is a *reduced* sounding. (See Fig. 1.1.)

In fact, the lead-line is rarely used and the process is streamlined by the echo-sounder. The echo-sounder effects a depth measurement typically at a rate of up to ten times per second, depending on the depth. The measurement is made by timing the interval between transmission and reception of an acoustic pulse which travels from the vessel to the seabed and back at a velocity of approximately 1500 ms^{-1}. A succeeding transmission is not made until the previous pulse has returned and the rate of transmission is thus

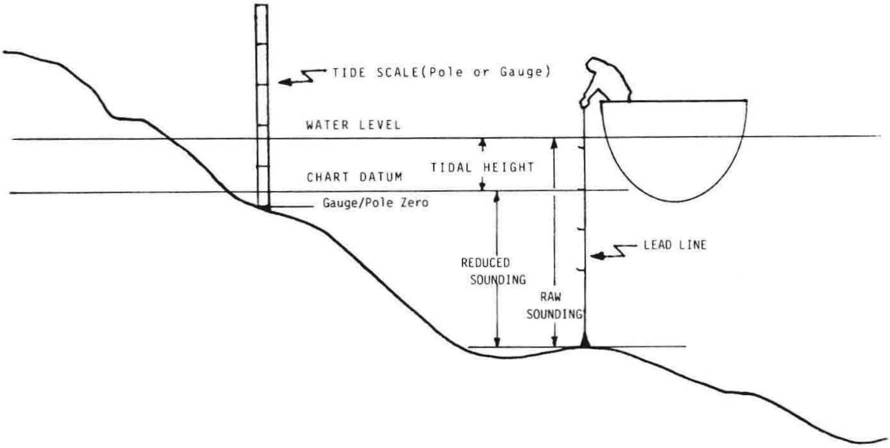

Fig. 1.1. The lead-line sounding

depth-dependent. The vessel is therefore able to proceed without stopping and, by sounding continuously, a profile is obtained of the seabed beneath the vessel's track. We then speak of a *line of soundings* having been run. In practice, a succession of parallel sounding lines is run across the survey area and contours are derived from the resulting profiles to build up a portrayal of the seabed topography.

In automated systems, position fixes may be obtained at a rate compatible with the sounding rate (i.e. several per second) or as required to drive an associated track-plotter. Failing this, a fix may be obtained at intervals of from one second to one minute and the survey vessel is then assumed to follow a track shown on the plot as a succession of fixes joined by straight lines. It is imperative that control of the vessel is such that this assumption is valid within the plottable accuracy of the chosen scale of the survey. (See Chapter 3, para. 3.6.)

The sounding procedure described above, while providing ample data for an indication of relief, cannot guarantee a complete coverage of the seabed. Isolated pinnacles, wrecks and other obstructions may be missed if they lie between the sounding lines. Further, the echo-sounder profile will not show the nature of the seabed - where rocks outcrop from sand, where gravel, stones or boulders occur, and so on. The conventional sounding operation may therefore be modified - by running intermediate lines (interlines) to increase the density of areal coverage or cross-lines to obtain an improved angle of cut of contours - or supplemented by special instrumentation, such as sea-bed samplers and the side-scan sonar, or techniques such as wire sweeping. Additionally, tidal and tidal-stream observations are frequently specified. These various operations are dealt with in succeeding chapters, while their roles in the hydrographic survey are illustrated in Fig. 1.2.

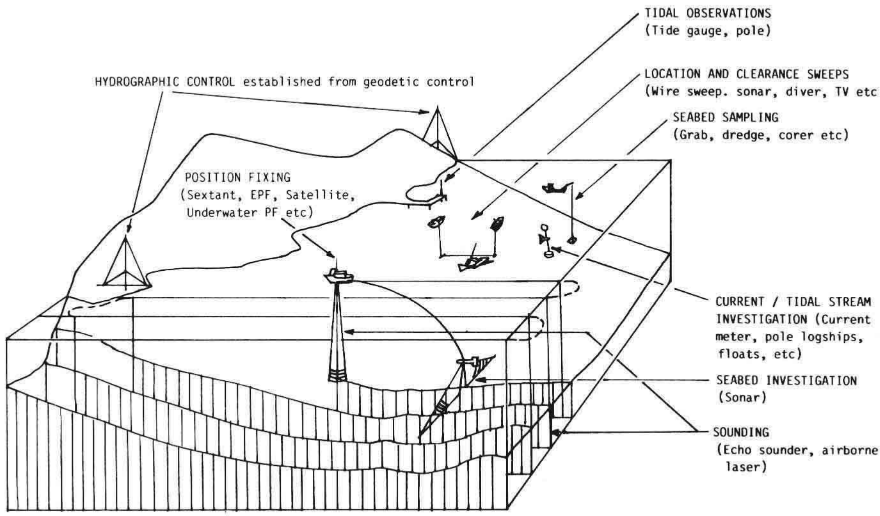

Fig. 1.2. The operations of hydrography.

2

Planning

2.1 GENERAL

As with any activity, careful planning and preparation will pay dividends in the subsequent operation. Although no two surveys are alike, the sequence of events will usually follow much the same pattern:

(i) the drawing up of a specification to the client's requirements;
(ii) the examination of available documents, e.g. charts, maps, air and ground photography, sailing directions, tide tables, triangulation and other control data from earlier surveys;
(iii) if at all possible, a field reconnaissance;
(iv) the preparation of sheets required for the survey, e.g. master plotting sheet, sounding sheets, track charts and the fair sheet;
(v) the preparation of the operational plan, including decisions on positional control, tide gauge location, instrumentation and techniques to be used, personnel, equipment and logistical requirements and time/resources schedules;
(vi) the field work, e.g. establishing positioning and tidal control, sounding, sweeping and miscellaneous operations;
(vii) the interpretation, processing and presentation of data.

The above list will be quite familiar to the land surveyor, only the manner in which each phase is executed being peculiar to the hydrographic operation.

It must be self-evident that the client, probably unacquainted with such operations afloat, will need to be educated accordingly (albeit tactfully!) so that he does not demand the impossible and pay dearly for it. Every item in the list must be approached with a marine-orientated eye, and possibly the example most vividly illustrative of this is that of cost.

Every aspect of hydrography is more costly than its land survey equivalent. An observing team ashore, for example, might consist of four men travelling by Land Rover and using two theodolites. For a sounding survey a team of perhaps only three men will be required, but, according to size, the boat may cost between twice and one hundred times more than the Land Rover, with correspondingly higher depreciation and running costs and a crew of between one and twenty men. An echo-sounder is essential at a cost of at least two theodolites, while the minimum of two sextants for position-fixing are equivalent to yet another. The Land Rover will travel at, say, 30 mph to observing points which can be quite conveniently located relative to the base camp. The vessel's speed will most likely be around 10 knots and the survey area is frequently over 150 km from the nearest harbour. The logistics - victuals, fuel, passage time between base and survey area - will probably play a much larger part in the scheduling of the survey afloat, and the effects of weather conditions on the progress of the survey will be more marked. The 'domestic' arrangements for a hydrographic survey are therefore as important as is the achievement of the required standards of accuracy and, whilst every care should be taken, it is always wise to aim for results which are *adequate* rather than those which are the best attainable.

Flexibility of plan is a desirable attribute, so that the effects of delays due to breakdowns, weather, sickness and the numerous other possible causes can be assessed and the correct remedial action taken at once. For this, the 'critical path' or network plan is highly recommended. Finally, though the survey at sea is more costly than similar work on land, the surveying phase is less costly by far than any succeeding phase of offshore activity, thus placing great reliance on the integrity of the surveyor.

The factors to be considered in the sounding operation are as follows:

(i) type of vessel required;
(ii) type of echo-sounder/sonar instrumentation required;
(iii) position-fixing method to be used;
(iv) data handling method;
(v) method of achieving the required coverage of the seabed;
(vi) personnel requirements;
(vii) logistical requirements.

2.2 THE SURVEY VESSEL

While many surveyors will be committed to a particular vessel, there will be those who must charter a vessel in the locality of the survey area. The most suitable craft for the job will obviously depend on the overall purpose of the survey (e.g. whether or not geophysical or other additional tasks are required), the weather conditions to be allowed for, the size of the survey team, whether they are to live on board the vessel, and so on. It is impossible to lay down rules, but the following requirements will always apply:

(i) The vessel should be spacious enough to allow for plotting and fixing, and/or for the equipment to be used, preferably under cover and free from engine vibration.
(ii) An unimpeded all-round view is required for the surveyor and position-fixing antennae.
(iii) The vessel should be stable and manoeuvrable at slow speeds.
(iv) Unless batteries or a generator are to be provided by the survey team, there should be ample electrical power for all foreseeable needs.
(v) The range (fuel capacity), food storage and working facilities should be compatible with the planned operational arrangements.
(vi) Speed capability need not normally exceed 10 knots or so, though the distance between the base and the survey area may dictate a faster vessel to avoid undue loss of time on passage.

2.3 THE SOUNDING PLAN

In order to achieve satisfactory coverage of the seabed with maximum economy it has already been explained that parallel lines of sounding should be run over the area. Further considerations will include the following, all of which are interrelated:

(i) the scale of survey appropriate to the precision and thoroughness required;
(ii) the spacing apart of the sounding lines;
(iii) the interval between fixes along a line;
(iv) the speed of the vessel while sounding;
(v) the direction in which lines are to be run.

Ship speed will rarely be limited by the data acquisition rate of modern echo-sounders. The position-fixing method is more likely to dictate the speed at which the sounding lines are run, and the following example illustrates the interaction of the factors involved.

Let us suppose that a survey is required of a harbour on a scale of 1:10 000. Position-fixing is to be by sextant angle resection, plotted by station-pointer. A fixing interval of one minute is reasonable for these circumstances. Now, the vessel will be assumed to follow the straight line joining the fixes taken every minute, and it follows that the fixes should be spaced not too far apart for such an assumption to be valid. It is convenient to relate the scale of the survey to two rules:

(i) fixes should never be further than, say, 25 mm apart on the scale of the survey, and
(ii) the spacing apart of sounding lines should not exceed, say, 10 mm.

Thus, by setting the scale of the survey at a particular value, a certain thoroughness (density of soundings or areal coverage) and precision are implied. If the above rules are followed in our example, fixes will lie 250 m apart. This, together with a time interval of one minute, decrees a vessel speed of 250 m min^{-1}, or 15 km h^{-1} (about 8 knots). (A scale of 1:5000 implies a sounding speed of 4 knots, and so on.) To obey the rule at a higher sounding speed, a more rapid method of position-fixing is required.

The sounding lines will normally be run in a direction as nearly as possible at right-angles to the expected direction of the depth contours at a spacing of 100 m. Here again, we are able to assess the degree of coverage given by the echo-sounder transmission. The acoustic power is focussed into a beam which will emanate from the vessel in a cone shape. A typical beam width is about 30° (see Chapter 4) and we can therefore calculate that the 'insonified' area of seabed beneath the vessel will meet that of the adjacent lines only in depths exceeding 185 m (Fig. 2.1). It is then left to the surveyor to decide whether the gap between lines in depths less than this can be accepted, or whether to increase the scale, decrease the sounding line spacing, or use additional instrumentation such as the side-scan sonar to investigate the seabed between lines for features which may require attention.

In the example above, the survey scale has been defined, and all other factors have been calculated from it. The converse may be the case. For example, the echo-sounder beam width of 30° is required to give complete seabed coverage in general depths of about 30 m. In this case, line spacing should be 15 m and, for this to be represented by about 10 mm on the scale of the survey, the scale should be 1:1500. The spacing of fixes at 25 mm on paper is therefore 37·5 m. If a fix is possible every minute, the sounding speed will be 2·25 km h^{-1} or about 1·2 knots. It is quite possible that at this speed the vessel will not be controllable (i.e. it will have lost 'steerage-way') and a more rapid fixing rate will be required.